1: **Explain the different modes of Excitation of stepper motor :- (hybrid SM)**

Single Phase Excitation :-

The sequences of single phase Excitation mode for three and four phase VR motor. In this mode, only one phase is Excited at a time. The shaded parts in the table represent the excited state and un shaded parts show the phases to which current is not supplied and so are excited.

Three phase VR motor :-

Clock state	R	1	2	3	4	5	6	7	8
Phase 1									
Phase 2									
Phase 3									

Four phase VR motor :-

Clock State	R	1	2	3	4	5	6	7	8
Phase 1									
Phase 2									
Phase 3									
Phase 4									

when a motor revolves clockwise in the excitation sequence of ph1, ph2, ph3..., it will revolve counter clock wise direction by simply reversing sequence of ph3, ph2, ph1 ...., single phase excitation is also known as 'one phase on drive'

TWO PHASE EXCITATION :-

The operation of a motor in which two phases are always excited is called two phase on operation.

Three Phase VR motor:-

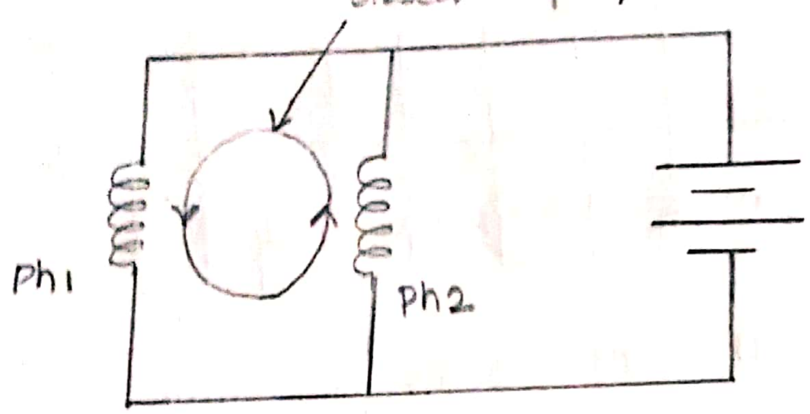
Clock State	R	1	2	3	4	5	6	7	8
Phase 1	■	■	→	■	■		■	■	
Phase 2		■	■ →		■	■		■	■
Phase 3	■		■	■		■	■		■

Four phase VR motor :-

Clock State	R	1	2	3	4	5	6	7	8
Phase 1	■	■			■	■			■
Phase 2		■	■			■	■		
Phase 3			■	■			■	■	
Phase 4	■			■	■			■	■

The characteristic difference between the single phase on and two phase on operation appears in the transient response which is already shown

In two phase on drive, the oscillations damp out more quickly than in the case of single phase on mode.



In the method1, Positioning are made in single phase excitation only and two phases are excited, while moving From one equilibrium point to another. the two phase excitation is used to suppress oscillation. In the other method 2, the equilibrium positions of both the single and two phase excitation are used for positioning. This Scheme reduces the step Angle to Half.

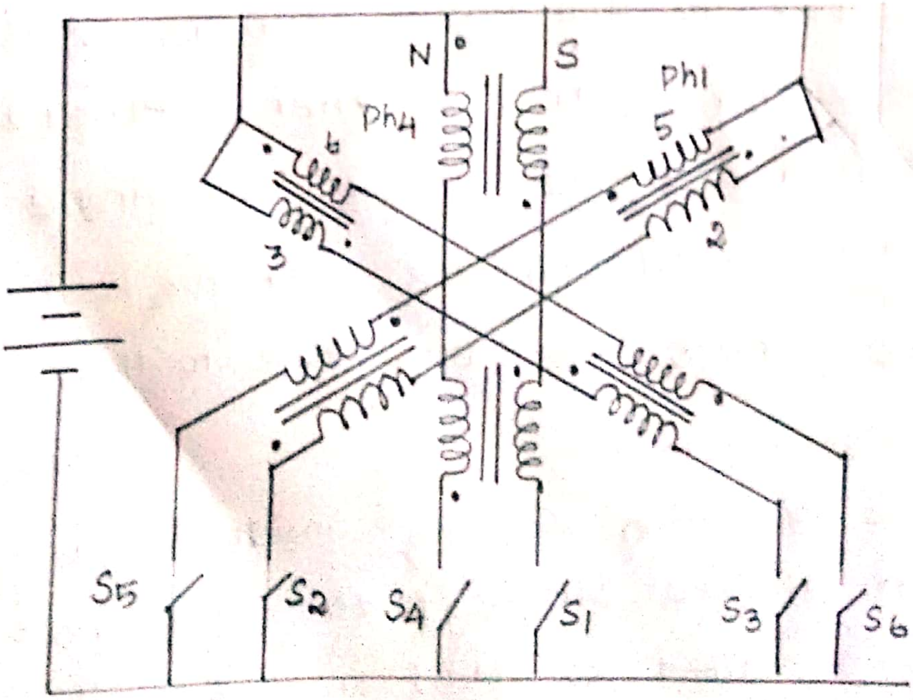
Half step Excitation:-

The excitation Scheme which is a combination of the single phase and two phase excitation is called as Half step Excitation.

clock state method 1	R	1		2		3		4		5	
clock state method 2	R	1	2	3	4	5	6	7	8	9	
Phase 1	■	■				■	■	■			
Phase 2		■	■	■				■	■	■	
Phase 3				■	■	■				■	■

Two phase on drive of Bifilar wound three phase VR motor :-

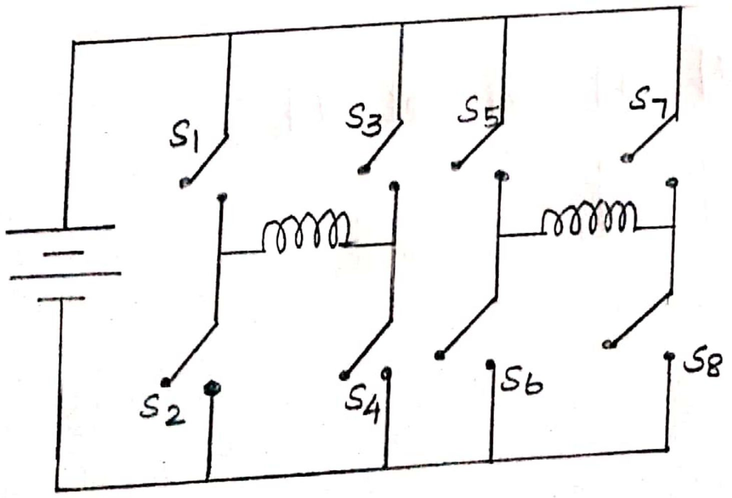
The essential requirements in motor design to make the machine size as small as possible for the demanded performance specifications bifilar wound three phase VR motor in two phase excitation meets this requirement.



the coils of the opposing poles are connected so that the fluxes in both poles are directed either outwards or inwards. the torque to machine volume ratio and damping are much better than monofilar wound motors.

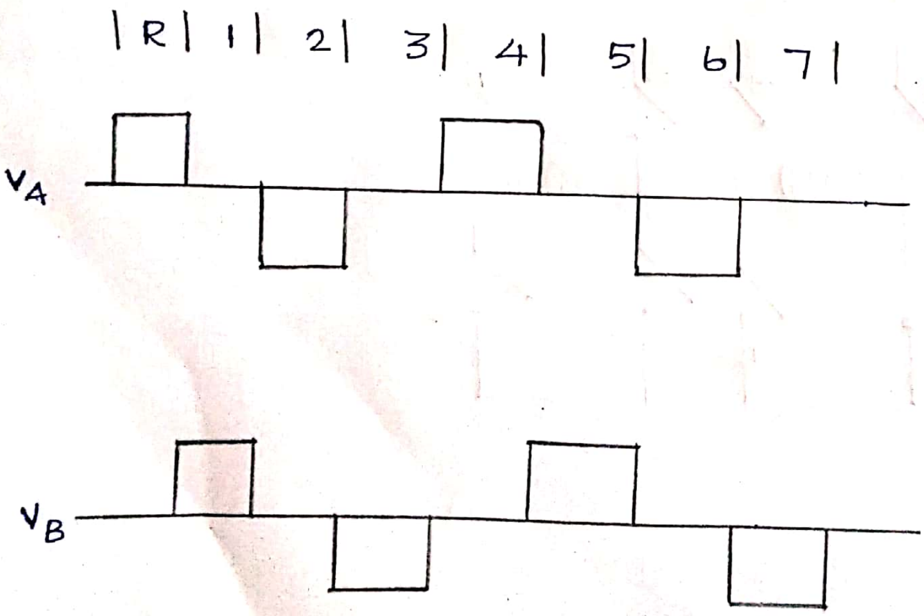
Excitation of two phase hybrid motor:-

There is no necessity to alter the magnetic polarity to drive a VR motor. But, for a PM motor (or) hybrid motor pole reversal is normally needed. If the windings are in the bifilar scheme. the situation is similar to 4 phase VR motor. Phase A, B, $\bar{A}$ and $\bar{B}$ corresponding to phases 1, 2, 3 and 4 and the proceeding three excitation methods are applied.



Excitation sequence in the bridge operation for two phase motors :-

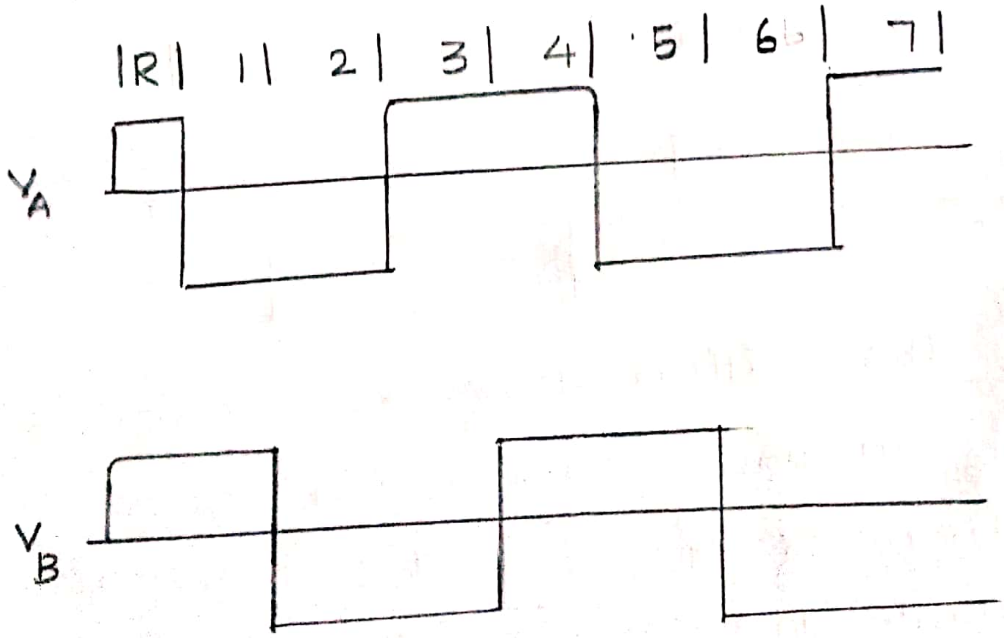
Clock state	R	1	2	3	4	5
S_1	■				■	
S_2						
S_3			■			
S_4			■		■	
S_5	■					■
S_6		■		■		
S_7				■		
S_8		■				■

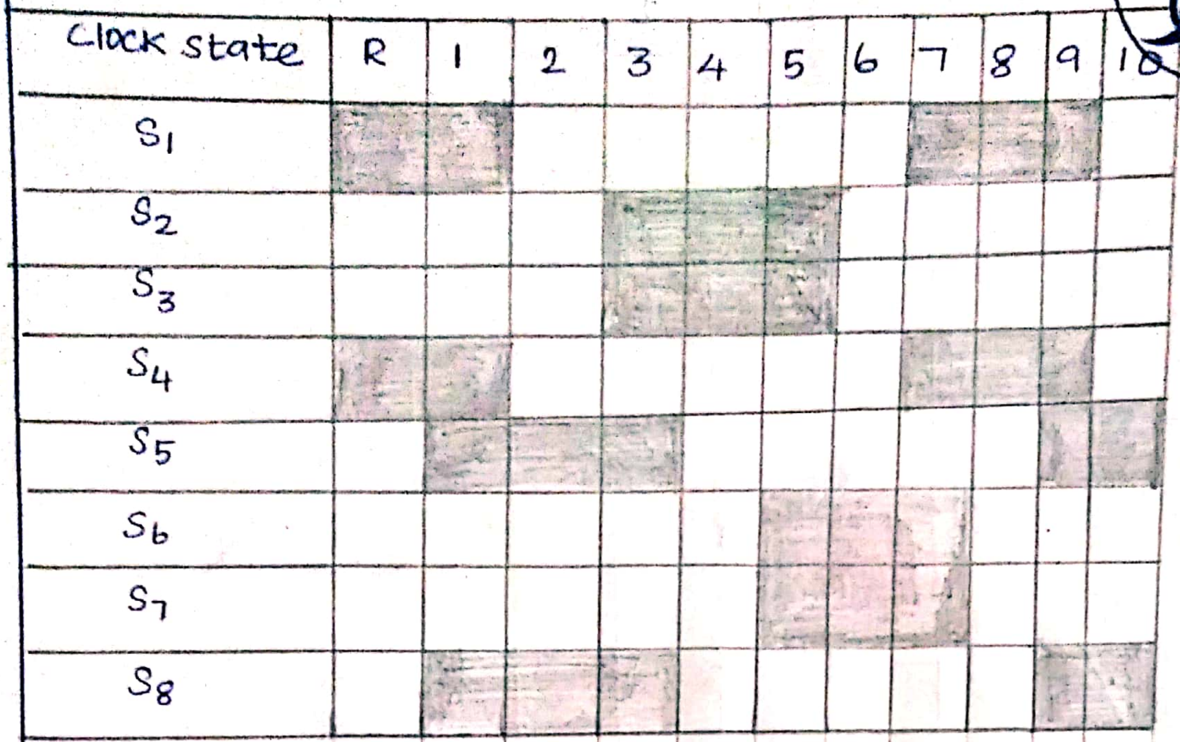


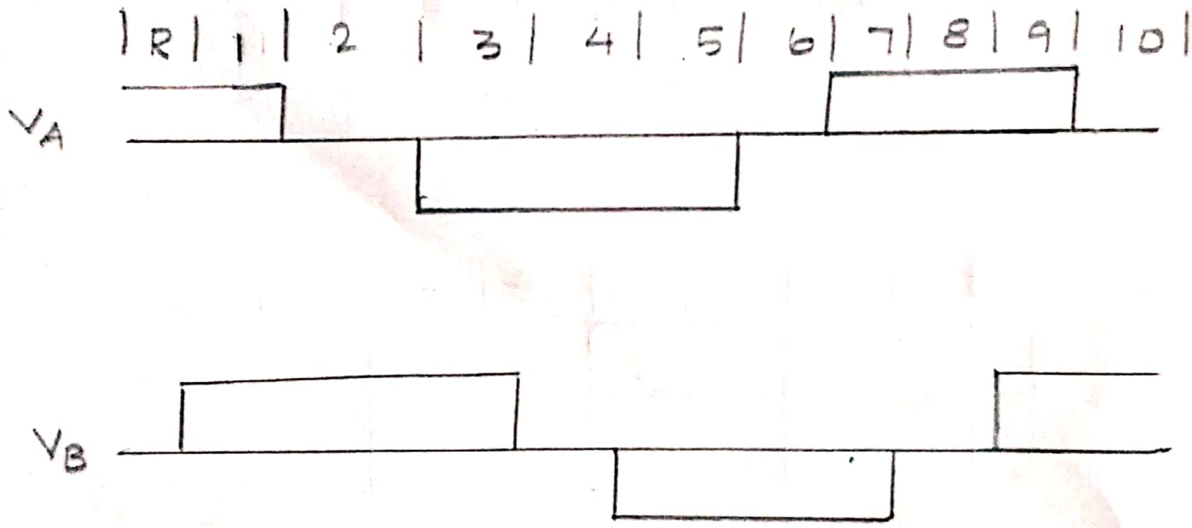
(a) one phase on

Clock State	R	1	2	3	4	5
S1						
S2						
S3						
S4						
S5						
S6						
S7						
S8						

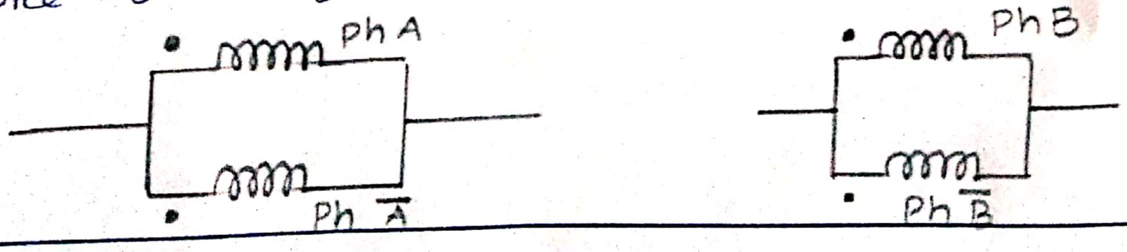
(b) two phase on





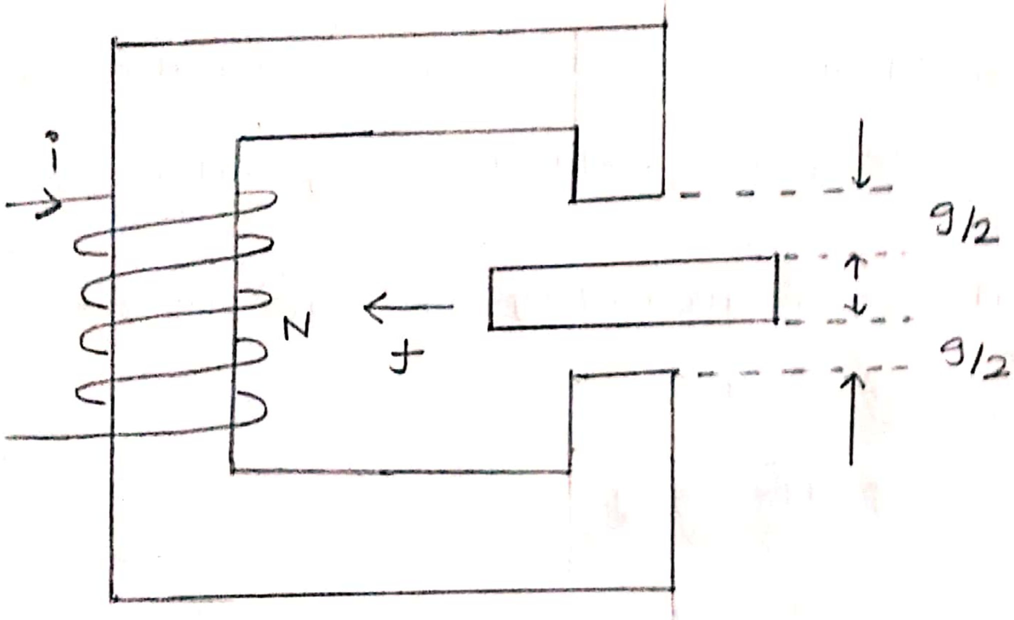


By using the bifilar drive, 25 to 30 percent Improvements in power consumption are possible. The only drawback of the bridge is that it needs twice as many transistors as the bifilar operation.



2. How the torque is predicted in step motors for various cases a) Infinitely permeable
b) constant permeabilities.

case i:- Infinitely permeable cores



A current I is flowing through the coil of N turns of yield magnetic flux, and a force f is acting on the iron piece in the x-direction.

Here the iron piece may be regarded as a tooth of the rotor of a stepping motor. The electromagnet corresponds to a pair of teeth of the stator in a VR motor,

Let us consider,

B_g - magnetic flux density in the air gaps, According to Ampere law,

$$\oint H dl = nI$$

$$\oint H dl = H_g(g/2) + H_g(g/2) + H_i(l)$$

$$= H_g(g) + H_i(l)$$

H_g – Magnetic Field intensity in the air gap.

H_i – Magnetic Field Intensity in the cores.

when the permeability of cores is extremely large, and $H_i = 0$.

$$\oint H dl = H_g \cdot g$$

$$H_g \cdot g = nI$$

$$H_g = \frac{nI}{g}$$

The air gap flux density,

$$B_g = \frac{\mu_0 nI}{g}$$

where,

μ_0 – permeability in the air length

w – transverse length of the iron piece.

x – Distance by which the rotor tooth and the iron piece overlap.

Overlapped area = xw

Magnetic Flux $\phi = \dfrac{xw\mu_0 nI}{g}$

Flux linkage $\psi = n\phi$

$$= \frac{xw\mu_0 n^2 I}{g}$$

Thus the Increment in the flux linkage $\Delta\psi$

$$\Delta\psi = \frac{w\mu_0 n^2 I \Delta x}{g}$$

The emf induced in the coils by the change in the flux linkage is,

$$e = \frac{-\Delta\psi}{\Delta t} = -\frac{w\mu_0 n^2 I}{g} \cdot \frac{\Delta x}{\Delta t}$$

The workdone Δpi by the source is

$$\Delta pi = I|e|\Delta t$$

$$= \frac{w\mu_0 n^2 I^2}{g} \Delta x$$

Δpi is expressed interms of Bg,

$$\Delta pi = \frac{Bg^2 g w \Delta x}{\mu_0}$$

The Increase in the gap field energy is given by,

$$\Delta wm = \frac{1}{2} \frac{Bg^2}{\mu_0} \times (\text{the Increase in the gap space})$$

$$= \frac{1}{2} \frac{Bg^2}{\mu_0} g w \Delta x$$

The Force f multiplied by the displace -ment.

$$\Delta w_m = f \Delta x$$

$$f \Delta x = \frac{1}{2} \frac{B_g^2}{\mu_0} (g w \Delta x) \longrightarrow (1)$$

Eliminating Δx from both sides.

$$f = \frac{1}{2} \frac{B_g^2}{\mu_0} g w \longrightarrow (2)$$

Subs (1) & (2) we get

$$f = \frac{1}{2} \frac{w \mu_0 n^2 I^2}{g}$$

on the other Hand, the magnetic energy w_m in the gap is,

$$W_m = \frac{1}{2} \frac{B_g^2}{\mu_0} g x w \longrightarrow (3)$$

From eqn (2) & (3)

$$f = \left(\frac{d w_m}{d x}\right)_{I = \text{constant}}$$

$$f = \left(\frac{\partial w_m}{\partial x}\right)_{I = \text{constant}}$$

$$f = -\left(\frac{\partial w_m}{\partial x}\right)_{\phi = \text{constant}}$$

case ii) constant permeabilities

In the Infinitely permeable cores, the magnetic field Appears only in the gaps & the Mathematical treatment is simple. when cores are of finite permeability, on the other Hand, magnetic energy Appears not only in the gaps, but also in the cores & spaces other than the gaps.

$$\psi = LI$$

ψ - Flux linkage

L - coil Inductance

the magnetic energy

$$W_m = \frac{1}{2} LI^2$$

Emf Induced in the coil,

$$e = \frac{-\Delta\psi}{\Delta t} = \frac{-\Delta(LI)}{\Delta t}$$

work Δp_i can be expressed as,

$$\Delta p_i = I|e|\Delta t$$

$$= I\left|-I\frac{\Delta L}{\Delta t}\right|\Delta t$$

$$\Delta p_i = I^2 \Delta t$$

Increase in the magnetic energy

$$\Delta W_m = \frac{1}{2} I^2 \Delta L$$

converted to mechanical work ΔP_0

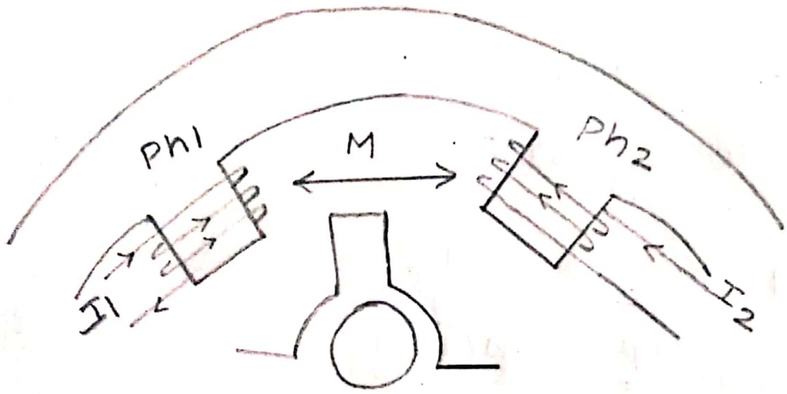
$$\Delta P_0 = f \Delta x$$

$$f \Delta x = \frac{1}{2} I^2 \Delta L$$

$$f = \frac{1}{2} I^2 \frac{\Delta L}{\Delta x}$$

Effects of mutual Induction:-

1. One-phase on drive
2. Two-phase on drive
3. Three-phase on drive
4. Half step drive



The Induced voltage at each phase.

$$e_1 = -I_1 \frac{\Delta L_1}{\Delta t} - I_2 \frac{\Delta M}{\Delta t}$$

$$e_2 = -I_2 \frac{\Delta L_2}{\Delta t} - I_1 \frac{\Delta M}{\Delta t}$$

e_1 - Induced voltage of phase 1

e_2 - Induced voltage of phase 2

f_1 - Inductance of phase 1

f_2 - Inductance of phase 2

M - Mutual Inductance between the two phases

The work done by the two power supplies during the Increment Δt is,

$$\Delta P_i = -(e_1 I_1 + e_2 I_2)\Delta t$$

$$= -I_1^2 \Delta L_1 + I_2^2 \Delta L_2 + 2 I_1 I_2 \Delta M$$

On the other Hand, the Increment of the magnetic energy in the system is

$$\Delta W_m = \frac{1}{2}(I_1^2 \Delta L_1 + I_2^2 \Delta L_2) + I_1 I_2 \Delta M$$

$$\Delta P_o = T \Delta \theta$$

$$T \Delta \theta = \frac{1}{2}(I_1^2 \Delta L_1 + I_2^2 \Delta L_2) + I I_2 \Delta M$$

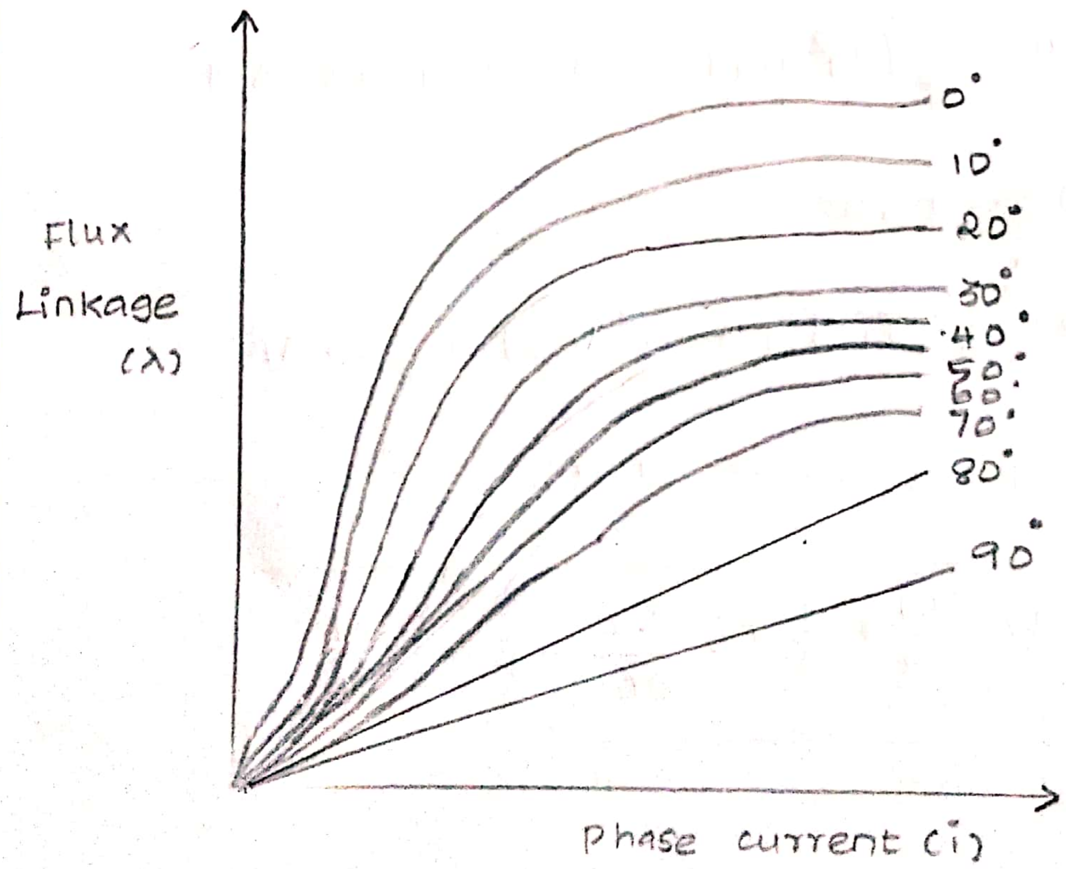
Hence, torque is expressed as,

$$T = \frac{1}{2} I_1^2 \frac{\partial L_1}{\partial \theta} + \frac{1}{2} I_2^2 \frac{\partial L_2}{\partial \theta} + I I_2 \frac{\partial M}{\partial \theta}$$

Discuss the Linear and Non-Linear Analysis of step motors.

3. Linear And Non Linear Analysis:-

The torque produced by the motor is to be observed through the linear and non linear analysis of the motor performance. In linear analysis, it is assumed that the magnetic material in the motor has constant permeability (i.e.,) the machine with linear magnetic characteristics means that it is having constant magnetic permeability and no magnetic saturation. The flux density is proportional to the winding current.



It cannot be overstated the magnetization curve is vital for the calculation of the torque and therefore for the design of the laminations and windings, in general,

Let us take,

Tm – the motor torque produced by the rotor in N-m.

J – the Inertial of the rotor and load combination in kgm^2

w – the Angular velocity of the rotor.

D – the damping coefficient (or) viscous Frictional coefficient.

Tf – the Frictional load torque Independent of the speed.

φ_s – the Step Angle in radians.

f – the stepping rate in steps/sec (or) PPS.

Frictional load torque,

$$T_f = K\theta$$

According of rotor dynamics,

$$T_M = J\frac{dw}{dt} + Dw + T_f$$

$$\theta_s = \theta = wt = \text{step Angle},$$

$$\omega = \frac{\theta_s}{t} = f\theta_s$$

$$f = \frac{1}{t}$$

By putting $\omega = f\theta_s$ in above eqn.

$$T_m = J\frac{d}{dt}(f\theta_s) + D(f\theta_s) + T_f$$

$\theta_s = \frac{360}{mN_r}$ is Fixed for a particular type of motor.

So θ_s can be considered as constant.

Therefore,

$$T_m = J\theta_s \frac{d}{dt}(f) + D\,\theta_s(f) + T_f$$

If viscous Friction constant is neglected, the equation will be a linear equation, the corresponding Analysis is a linear Analysis where linear acceleration is present.

Linear Acceleration (or) Linear Analysis :-

If the damping coefficient is neglected.

$$D = 0$$

The expression for motor torque becomes

$$T_m = J\frac{d\omega}{dt} + T_f$$

$$T_m - T_f = J\frac{d\omega}{dt}$$

Integrating

$$\omega = \left(\frac{T_m - T_f}{J}\right) t + \omega_1$$

where, ω_1 - Integration constant.

Mathematically ω_1 is the constant of Integration but it Indicates the Initial angular Velocity of the motor before the occurrence of acceleration.

Therefore,

$$\omega = \theta_s f \text{ and } \omega_1 = \theta_s f_1$$

Subs (ω) and (ω_1) in the above eqn.

$$\left(\frac{T_m - T_f}{J}\right) t + \theta_s f_1 = \theta_s f$$

Dividing throughout by θ_s we get

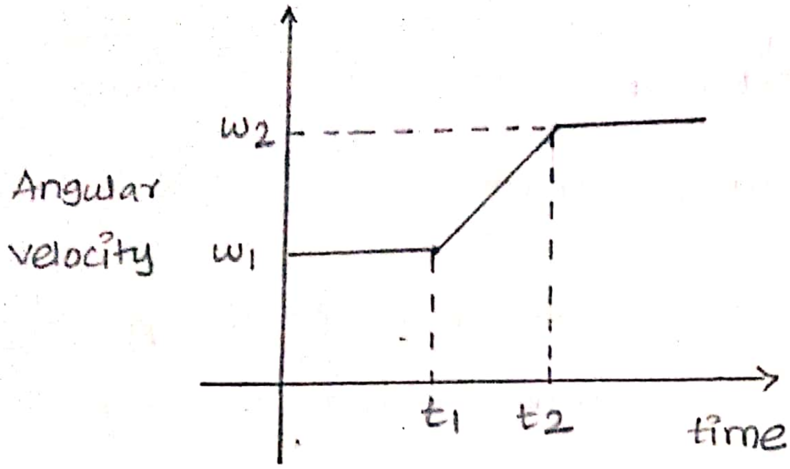
$$\left(\frac{T_m - T_f}{J\theta_s}\right) t + f_1 = f$$

Therefore stepping rate,

$$f = \left(\frac{T_m - T_f}{J\theta_s}\right) t + f_1$$

$$T_f = K\theta$$

Linear acceleration ω_1 to ω_2



Non Linear (Exponential) Acceleration (or) non-linear Analysis considering the torque Produced by the motor :-

$$T_m = J\theta \frac{df}{dt} + D\theta_s f + T_f$$

$$(T_m - T_f) = J\theta \frac{dJ}{dt} + D\theta_s f$$

Dividing throughout $J\theta_s$, we get

$$\frac{df}{dt} + \left(\frac{D}{J}\right)f - \frac{T_m - T_f}{J\theta_s} = 0$$

(or)

$$\frac{df}{dt} + \left(\frac{D}{J}\right)f = \frac{T_m - T_f}{J\theta_s}$$

$$\frac{dy}{dx} + Py = Q$$

$$ye^{\int P dx} = \int Q e^{\int P dx} + C$$

Here

$y = f$; $x = t$; $P = D/J$ and $Q = \frac{T_m - T_f}{J\theta_s}$ = constant

$$f e^{\int (D/J)dt} = \int \left(\frac{T_m - T_f}{J\theta_s}\right) e^{\int (D/J)dt} + C$$

$$f e^{(D/J)t} = \left(\frac{T_m - T_f}{J\theta_s}\right) \int e^{(D/J)t} + C$$

$$f e^{(D/J)t} = \left(\frac{T_m - T_f}{J\theta_s}\right) \frac{e^{(D/J)t}}{D/J} + C$$

where c is the integration constant,

To Find c substituting the initial condition at $t = 0$,

$$f = f(0) = f_1$$

$$f_1 e^0 = \left(\frac{T_m - T_f}{J\theta_s}\right) \frac{e^0}{D/J} + C \text{ .....}$$

$$f_1 = \left(\frac{T_m - T_f}{J\theta_s}\right) \left(J/D\right) + C$$

$$f_1 = \frac{T_m - T_f}{D\theta_s} + C \longrightarrow (1)$$

$$C = f_1 - \left(\frac{T_m - T_f}{D\theta_s}\right) \longrightarrow (2)$$

Subs the above (1) & (2) eqns.

$$f.e^{(D/J)t} = \left(\frac{T_m - T_f}{J\theta_s}\right)\left(\frac{J}{D}e^{(D/J)t}\right) + \left[f_1 - \left(\frac{T_m - T_f}{D\theta_s}\right)\right]$$

$$f.e^{(D/J)t} = \left(\frac{T_m - T_f}{D\theta_s}\right)e^{(D/J)t} + \left[f_1 - \left(\frac{T_m - T_f}{D\theta_s}\right)\right]$$

Dividing throughout by $e^{(D/J)t}$ we get,

$$f = \frac{T_m - T_f}{D\theta_s} + \left[f_1 - \left(\frac{T_m - T_f}{D\theta_s}\right)\right]e^{(-D/J)t}$$

The stepping Frequency,

$$f = \frac{T_m - T_f}{D\theta_s} + \left[f_1 - \left(\frac{T_m - T_f}{D\theta_s}\right)\right]e^{(-D/J)t}$$

which gives rise to non-linear acceleration of the rotor of the machine.

Thus, though the torque production is assumed as linear one in some cases, the saturation of the magnetic material of the machine leads to non-linear operation.

4. Explain the Performance ~~of~~ characteristics of stepper motor :-

The stepper motor characteristics are classified as.

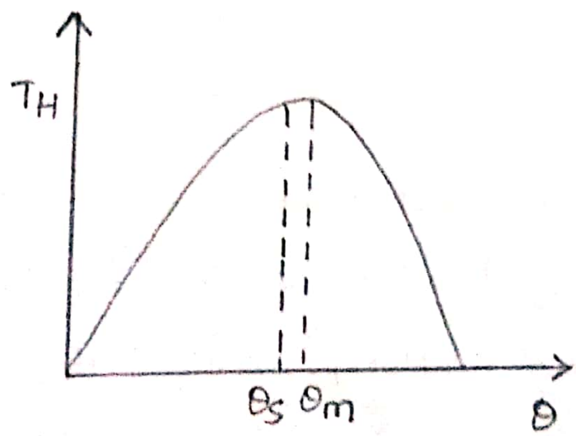
1. Static characteristics
2. Dynamic characteristics.

Static - characteristics :-

1. Torque - displacement characteristics
2. Torque - current characteristics.

Torque - Displacement characteristics:-

Under the torque - displacement characteristics, the nature of torque angle curve of a stepping motor is being studied. This gives the relationship between electromagnetic torque developed and displacement angle θ from steady state position.

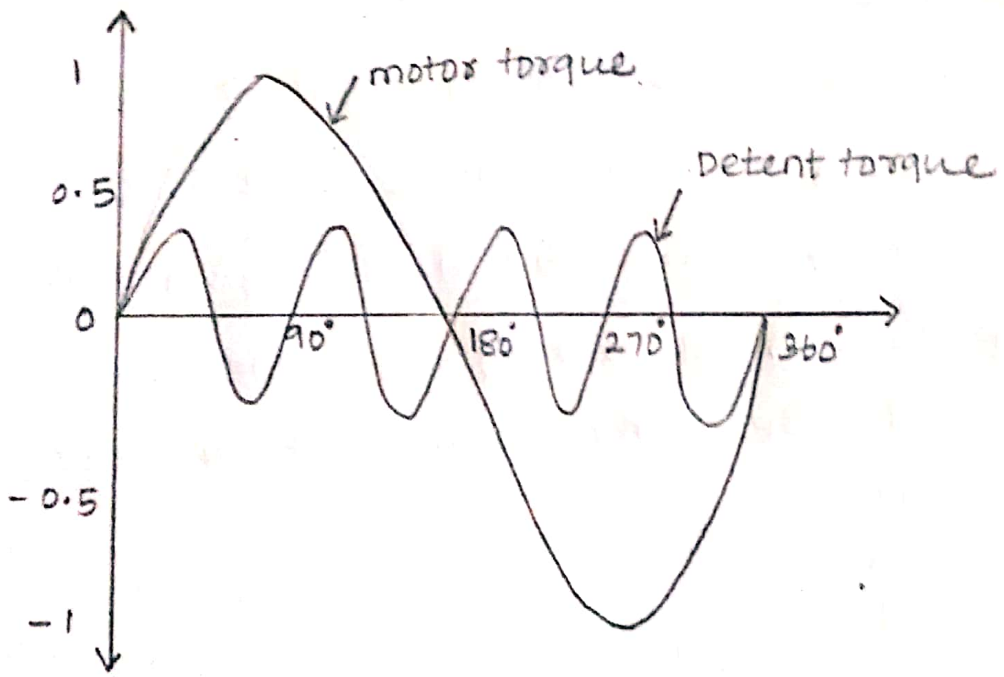


Holding torque (T_H)

It is the maximum load torque which the energized stepper motor can withstand without slipping from 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.

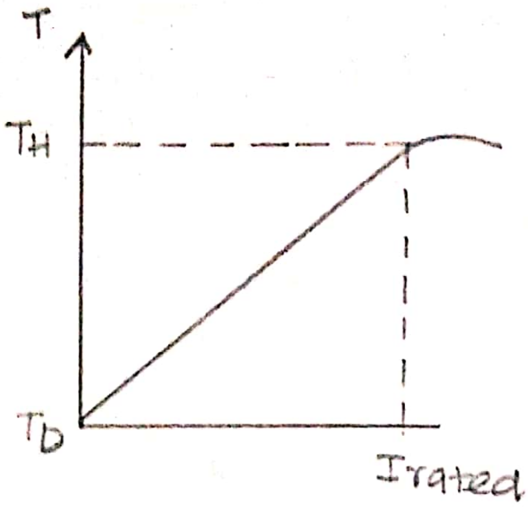
Detent torque (T_D):-

It is the maximum load torque upto which unenergized stepper motor can withstand without slipping. Detent torque is due to residual magnetism, and is therefore available only in permanent magnet and hybrid stepper motor.



Torque current characteristics:-

The holding torque of the stepper motor increases with the exciting current. The relationship between the holding torque and current is known as torque current characteristics. The curve is initially linear but later on its slope progressively decreases as the magnetic circuit of the motor saturates.



a) **Torque constant (K_t)**

Torque constant of the stepper motor is defined as the Initial slope of the torque current (T-I) curve of the stepper motor. It is also known as torque sensitivity. Its units are N/m/A

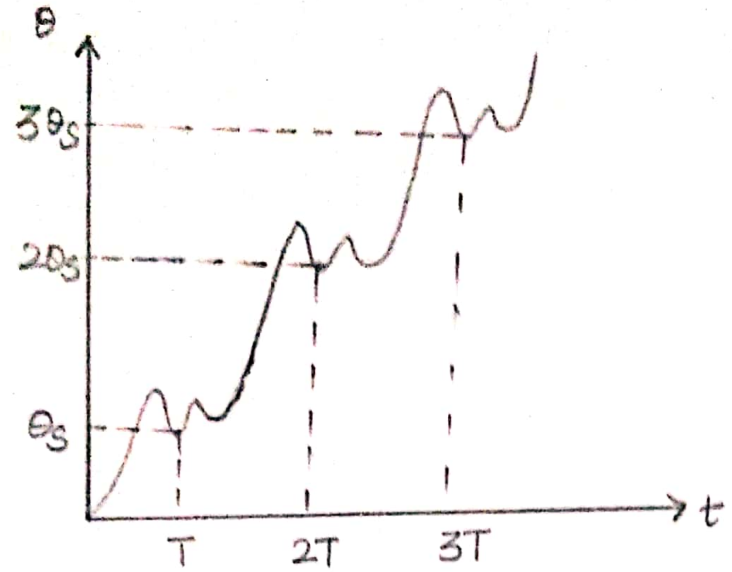
Dynamic characteristics :-

Two modes of operation with regards to Dynamic characteristics,

1. Start stop mode
2. Slewing mode.

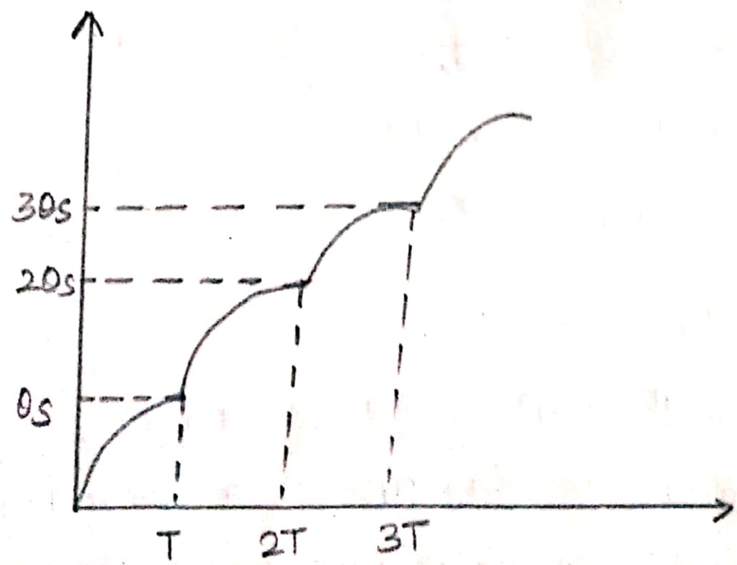
Start stop mode :-

The start stop mode is called as pull in curve (or) single stepping mode. A second pulse is given to the stepper motor only after the motor attained a steady (or) rest position due to First pulse.

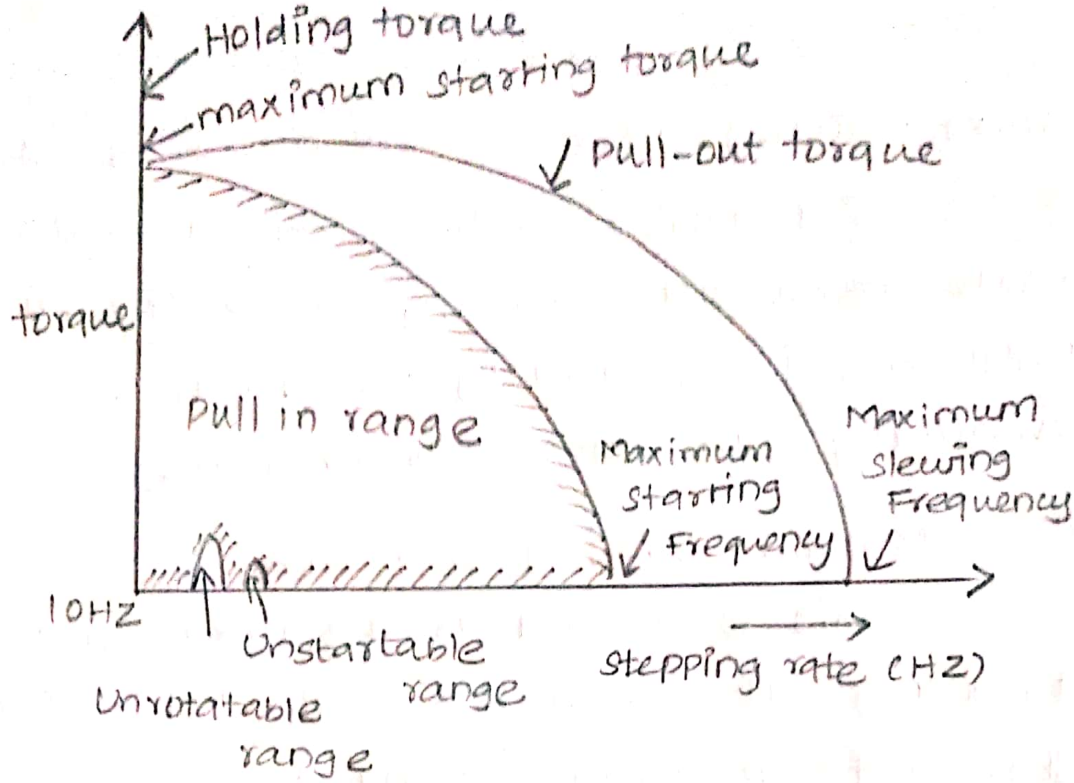


Slewing mode :-

In the start stop mode, the stepper motor always operates 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.



Dynamic characteristics of Stepper motor:-



a) Pull in torque characteristics

b) Pull out torque characteristics.

c) The maximum starting Frequency

d) Maximum pull out rate

e) Maximum starting torque.

Pull in torque characteristics:-

These are alternatively called the starting characteristics and refers to the range of Frictional load torque at which the motor can Start and stop without losing steps for various Frequencies in a pulse train. The no. of. Pulses in the pulse train used for the test is 100 (or) so,

Pull out torque characteristics:-

This is alternatively called the slewing characteristics. After the test motor is started by a specified driver in the specified excitation mode in the self-starting range, the pulse frequency is gradually increased. The motor will eventually run out of synchronism.

The maximum starting frequency:-

This is defined as the maximum control frequency at which the unloaded motor can start and stop without losing steps.

Maximum pull out rate:-

This is defined as the maximum frequency (i.e.,) stepping rate at which the unloaded motor can run without losing steps and is alternatively called the maximum slewing frequency.

Maximum-starting torque:-

This is alternatively called maximum pull-in-torque and is defined as the maximum frictional load torque with which motor can start and synchronize with the pulse train of the frequency as low as 10Hz.

5. Discuss the construction and working principle of hybrid stepper motors.

HYBRID STEPPER MOTOR :- (Construction)

A Hybrid stepping motor combines the important features of variable reluctance and permanent magnet motors. 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. This is achieved by incorporating an axial permanent magnet in the middle of the rotor whose conduction is some what similar to the rotor of a variable reluctance motor.

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 section of hybrid stepper motor.

But in order to give high angular resolution, the practical hybrid stepping motors are built with more rotor poles, the stator also usually has 8 poles in practical motors, Each poles between 2 to 8 teeth. Most widely used hybrid motors are two phase type.

The coils on poles 1, 3, 5 and 7 are connected in series to form phase A while the coils on poles

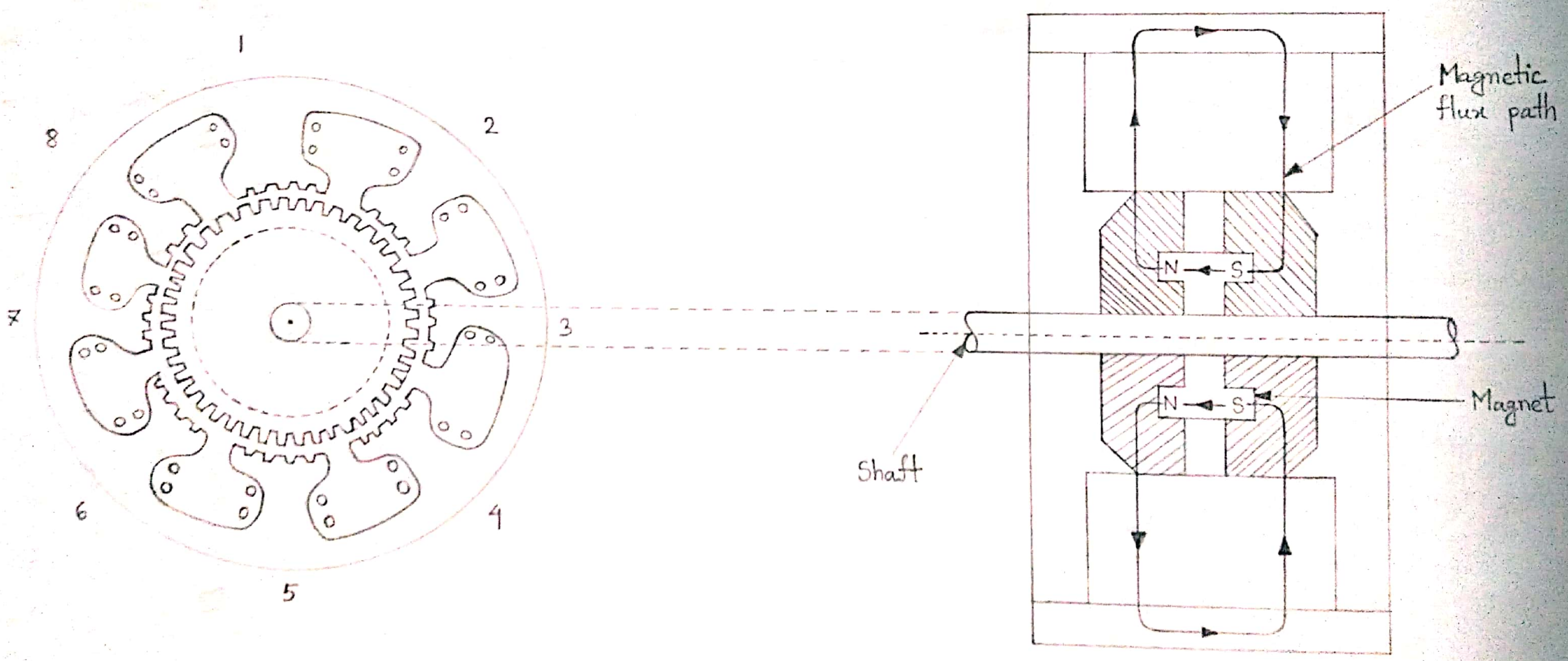
2, 4, 6, 8 are connected in series to form phase B. The windings A and B are energized alternatively. The rotor has two end caps, each with 50 teeth and separated by a permanent magnet. The teeth on both end caps of the rotor have the same pitch as teeth on the stator poles. However, teeth of the two end caps are offset from each other by one tooth so that a tooth on one end cap coincides with a slot at the other.

working principle:

The main flux path is from the north pole of the magnet, into the end stack, across the air gap and back to the magnet south pole via the other end stack.

When phase A carries positive current, stator poles 1 and 5 become south and 3 and 7 become north. The rotor teeth with north and south polarity align with the teeth of stator poles 1 and 5 and 3 and 7 respectively. When phase A is de-energized and phase B is excited, rotor will move by one quarter of tooth pitch. The torque in a hybrid motor is produced by the interaction of the rotor and the stator produced fluxes. The rotor field remains constant as it produced by the PM. The motor torque is proportional to the phase current.

fig: Hybrid stepper motor with 8 stator poles.



when coils does not carry current (any) because of the presence of PM, the detent torque is produced. Due to the offset between teeth of rotor end caps, the torque is close to zero, the rotor steps depends only on the torque produced by the current in stator phases.

---

(6) i) A stepper motor driven by a bipolar drive circuit has the following parameters: winding inductance = 20mH, rated current = 2.5A, DC supply = 45V, total resistance in each phase = 18Ω. When the transistors are turned off determine i) the time taken by the phase current to decay to zero and ii) the proportion of the stored inductive energy returned to the supply.

soln::

i) The current in the winding decays to zero in time

$$t' = \frac{1}{2}\tau_{e1} \quad \text{but } \tau_{e1} = \frac{L_m}{R_m} = \frac{20\times10^{-3}}{18}$$

$$\tau_{e1} = 1.11 \text{ msec.}$$

$$t' = \frac{1.11\times10^{-3}}{2} = 0.55 \text{ msec.}$$

ii) The Energy required to supply during current decay $= \frac{1}{2} L_m I_{ph}^2$

$$= \frac{1}{2} \times 20\times10^{-3} \times (2.5)^2 = 62.5 \text{ mW}$$

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(6) ii) What is the motor torque T_m required to accelerate an initial load of 10^{-4} Kg/m2 from $\omega_1 = 100$ to $\omega_2 = 300$ rad/sec during 0.2 sec. Frictional load torque is 0.06 N-m

Soln:-

$J = 10^{-4}$ kgm2

$\omega_1 = 100$ rad/sec

When the stepping motor is in running condition or about to start optical encoder coupled to the rotor detects the rotor position and supplies its information to the logic sequencer. Then the sequencer determines the proper phases to be excited taking account of the position information. The relation between the rotor's present position and the phases to be excited is specified in terms of lead angle. In this example the motor is a 3ϕ motor, the sequence of excitation is ph1→ph2→ph3→ in the 1ϕ ON mode. Now the ph1 is excited and the rotor is stopping at an equilibrium position.

Then ph1 is de-energized and ph2 is excited. The lead angle in this case is one step. 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 turn ON on ph(N+1) to continue the motion. Thus a stepping motor in a closed loop system runs like a brushless dc motor in which the proper windings to be energized is (are) automatically selected by a position sensor incorporated in or coupled to the motor.

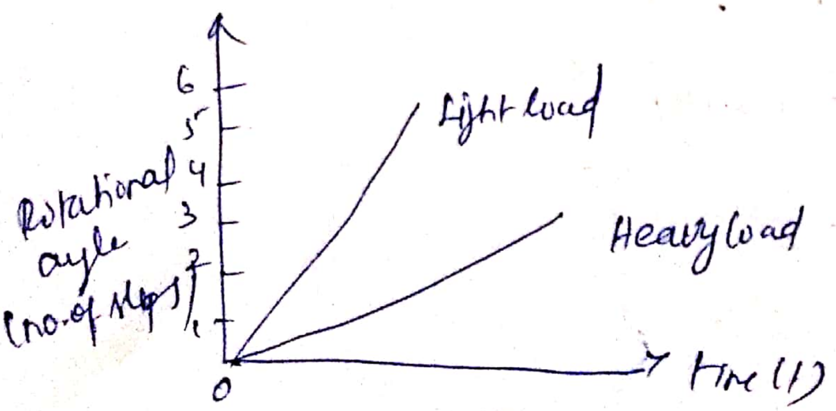


fig: variation of speed with load in closed loop operation

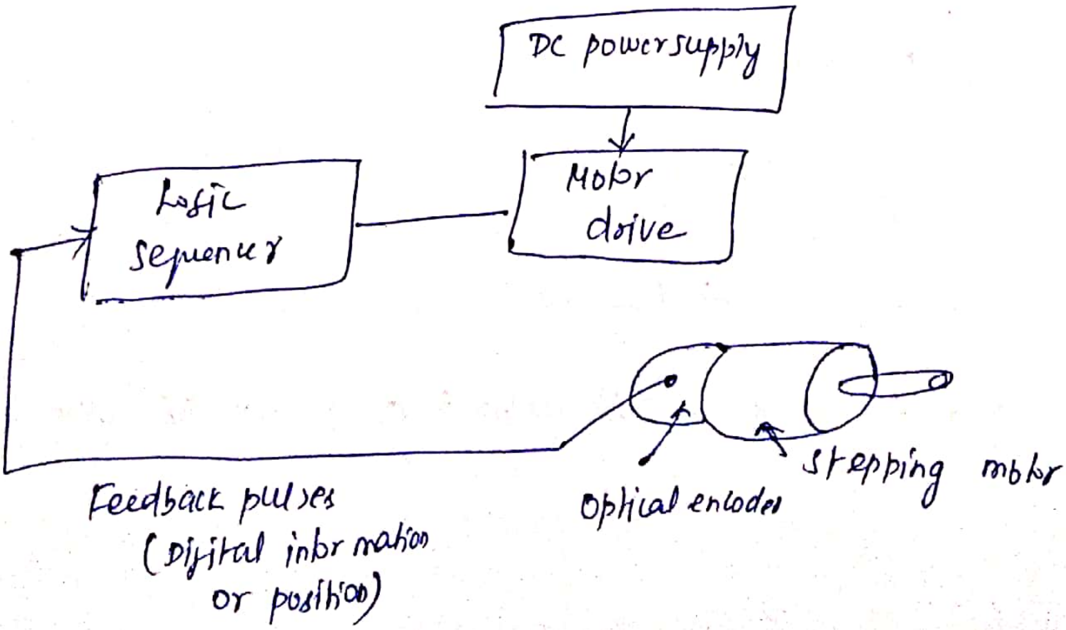
(7) ii) Compare VR, PM and hybrid stepper motors:

VR stepper motor	PM stepper motor	Hybrid stepper motor
1. Low Rotor inertia	High inertia	High inertia
2. Less weight	More weight	More weight
3 No permanent magnet in rotor	Rotor consists of permanent magnet	Rotor consists of permanent magnet
4. Rotor is a salient pole type	Rotor is a cylindrical type	Rotor is a salient pole type

(7) iii) Explain the closed loop control scheme of stepper motor.

The performance of a stepping motor can be improved by employing position feedback and/or speed feedback to determine the proper phases to be switched at proper timings. This type of control is termed as closed loop drive. In a closed loop control a position sensor is needed for detecting the rotor position. Nowadays optical sensor is used as a RPS.

The block diagram of closed loop system is given by



$\omega_2 = 300$ rad/sec

$\Delta t = 0.2$ sec

$T_f = 0.06$ N-m

To find. T_m => motor torque

$$T_m = J\frac{d\omega}{dt} + T_f$$

$$\frac{d\omega}{dt} = \frac{\omega_2 - \omega_1}{\Delta t} = \frac{300-100}{0.2} = 1000$$

$$T_m = 10^{-4}[1000] + 0.06 = 0.16 \text{ N-m.}$$

(6) iii) A stepper motor has the resolution of 180 steps/rev. Find the pulse rate required in order to obtain a rotor speed of 2400 rpm.

Soln:-

Resolution = 180 steps/rev

Required motor speed = 2400 rpm

$$\text{speed in rps } (n) = \frac{\text{Speed in rpm}}{60} = \frac{2400}{60} = 40 \text{ rps}$$

$$\text{Step angle } \beta = \frac{360°}{\text{No. of steps/rev}} = \frac{360°}{180} = 2°$$

W.K.T $$n = \frac{\beta \times f}{360°}$$

$$\text{pulse rate. } f = \frac{n \times 360}{\beta} = \frac{40 \times 360°}{2} = 7200 \text{ pps}$$

(7) i) Calculate the step angle of a 3φ switched reluctance motor having 8 rotor poles. Also determine the commutation frequency at each phase of the speed of 2400 rpm. For a stepper motor having the same step angle, calculate the number of stator and rotor poles.

Soln:-

Step angle $\beta = \frac{360^\circ}{q N_r} = \frac{360^\circ}{3 \times 8} = 15^\circ$

Commutation frequency at each phase $= \frac{N_r \times \text{Speed}}{60}$

$= \frac{8 \times 2400}{60}$

$= 320$ Hz

For the same step angle of stepper motor

No. of rotor poles $N_r = \frac{360^\circ}{q\beta} = \frac{360^\circ}{3 \times 15^\circ} = 8$

Case i) $N_s > N_r$

No. of stator poles $\frac{N_s - N_r}{N_s . N_r} 360^\circ = \beta$

$360^\circ \frac{N_s - 8}{N_s . 8} = 15^\circ$

$360^\circ (N_s - 8) = 120 N_s$

$3N_s - 24 = N_s$

$2N_s = 24 \Rightarrow N_s = 12$ poles.

Case ii) $N_s < N_r$

No. of stator poles $\frac{N_r - N_s}{N_r N_s} 360^\circ = \beta$

$\frac{8 - N_s}{8 N_s} 360^\circ = 15^\circ$

$24 - 3N_s = N_s$

$24 = 4 N_s$

$N_s = 6$ poles.