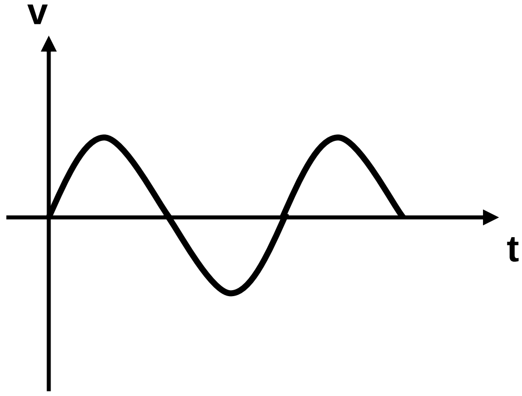
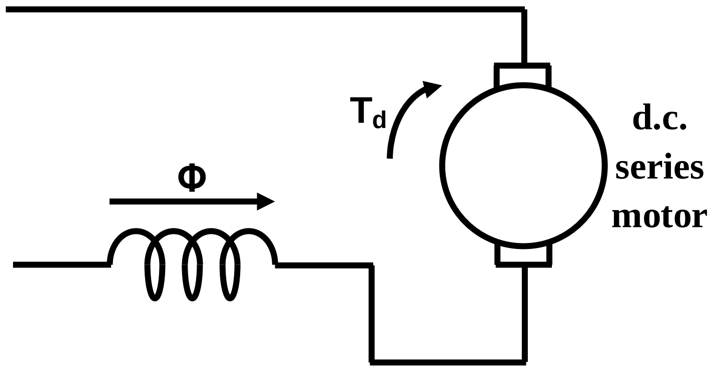
Chapter one

Commutator Motors

Single phase series motors:





A d.c. series motor when supplied with an alternating voltage, will have the torque in the same direction. Since when the current in the armature conductors is reversed the flux due to the main field is also reversed (the field and the armature current both reverse every half cycle). However, the alternations in field flux would cause excessive eddy current losses in the field poles and yoke.

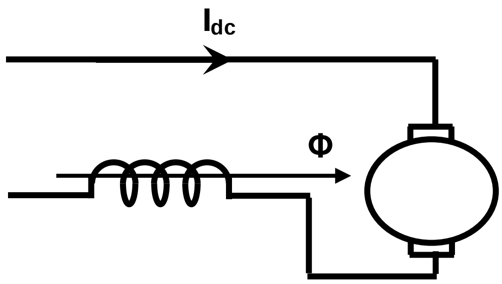
The motor will operate with:

1- Low p.f. as the reactances of the field and armature are high.

2- Low efficiency as the iron losses will be high.

3- Commutation voltage is large and sparking between the commutator segment and the brushes is much.

Voltage induced in d.c. series motor:



Let the speed =n r.p.s

$E_{dc} = k\Phi\omega = \frac{2p}{2a} Zn\Phi$

where:

Z= Total number of armature conductors.

Φ =Flux per pole (wb).

2p= Number of poles.

2a= Number of parallel paths.

ω = Angular speed rad/sec.

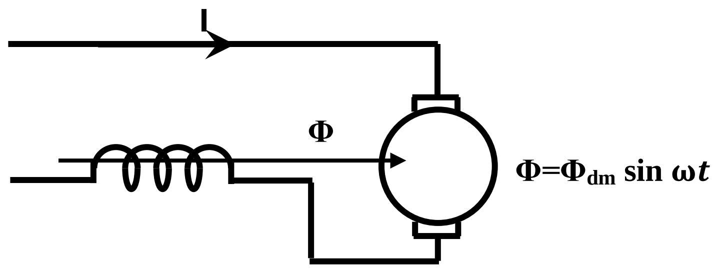
As flux is steady and unvarying with reference to time, the e.m.f. produced by it due to speed of the armature is constant.

Voltages induced in a.c. series motor:

1-Speed e.m.f. across the armature brushes= E_{sa}

Let the speed=n r.p.s.

$\Phi=\Phi_{dm}\sin\omega t$



where:

$\omega = 2\pi f$

f=Supply frequency.

Φ_{dm}=Maximum flux per pole.

Instantaneous e.m.f. induced across the brushes = e_{sa}

$$= \frac{2p}{2a} Z\, n\Phi_{dm}\sin\omega t$$

R.m.s. value of this e.m.f. = E_{sa}

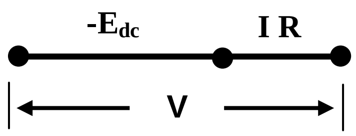
$$= \frac{2p}{2a} Z\, n\frac{\Phi_{dm}}{\sqrt{2}}$$

$$\therefore \boxed{E_{sa} = \frac{2p}{2a} Z\, n\Phi_d}$$

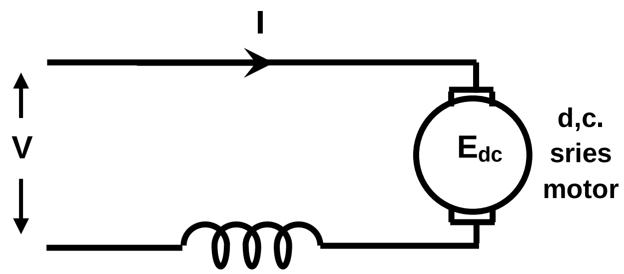
where $\Phi_d = \frac{\Phi_{dm}}{\sqrt{2}}$ is the r.m.s. value of the flux per pole.

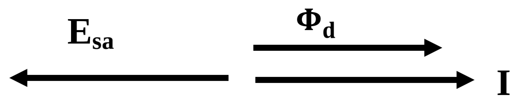
The frequency of this e.m.f. (E_{sa}) is the frequency of the supply (f).

The speed n does not have any influence over the frequency of the e.m.f. E_{sa} but the magnitude of E_{sa} is directly proportional to n.



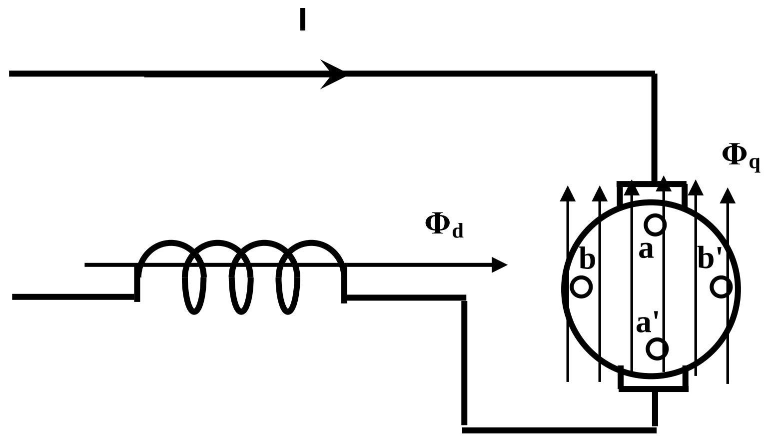
$V=E_{dc}+I\,R$





speed e.m.f. in a.c. series motor

2- Transformer e.m.f. induced in armature across the brushes $=E_{ta}$



Let Φ_q be the r.m.s value of the flux per pole produced by the armature m.m.f.

Φ_{qm} be the maximum value of this flux.

R.m.s. value of the e.m.f. induced in the coil b-b' which links all the flux Φ_{qm} by transformer action= 4.44 f Φ_{qm} *1.

e.m.f. induced in the coil a-a' =0

Total e.m.f. induced = E_{ta} = (Average e.m.f. in one turn)* N

$$=(4.44\, f\, \Phi_{qm} *1*\frac{2}{\pi}) *N$$

where: N= the number of turns between two brushes (in one path)

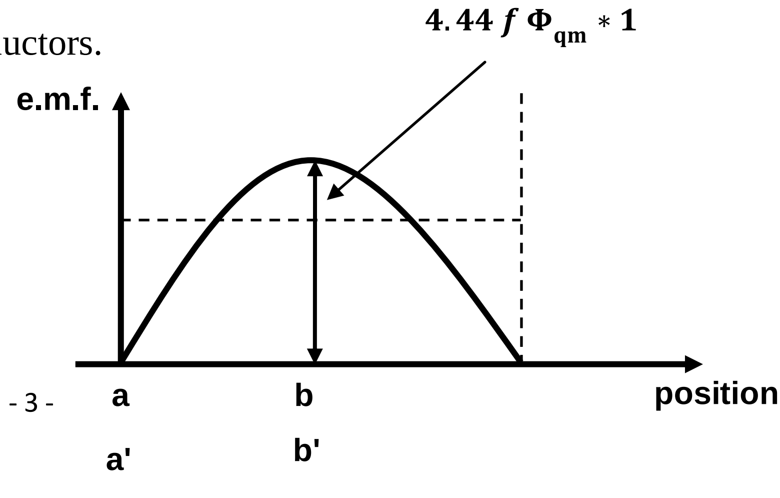
$$N=\frac{Z/2}{2a}$$

where: Z=Total number of armature conductors.

2a= Number of parallel paths.

$$E_{ta} = 4.44\, f\, \Phi_{qm} * \frac{2}{\pi} * \frac{Z/2}{2a}$$

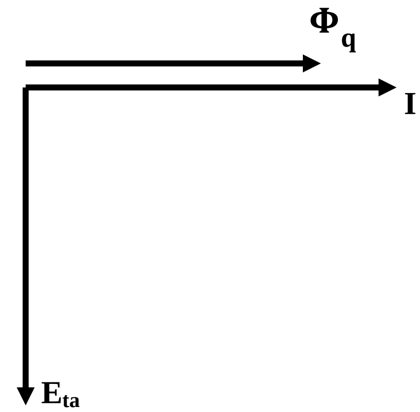
$$= \frac{4.44}{\pi} f\, \Phi_q * \sqrt{2} * \frac{Z}{2a}$$



$$E_{ta} = 2\,f\,\Phi_q * \frac{Z}{2a}$$

The frequency of this e.m.f. is the source frequency (f).

This e.m.f. E_{ta} due to transformer action lags behind Φ_q (and hence I) by 90^o.



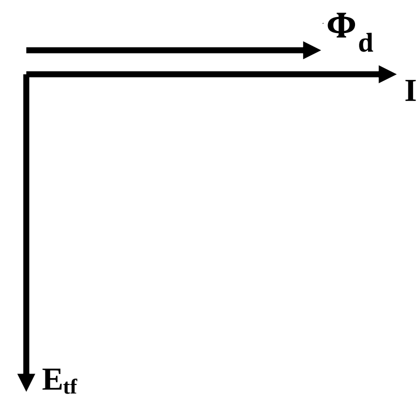
Total e.m.f. in a.c. series motor:

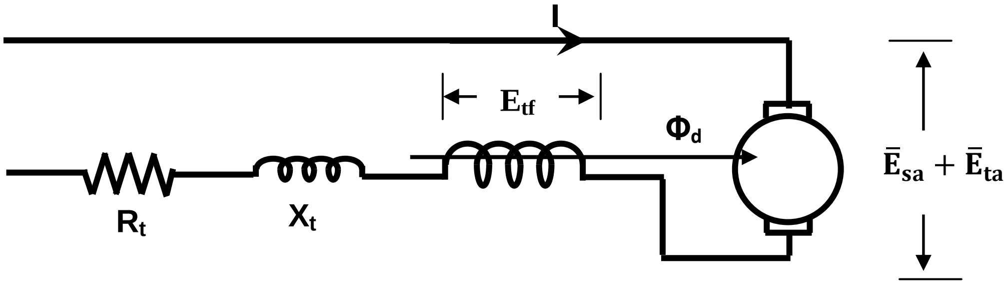
Armature: E_{ta} , E_{sa} , voltage drop in resistance and leakage reactance.

Field: 1- $E_{tf} = 4.44\,f\,\Phi_{dm} * N_f$

where N_f is the number of turns in the field winding.

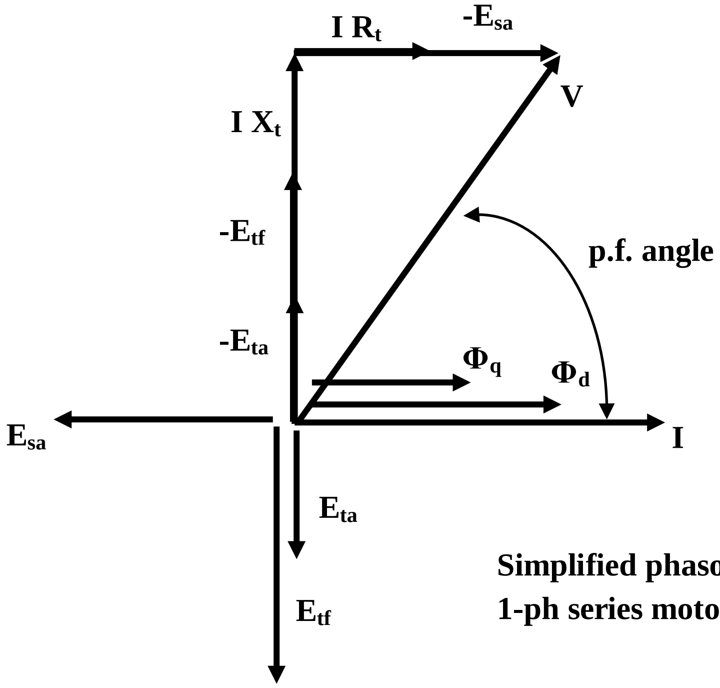
2- Resistance and leakage reactance drop in the field winding.





R_t = Total resistance.

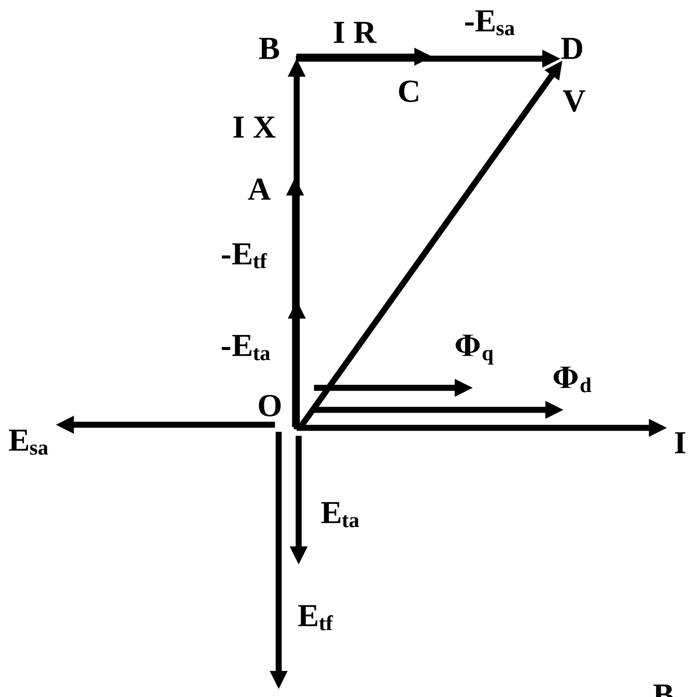
X_t = Total leakage reactance.

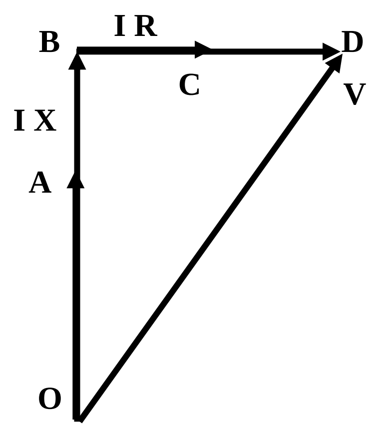


Simplified phasor diagram of 1-ph series motor.

It is possible to improve the p.f. by reducing E_{tf} (by reducing Φ_{dm})

Speed-Torque characteristic of a.c. series motor and comparison with d.c. operation:





CD in magnitude

$$= E_{sa} = \frac{2p}{2a} Z\, n\Phi_d$$

$$= \left(\frac{2p}{2a} Z\right) \Phi_d n$$

$$= C\,.\,I\,.\,n$$

where C is a constant , since Φ_d is a function of current in magnitude.

OA in magnitude = $E_{ta} + E_{tf} = X'\ I$

where X' is a constant, as E_{ta} and E_{tf} are functions of the flux which is a function of the current.

$OB = I(X + X')$

$BD = IR + C\,I\,n = I\,(R + C\,n)$

$OD^2 = OB^2 + BD^2$

$V^2 = I^2\,(X + X')^2 + I^2\,(R + C\,n)^2$

$(X + X')^2 + (R + C\,n)^2 = (\frac{V}{I})^2$

$R + C\,n = \sqrt{(\frac{V}{I})^2 - (X + X')^2}$

$$\therefore\ n = \frac{1}{C}\ [\sqrt{\left(\frac{V}{I}\right)^2 - (X + X')^2}\ \ - R]$$

T_d = developed torque = $K'\Phi I = K'' I^2$ since Φ is a function of I in series motor.

$\therefore\ I^2 = K\,T_d$

$$\therefore\ n = \frac{1}{C}\ [\sqrt{\frac{V^2}{K\,T_d} - (X + X')^2}\ \ - R]$$

<u>For d.c. series motor:</u>

$E_{dc} = \frac{2p}{2a} Z\, n_{dc}\, \Phi$

where Φ is the flux per pole.

$E_{dc} = \left(\frac{2p}{2a}\ Z\,\Phi\right) n_{dc} = C\,I\,n_{dc}$

$V = E_{dc} + I\,R$

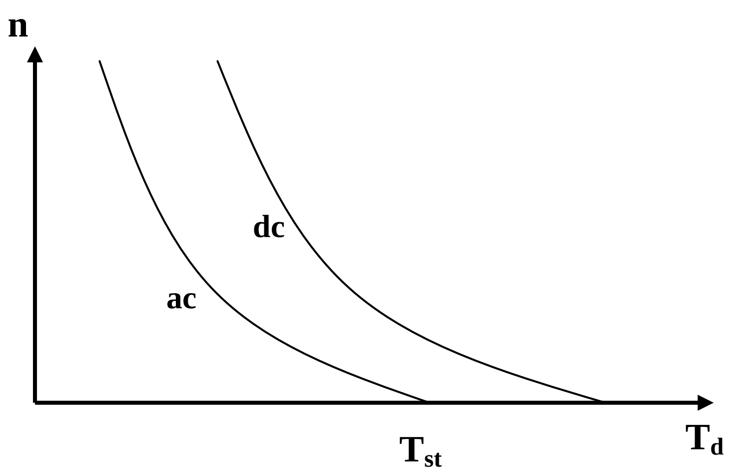
$= C\,I\,n_{dc} + I\,R = I\,(C\,n_{dc} + R)$

$\frac{V}{I} = C\,n_{dc} + R$

$$\therefore\ n_{dc} = \frac{1}{C}[\frac{V}{I} - R]$$

$\because\ I^2 = K\,T_d \qquad \therefore\ I = \sqrt{K\,T_d}$

$$\therefore\ n_{dc} = \frac{1}{C}[\frac{V}{\sqrt{K\,T_d}} - R]$$



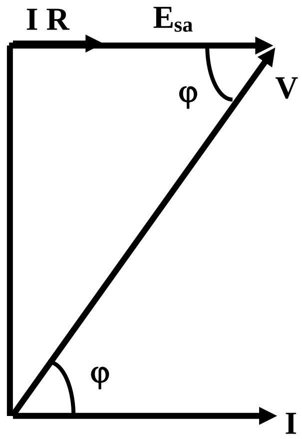
Speed-Torque characteristic

Relation between n & n_{dc}:

$V \cos \varphi = I R + E_{sa}$

$E_{sa} = V \cos \varphi - I R$

$E_{dc} = V - I R$



$$\frac{E_{sa}}{E_{dc}} = \frac{\frac{2p}{2a} Z\, n \Phi_d}{\frac{2p}{2a} Z\, n_{dc} \Phi}$$

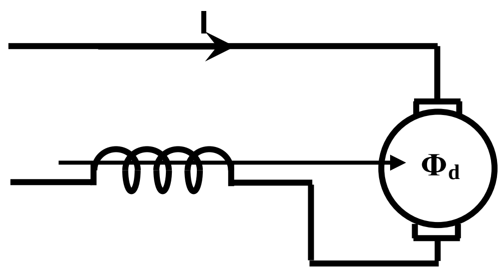
For the same flux per pole (i.e. $\Phi_d = \Phi$), this means that the steady value of the current in d.c. is equal to the r.m.s. value current in a.c.

$$\therefore \boxed{\frac{E_{sa}}{E_{dc}} = \frac{n}{n_{dc}} = \frac{V \cos \varphi - I R}{V - I R}}$$

If I R drop is ignored, then:

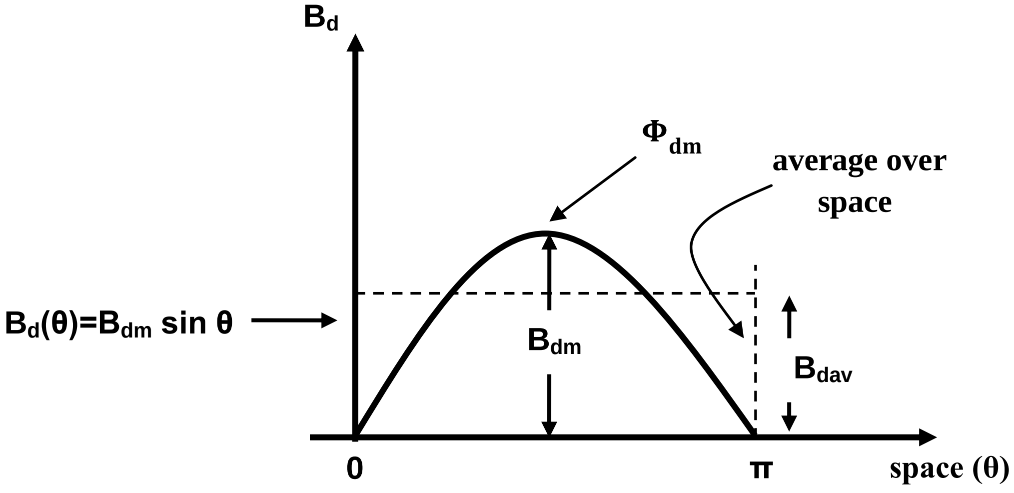
$$\boxed{\frac{n}{n_{dc}} = \cos \varphi}$$

T_d of a single phase series motor:



Flux in the airgap is distributed sinusoidally. Let the maximum value of Φ_d be equal to Φ_{dm}. where Φ_{dm} is the maximum flux per pole.

Let B_{dm} be the maximum flux density in the air gap. Average of this density over one pole pitch be equal B_{dav}.



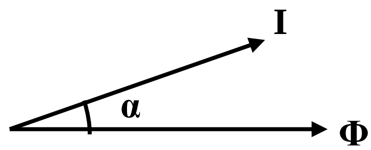
Let the instantaneous value of the input current be equal to $i=I_m \sin(\omega t+\alpha)$.

∴ The instantaneous current in the conductors

$$i_C = \frac{I_m}{2a}\sin(\omega t + \alpha)$$

where α is the phase angle between flux and the current.

$B_d(t,\theta)=B_{dm}\sin\theta\sin\omega t$



As the current changes sinusoidally with respect to time, the flux in the airgap also changes accordingly (similarly). Therefore B_{dav} changes sinusoidally.

The instantaneous average flux density in the airgap can be therefore be written as:

$$B = B_{dav}\sin\omega t$$

$$\therefore \text{Force per conductor} = f = B * \text{current} * L$$

$$= B_{dav}\sin\omega t * \frac{I_m}{2a}\sin(\omega t + \alpha) * L$$

$$= B_{dav}\frac{I_m}{2a} L\,[\sin\omega t * \sin(\omega t + \alpha)]$$

$$= B_{dav}\frac{I_m}{2a}\frac{L}{2}\,[\cos\alpha - \cos(2\omega t + \alpha)]$$

$$B_{dav} = \frac{\Phi_{dm}}{\frac{\pi D}{2P}L} = \Phi_{dm}\frac{2P}{\pi DL}$$

$= \sqrt{2}\Phi_d \ \frac{2P}{\pi DL}$

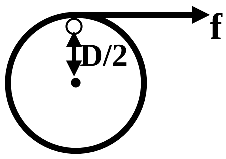
where: D= The diameter of the armature arc.

L= The length of the armature (Length of conductors).

$I_m = \sqrt{2}\, I$

Instantaneous torque = t_d

= Instantaneous force per conductor x No. of conductors in the motor x $\frac{D}{2}$



$\therefore\ t_d = B_{dav}\ \frac{I_m}{2a}\ \frac{L}{2}\ Z\ \frac{D}{2}[\cos\alpha - \cos(2\omega t + \alpha)]$

$= \sqrt{\cancel{2}}\Phi_d \quad \frac{2P}{\pi \cancel{D}\cancel{L}} \quad \frac{\cancel{\sqrt{2}}I}{2a}\ \frac{\cancel{L}}{\cancel{2}}\ Z\ \frac{\cancel{D}}{2}[\cos\alpha - \cos(2\omega t + \alpha)]$

$= \frac{2P}{2a}\ Z\ \Phi_d\ \frac{I}{2\pi}\ \ [\cos\alpha - \cos(2\omega t + \alpha)]$

$\therefore\ E_{sa} = \frac{2p}{2a} Z\, n\, \Phi_d$

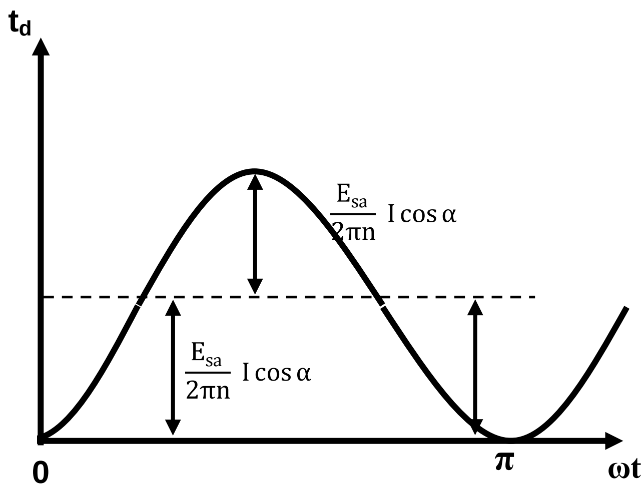
$\therefore\ \ \frac{2p}{2a} Z\ \Phi_d = \frac{E_{sa}}{n}$

$\therefore$ Instantaneous torque = $t_d = \frac{E_{sa}}{2\pi n}\ I\,[\cos\alpha - \cos(2\omega t + \alpha)]$

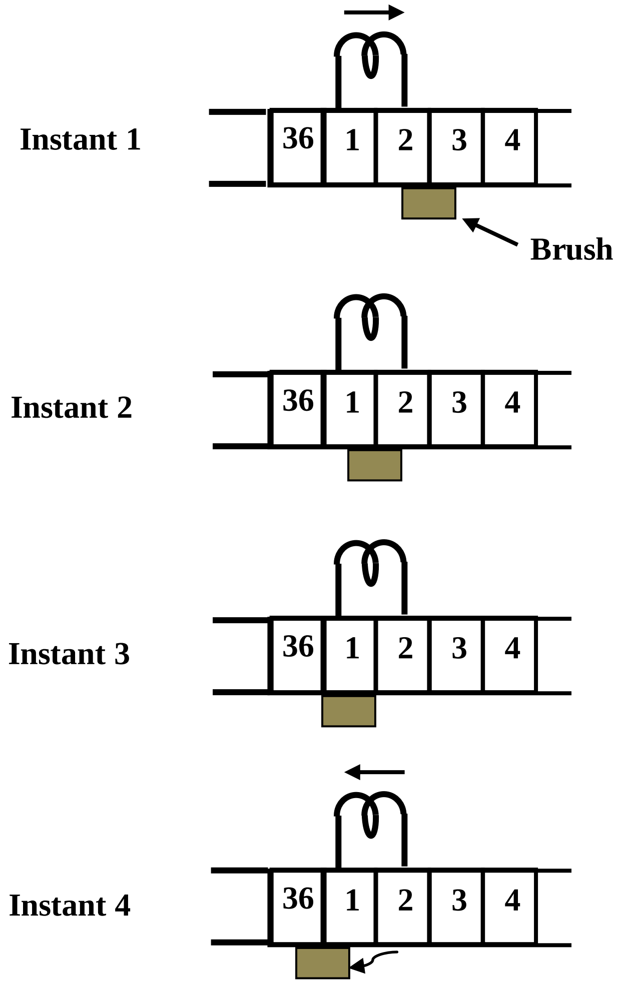
Average torque developed = $T_d = \frac{E_{sa}}{2\pi n}\ I\cos\alpha$

(if α =0 $T_d\ \omega = E_{sa}\ I$ a.c. sense)

($T_L\ \omega$ = E I d.c. sense)

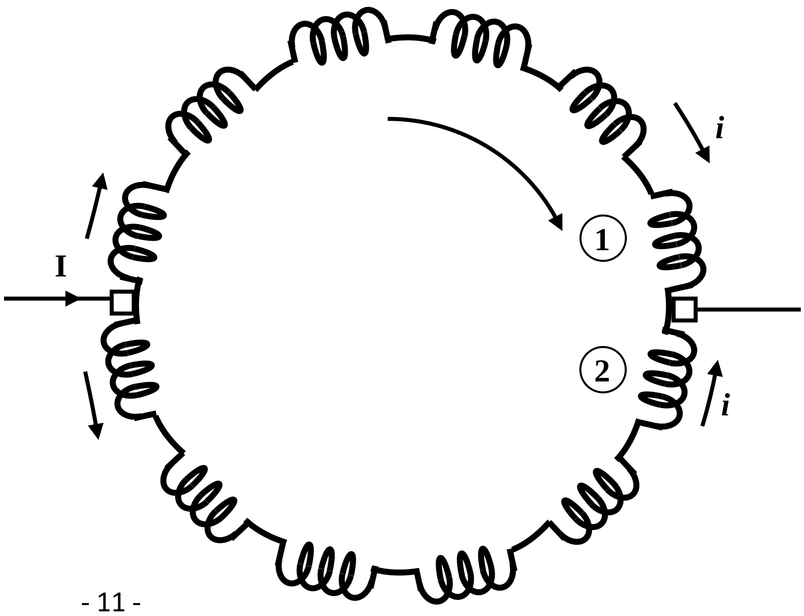


Commutation in 1-ph series motor:

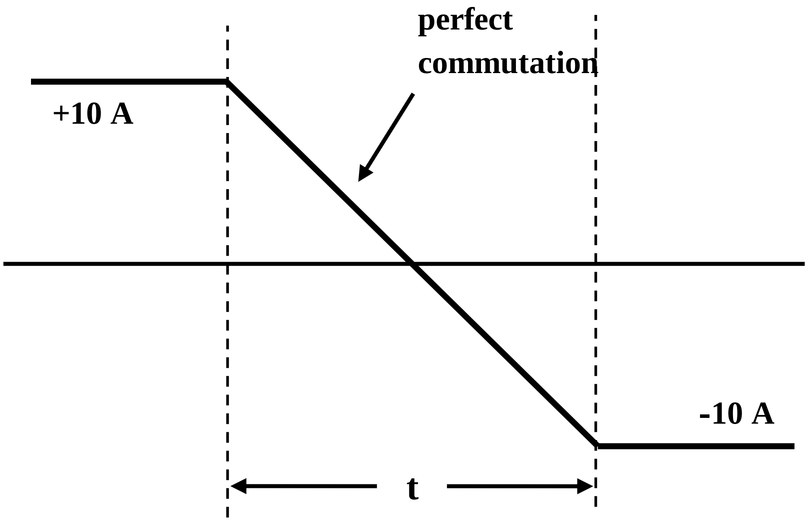


The current in a given coil has to change from say +10 A at instant "1" to -10A at instant "3". This is because the coil is transferred from one circuit to another circuirt carrying current in the opposite direction.

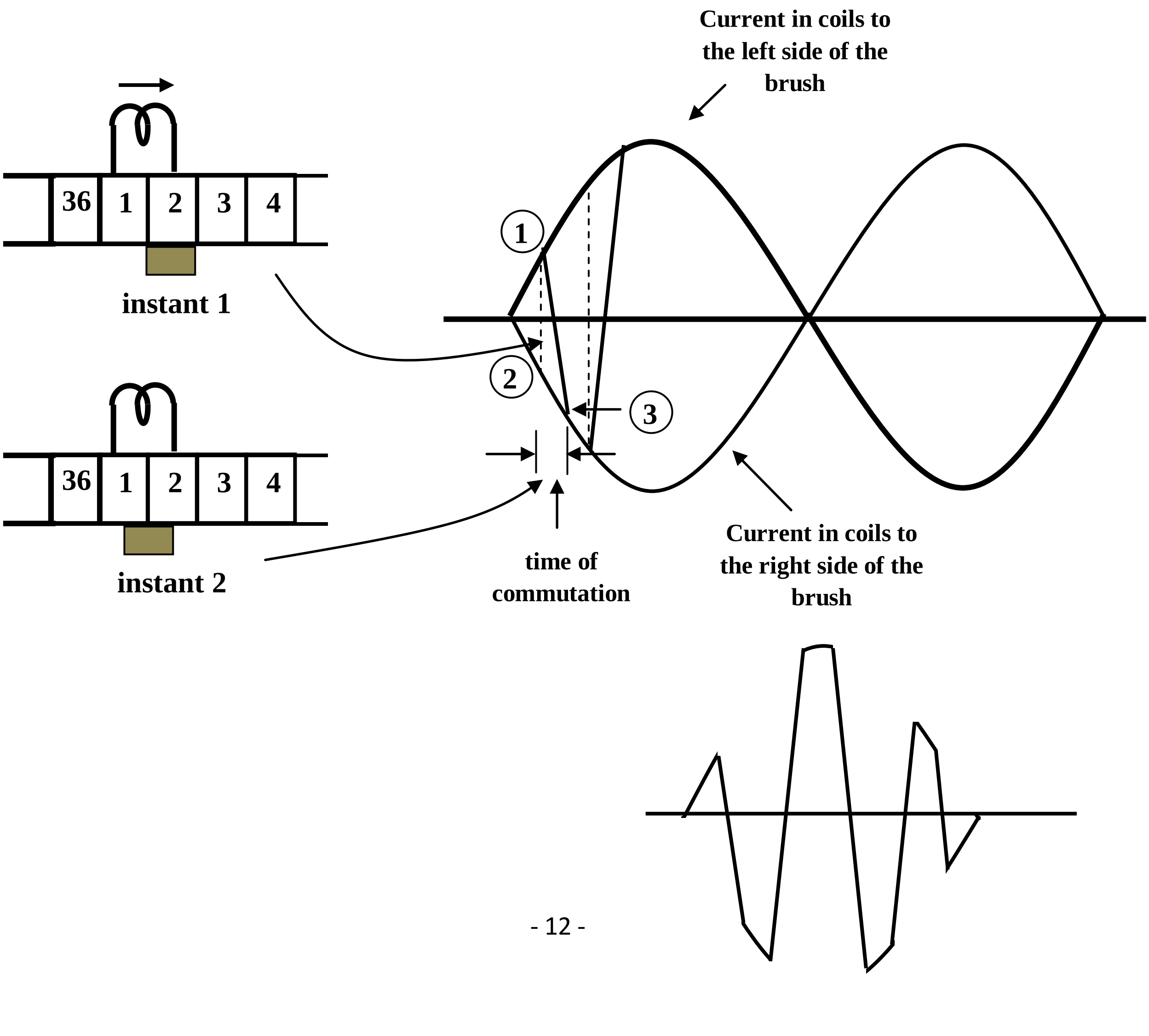
The current in the coil in position 1 has to change the direction when reaching position 2 .



Due to reactance voltage and other reasons when the brush leaves segment 2 the current in the coil is not completely reversed to -10 A. Due to this, some current will jump over the segment 2 to the brush as the segment leaves the brush (sparking). The sparking reduces the life of the commutator.



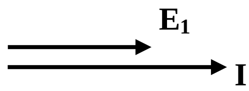
Time of commutation



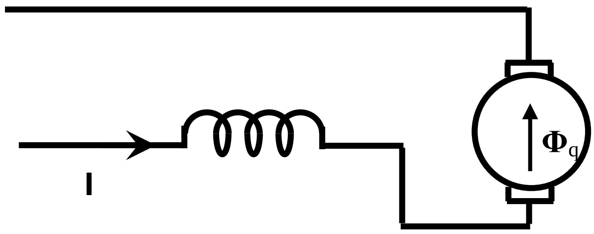
Voltages in the coil undergoing commutation:

a- Reactance voltage: Time of commutation is small when compared to the period of the source.

The current to be commutated (di) is maximum when the armature current is maximum. Therefore, the reactance voltage ($L\frac{di}{dt}$) is also a maximum when the current is a maximum. Therefore E_1, the reactance voltage, is inphase with the current I.



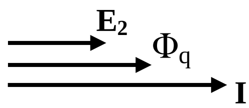
b- E.m.f. due to rotation through Φ_q:



An e.m.f. is produced in the coil undergoing commutation due to the cutting of the flux Φ_q as the armature rotates.

This e.m.f. E_2 is zero when Φ_q is zero and is maximum when Φ_q is maximum, so that they are in phase with each other.

Φ_q is produced by armature current I and as such I and E_2 are in phase.



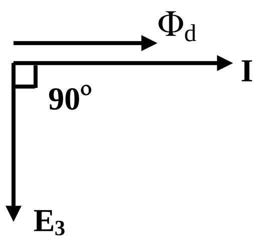
c- Transformer e.m.f. due to Φ_d:

The coil undergoing commutation links with the full Φ_d which is pulsating and therefore an e.m.f. E_3 is induced (by transformer action). This means that the coil undergoing commutation (short-circuited coil) will acts as a secondary of a transformer with the field winding playing the part of the primary.

If the number of turns in the coil undergoing commutation is N_c and Φ_{dm} is the maximum value of Φ_d then:

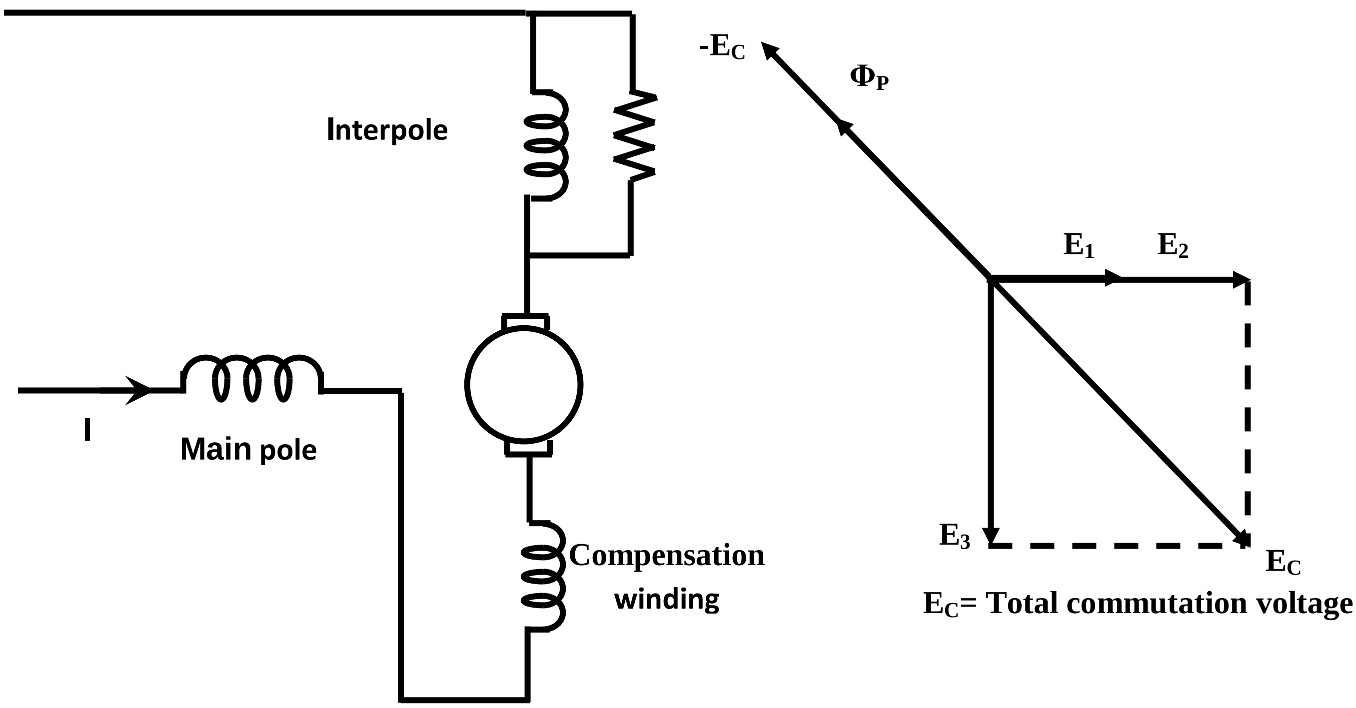
$E_3 = 4.44\, f\, \Phi_{dm}\, N_C$

This e.m.f. E_3 lags behind Φ_d and I by 90^o (by transformer action). This e.m.f. is present always whatever may be the speed. In particular it appears when the machine is at standstill when compensation cannot be given since the compensating voltage is produced by rotation and when the speed is zero the compensating voltage is also zero.



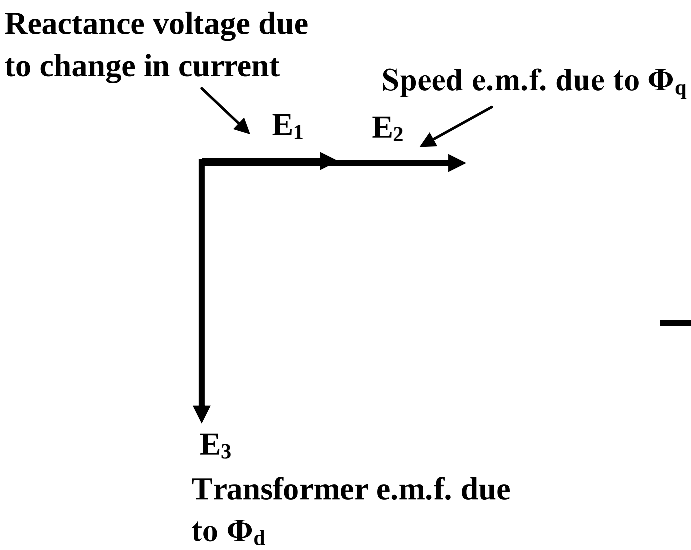
Since the magnitude of the transformer e.m.f. decreases with frequency, it is advantages to use as low frequency as possible. A frequency of 16.6 Hz / 25 Hz are sometimes used.

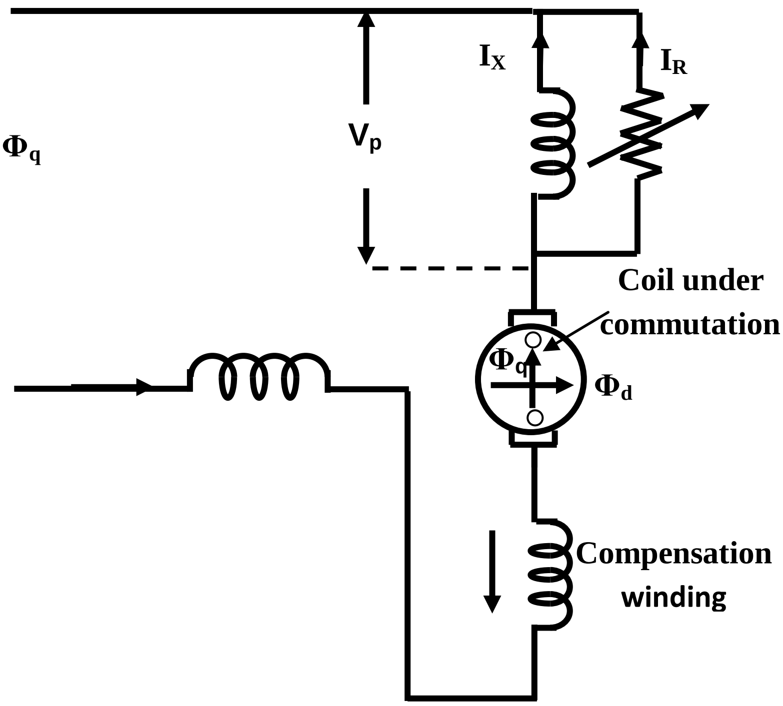
Total voltage in commutated coil and compensation:



The total commutation voltage is E_C. This can be compensated by producing an e.m.f. $-E_C$ by speed action if a flux Φ_p can be produced.

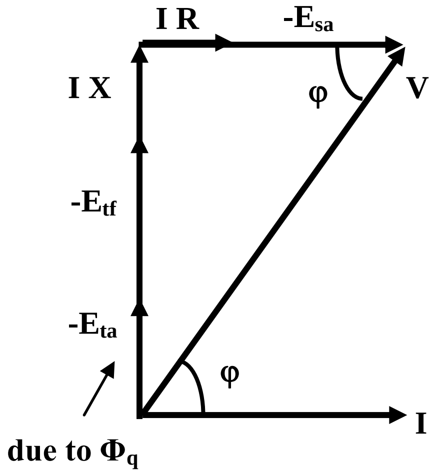
Reduction of commutation voltage in 1-ph series motor:





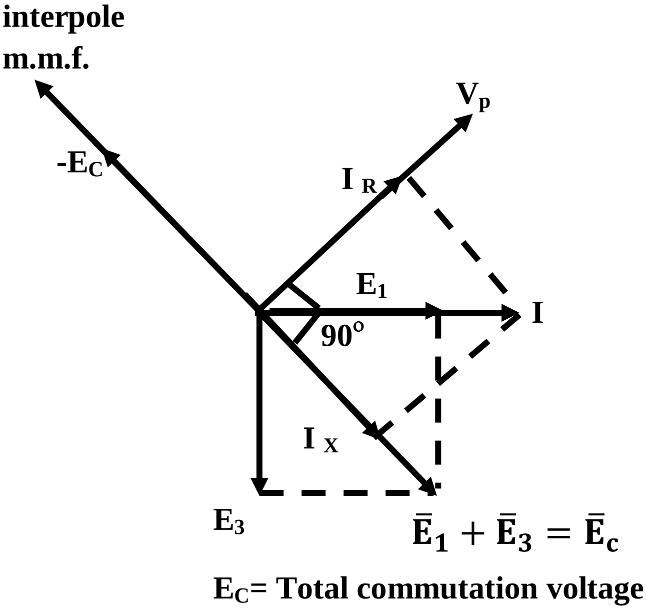
Compensating winding is placed on the quadrature axis of the stator and it carries the armature current. It produces an m.m.f. that nearly cancels out the flux Φ_q. This results in the elimination of E_{ta} and E_2.

From the phasor diagram the elimination of E_{ta} decreases φ and therefore improving the p.f. and thus improving the efficiency.



If we assume that compensating winding takes care of E_2 then the interpole m.m.f. has to be designed to compensate for E_1 and E_3.

$\bar{E}_1 + \bar{E}_3 = \bar{E}_c$ is to be compensated



Interpole winding is made mostly reactive so that its current I_X lags behind the voltage V_p by 90^o. Interpole is shunted by a resistance which carries a current I_R. The magnitude and the phase of I_X (and therefore interpole m.m.f.) can be controlled by varying the shunt resistance. The current I_X produces the interpole m.m.f. which results in speed e.m.f. just sufficient to cancel the commutation voltage E_C.

Since - E_C depends on speed, compensation is only possible under continuous speed.

As - E_C , the compensating voltage by interpole, is a function of speed, complete compensation is possible for one speed for a given value of shunt resistance.

Universal Motors:

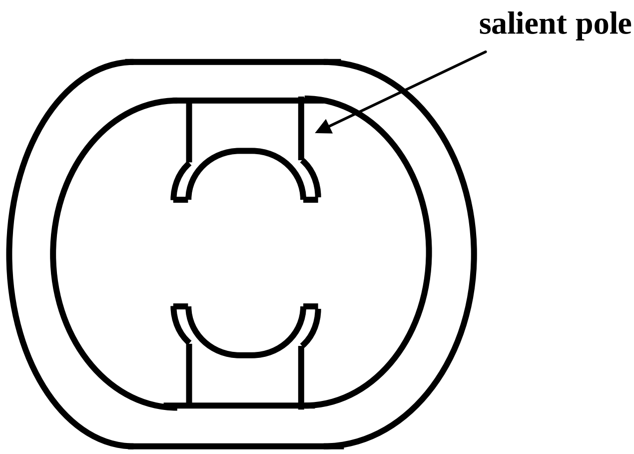
A universal motor is defined as a motor which may be operated either on direct current or single-phase a.c. supply at approximately the same speed and output.

It has high starting torque and a variable speed characteristic (like series d.c. motor speed-torque characteristic). It runs at dangerously high speed on no-load, sometimes over 20000 r.p.m. The armature are designed so that they will not be damaged at these speeds.

Usually, universal motors are manufactured in two types:

1- The concentrated-pole noncompensated motor (low h.p. rating):

The noncompensated motor has two salient poles and is just like a 2-pole series d.c. motor except that whole of its magnetic path is laminated.

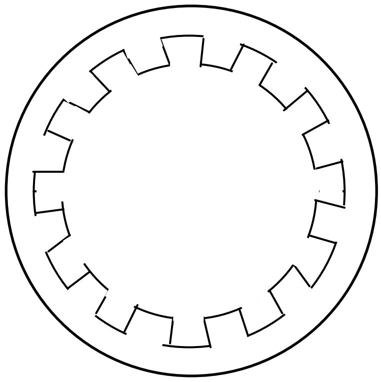


The laminated stator is necessary because the flux is alternating when the motor is operated from a.c. supply. The armature is of wound type and similar to that of a small d.c. motor.

2- Distributed-field compensated universal motors (high h.p. rating):

The armature of a distributed-field compensated universal motor is generally the same as that used in noncompensated universal motors. The stator looks very much like the stator of a two-pole induction motor (laminated stator with slots on the inner periphery).

It has field winding and compensating winding. The compensating winding is displaced 90^o from the main winding (along the quadrature axis).



Principles of operation:

If the motor is supplied with d.c. current , it will operate just like d.c. series motor. But, if alternating current is applied to the motor it will start to run. The developed torque is always in one direction. However, the motor will have:

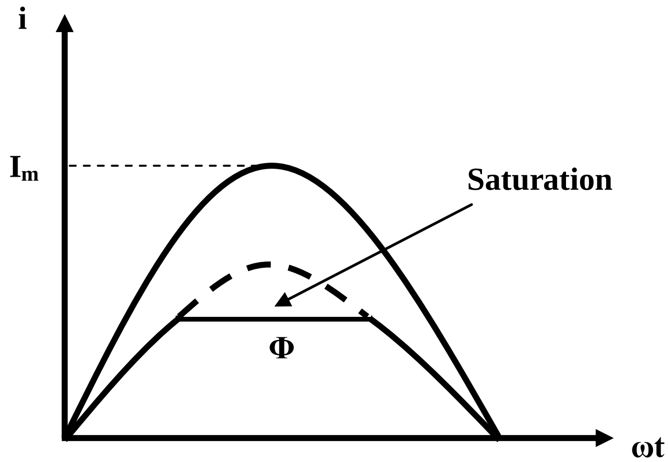
1- laminated-field construction: It is necessary to use a laminated field structure in order to reduce hysteresis and eddy current losses.

2- Reactance voltage drop: Due to a.c. operation the motor will have voltage drop in its leakage reactance as well as in its resistance. This means that the voltage drop in a.c. operation is more than that in d.c. operation. Thus the speed will be lower in a.c. operation for a given current.

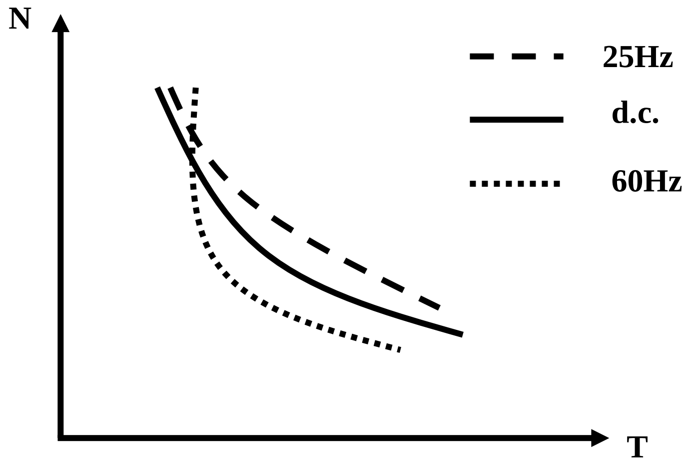
3- Saturation effect:

$i = I_m \sin \omega t$

$I_{(r.m.s.)} = \frac{I_m}{\sqrt{2}}$



The r.m.s. value of current will produce less flux than will a direct current of the same value because of the saturation effects in the iron (this is because of the peak value of the instantaneous current). Since at low currents the reactance voltage drop (I X) is relatively small, the saturation effect of producing less flux will cause the motor to operate at higher speed at no load (since the speed is inversely proportional to flux). Likewise, under 25 Hz operation, the saturation effect is as much as on 60 Hz, but the effect of the reactance voltage is less. The net result is that the motor may sometimes operate at a higher speed on 25 Hz than it does on direct current.



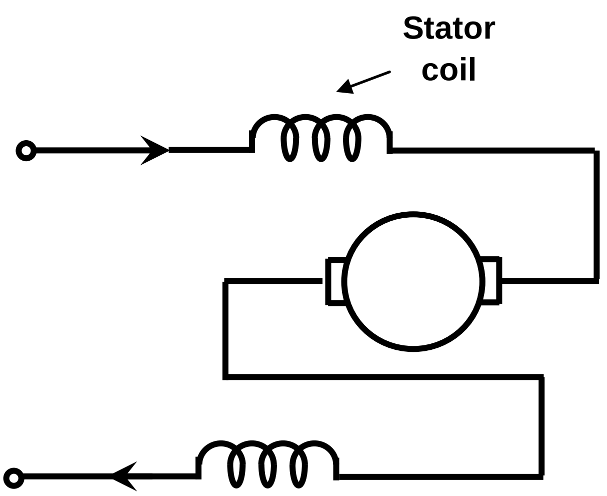
4- Commutation and brush life: The commutation on alternating current is poorer than on direct current and the brush life is less. This is because of the voltages induced in the coil undergoing commutation by the transformer action.

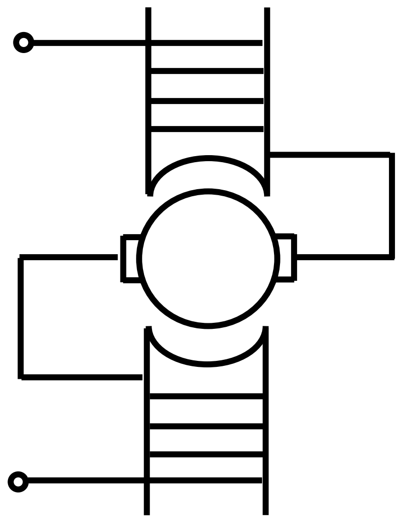
<u>Compensated universal motors:</u>

The compensating winding is placed along the quadrature axis. It produces an m.m.f. that eliminates the voltage drop due to reactance of the armature, i.e., improves the speed of the motor. It neutralize the m.m.f. of the armature (armature reaction) thus eliminating the e.m.f. produced in the coil undergoing commutation due to this m.m.f., i.e. , the compensating winding improves the commutation process.

<u>STATOR windings:</u>

<u>1- Concentrated-pole noncompensated motors:</u>

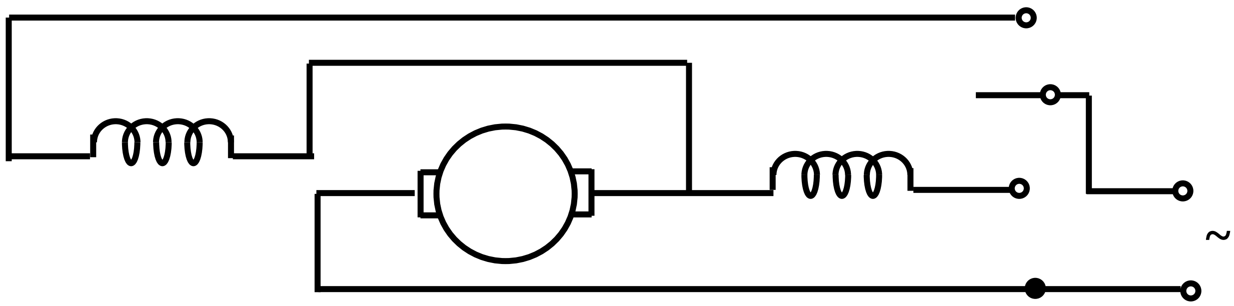




It is shown that the armature could be caused to rotate in either direction simply by interchanging the leads on the brush holders.

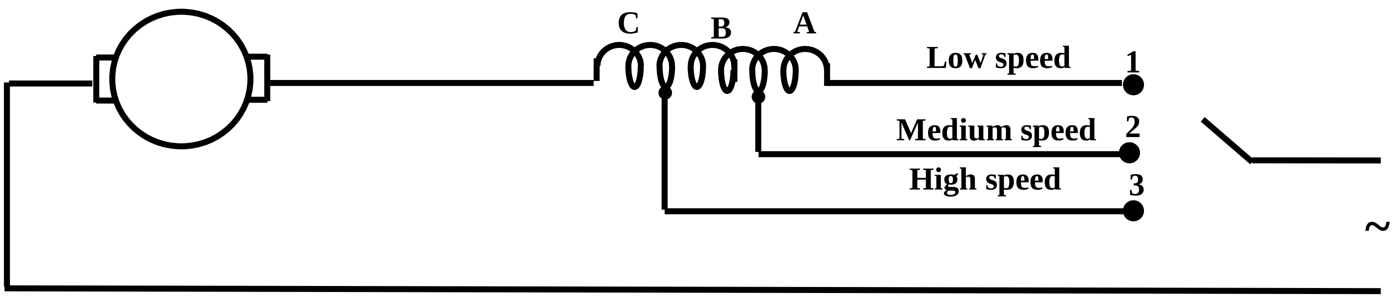
2- Split series electrically reversible motors:

The stator has two coils.



With this arrangement, one stator coil is used to obtain one direction of rotation and the other stator coil to obtain the other direction of rotation. Only one stator coil is to be the circuit at a time.

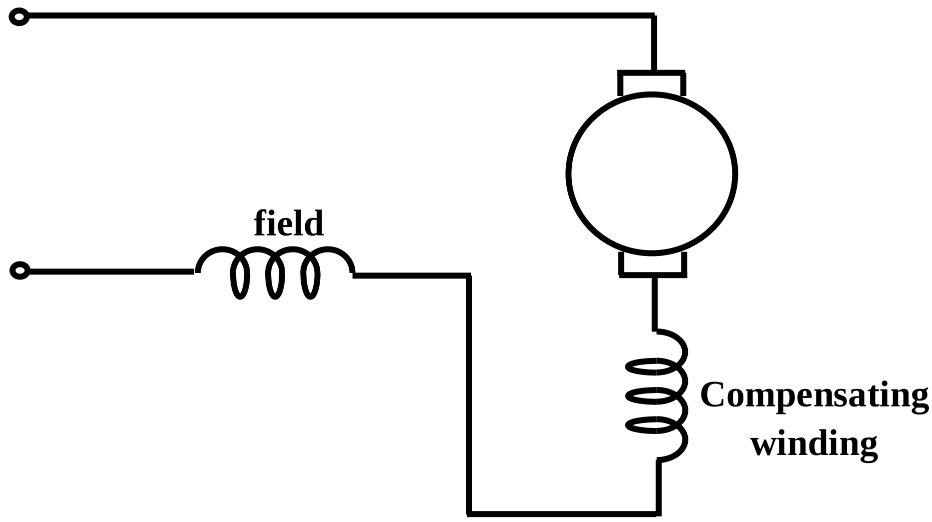
3- Tapped field winding:



Speed control of concentrated-pole noncompensated universal motors is sometimes affected by using tapped-field winding. It is used for fans, blowers and many other applications.

Sometimes a tapped field is employed merely to obtain the same speed operation on direct current as on alternating current. For operation on alternating current tap 2 is used and for operation on direct current tap 1 is used.

4- Field and compensated winding:



The compensating winding and the armature are permanently connected in series as a single unit. Thus, the compensating winding and the armature must be reversed together in order to reverse the speed.

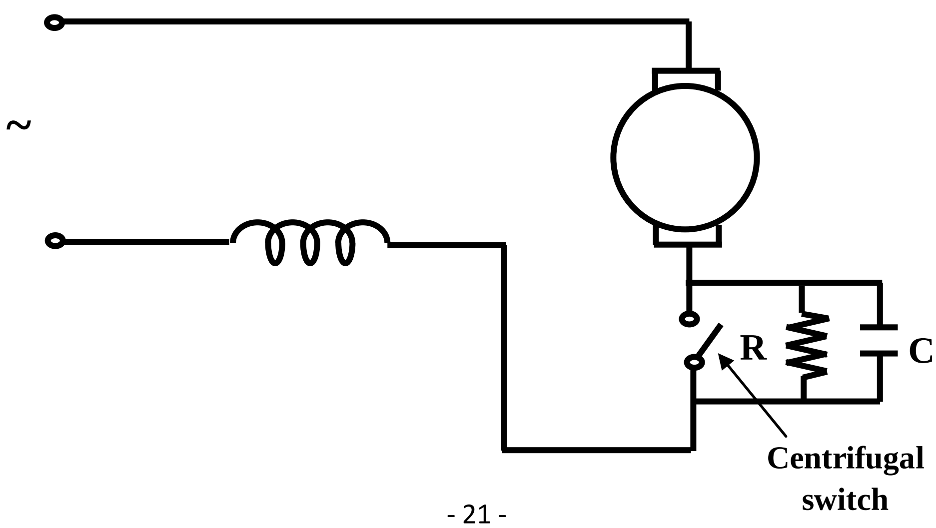
Armature windings:

Universal motors almost wound as two poles motors. The windings are almost the same as the windings used in small d.c. motors.

Speed control of universal motors:

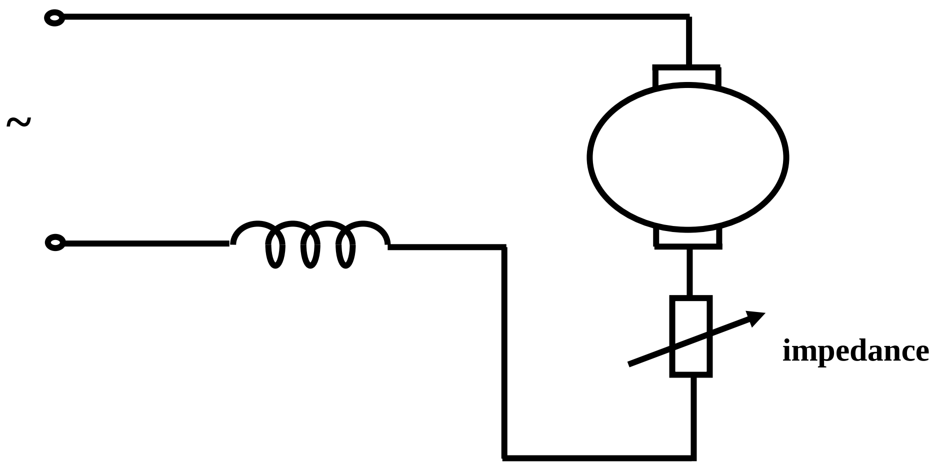
1- By using tapped field.

2- By using mechanical governor:



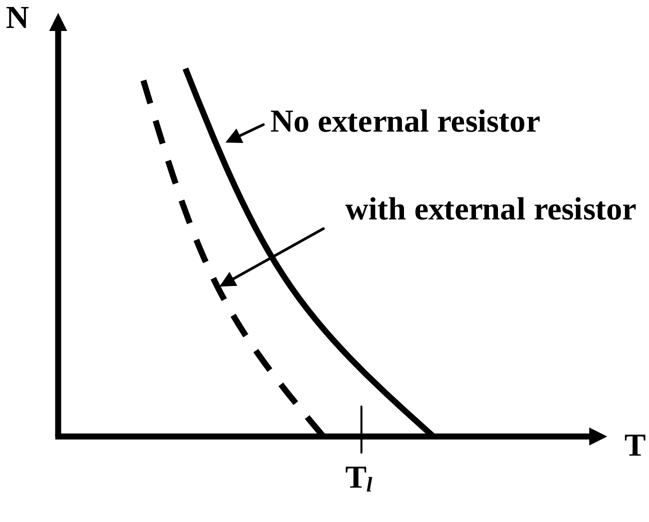
The speed control is done by using centrifugal switch that will insert resistance R in series with the motor when the contacts of the switch opened by the centrifugal force. The centrifugal switch has adjustment so that the switch can operate at a higher or lower speed. The capacitor C tends to reduce the sparking at the switch contacts.

3- By using an external impedance:

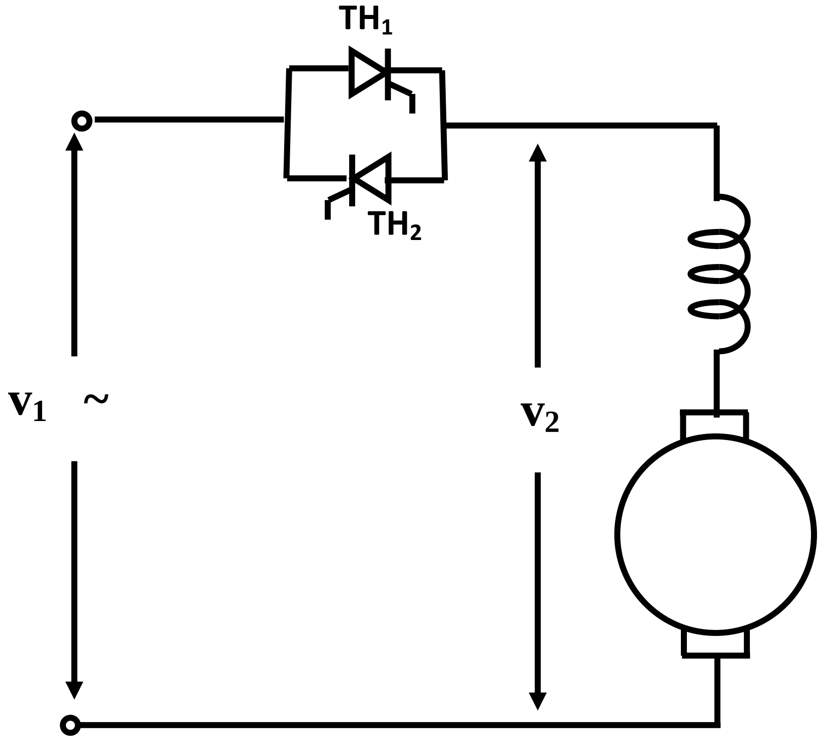


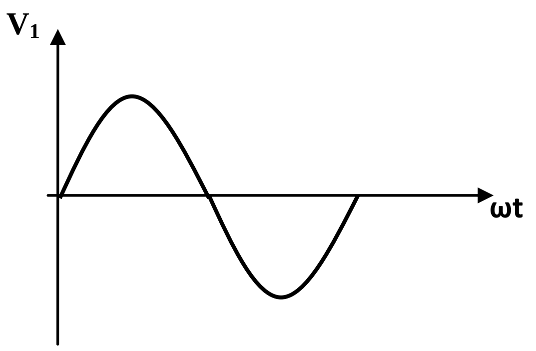
The speed of the universal motor is often varied by means of an external resistor connected either in series with the motor or across the brushes. When an external resistor is connected in series, the speed torque of the motor is more dropping.

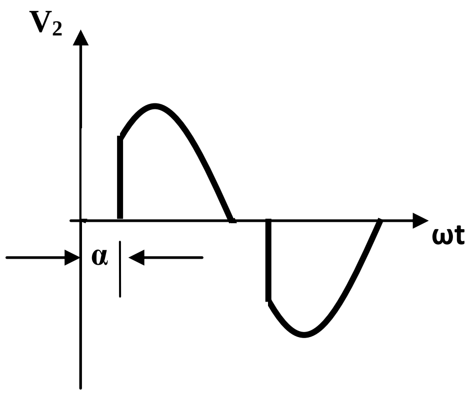
With such a dropping torque characteristic, the motor may sometimes fail to start.



4- By using solid-state electronic controller:







By controlling the voltage applied to the motor, it is possible to control its speed.

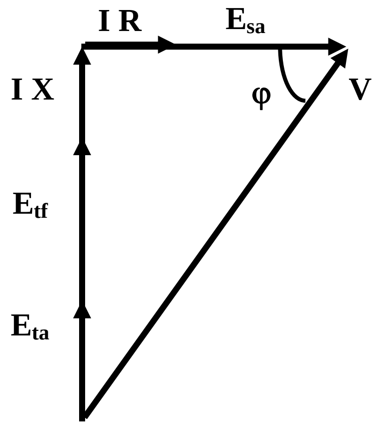
Speed comparsion between a.c. series motors and universal motors:

The speed in a.c. series motors:

$n = n_{dc} \cos\varphi$

and since the motor is low p.f. motor, then the a.c. speed is much less than d.c. speed. For universal motor the reactance of the series field is reduced by reducing the number of field turns and this action is balanced through increasing number of armature turns. Thus the drop in field reactance is reduced.

The voltage drop in armature reactance and e.m.f. E_{ta} are cancelled by compensating winding thus improving the p.f. and improving the speed, i.e., the speed in a.c. & d.c. operations is almost the same.



Reference:

Fractional and Subfractional Horsepower Electric Motors.

by Cyril G. Veinott, D. ENG.

McGraw-Hill Book Company 1970, Third Edition

Sheet No. 1

A.C. series Motor and Universal Motor

1- An universal fractional horsepower series motor has a resistance of 30 Ω and a total inductance of 0.5 H. When connected to a 250 V d.c. supply and loaded to take 0.8 A, it runs at 2000 r.p.m. Estimate the speed and p.f. when connected to a 250 V a.c. supply and loaded to the same current.

(1700 r.p.m. ; 0.86436)

2- The following data refers to a 220 V 2- pole series commutator motor when run on a 50 Hz single-phase supply:-

Applied voltage = 220 V
Input current = 1.5 A
Input power = 198.75 W
Field resistance = 8.8 Ω
Armature resistance = 4.2 Ω
Speed = 4800 r.p.m.
No. of turns in field = 300
No. of armature conductors = 1200
Leakage reactance drop is 20 % of total reactive drop of the motor.
Calculate:
(a) The induced voltage in the armature due to speed E_{sa}.
(b) Flux per pole, Φ_d.
(c) Speed of the motor when run on 220 V d.c. supply and loaded to take 1.5 A.
(d) Armature flux per pole, Φ_q.

(E_{sa} = 113 V ; $\Phi_d = 1.177*10^{-3}$ wb ; 8517 r.p.m. ; $\Phi_q = 0.494*10^{-3}$ wb)

3- A 230 V , 50 Hz fractional h.p. series motor has 400 field turns and 1200 armature turns. At full load the current is 1 amp. The maximum value of exciting flux is 0.0008 wb and speed is 7000 r.p.m. The total resistance is 20 Ω and leakage reactance is 30 Ω. Draw the phasor diagram and find:-
(a) The transformer induced e.m.f. in armature by quadrature flux.
(b) The magnitude of the quadrature flux.
(c) The h.p. output.

(d) the speed at which it would run if supplied with a direct voltage of 230 V and takes a current of 1 A.

(E_{sa} = 158.42 V ; E_{ta} = 44.11 V ; Φ_q= 3.676*10^{-4} wb; output = 158.42 W ; N_{dc} = 9279.6 r.p.m.)

4- 220 V, 2-pole, 50 Hz a.c. series motor has 350 field turns and 2000 armature conductors. At full load the current is 1.2 A and the direct axis flux per pole is 0.565 mwb and the speed is 8000 r.p.m. The total resistance is 16 Ω and leakage reactance is 24 ohms. Determine the following:

1- The speed e.m.f. in armature , E_{sa}.
2- The transformer e.m.f. in armature, E_{ta}.
3- Quadrature axis flux, Φ_q.
4- The power factor.
5- The mechanical power developed.
6- The efficiency if the rotational losses are 20 W.
7- The speed at which the motor would run with a direct voltage of 220 V when taking a current of 1.2 A.

(E_{sa} = 150.667 V ; cos φ = 0.772 ; E_{ta} = 48.919 V ; Φ_q= 0.4892 mwb; 180.8 W ; 78.898 % ; 10661.923 r.p.m.)

Repulsion motors:

Repulsion motor consists of the following parts:

1- Stator winding of the distributed non-salient pole type housed in the slots of a smooth-cored stator (similar to 1-ph split-phase I.M.) The stator is generally wound for four, six or eight poles.

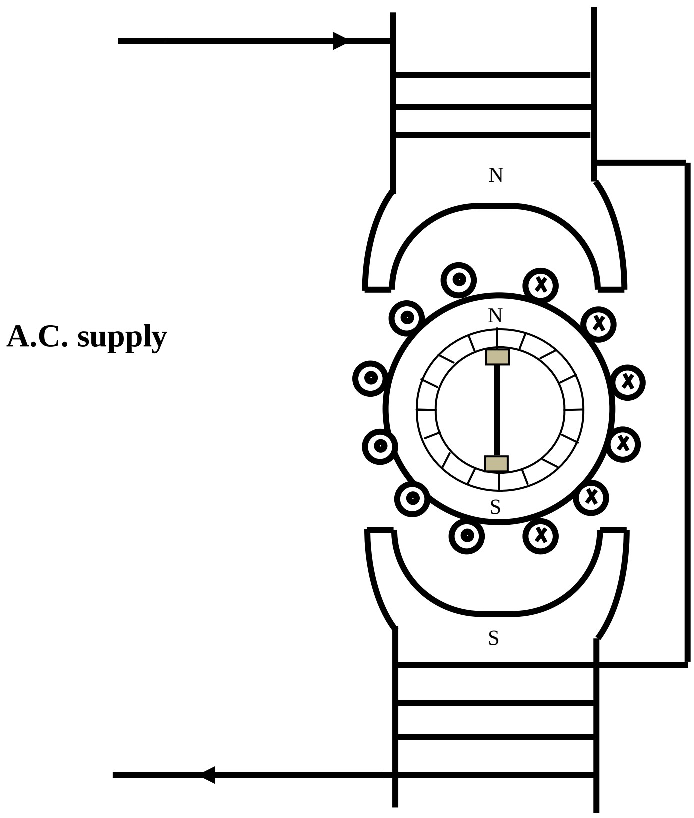
2- A slotted core rotor carrying a distributed winding (Lap or Wave) which is connected to the commutator. The rotor is similar in construction to the d.c. armature.

3- A commutator made of copper bars.

4- Carbon brushes fitted against the commutator and are connected to getter (short-circuited brushes).

Repulsion principle:

For simplicity, it is assumed that the stator winding is concentrated around salient poles (actually it is of distributed non-salient type).

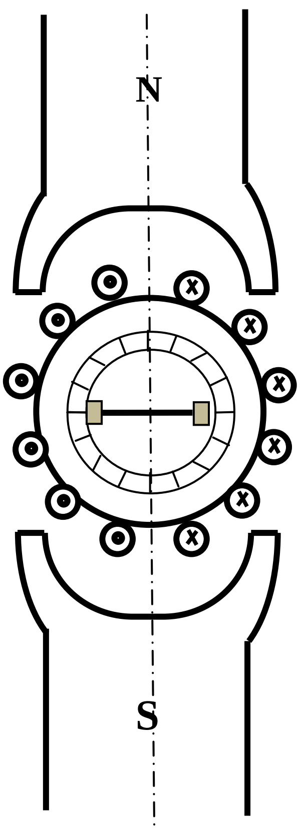


- a -

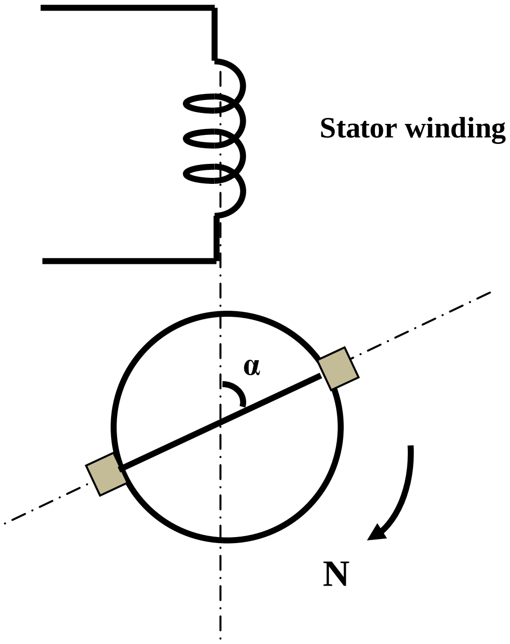
During the positive half cycle of a.c. current the polarity of the main poles will be as shown in the figure. The alternating flux produced by the stator winding will induce an e.m.f. in the armature conductors by transformer action. [In series motor the armature current flows due to direct connection to the source. In repulsion motor the armature current is excited inductively by transformer action].

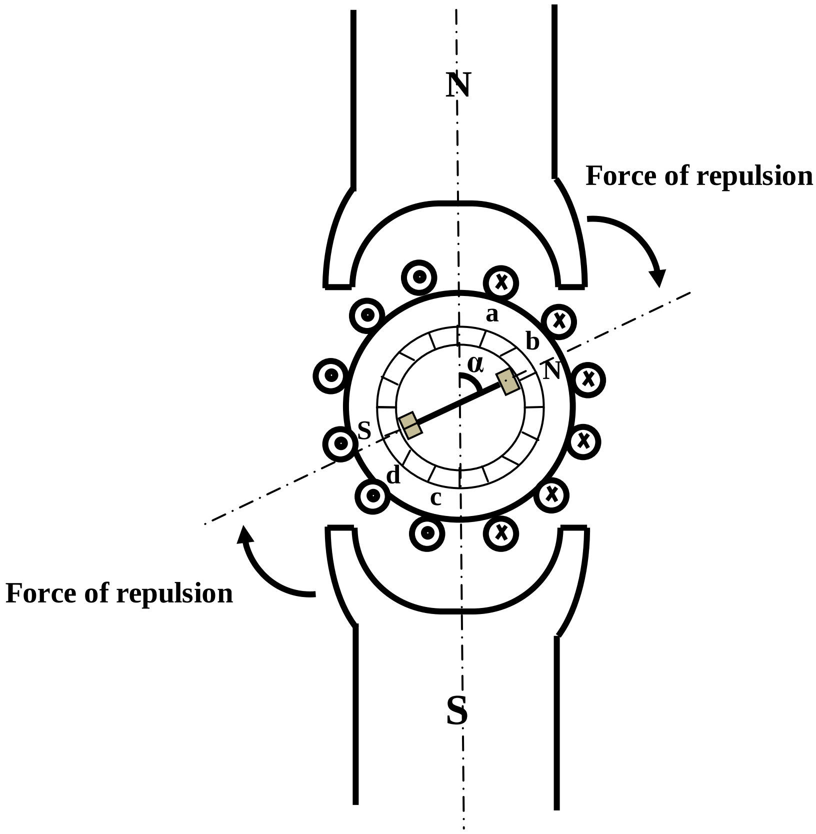
The direction of this induced e.m.f. is such that its current will produce a flux opposite to the main flux (Lenz law). If the brush axis is as shown in the figure (along the direct axis), the electromagnetic polarity of the armature will be as shown and the two forces of repulsion will cancel each other. Thus, no torque will be developed.

If the brushes are shifted through 90^{o}, i.e. , along the quadrature axis. The direction of the induced e.m.f. in the conductor is the same as in the first case since it is produced by transformer action and it has no relation with brushes position. As shown in the figure, the voltages induced in the armature conductors in each path between the brush terminals will cancel each other and hence there will be no voltage across the brushes to produce armature current. If there is no armature current no torque will be developed.



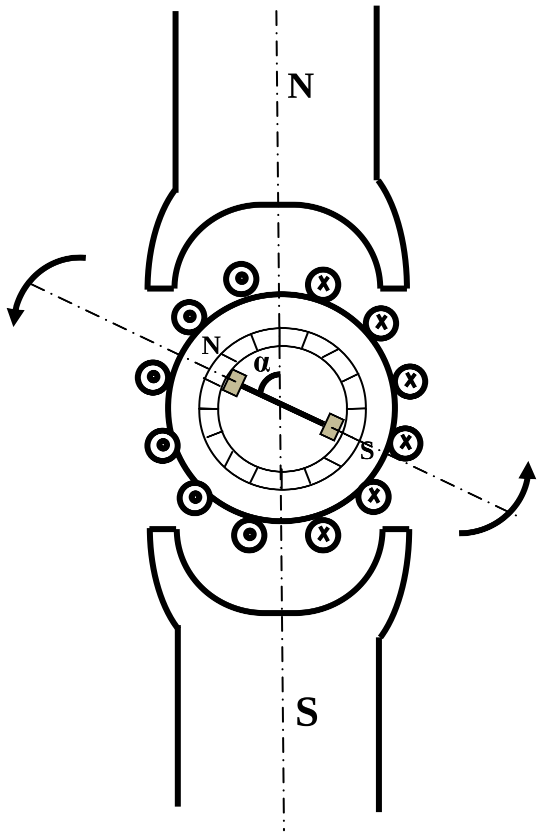
-b-



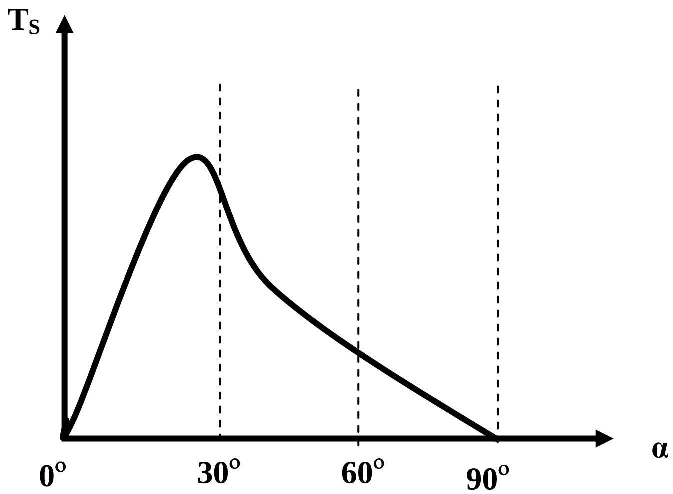


-c-

If the brushes are shifted by angle α (α< 90^{o}), a net voltage will be induced between the brush terminals which will produce armature current. This armature current will set the magnetic polarity of the armature as shown in Fig. - c -. Thus, forces of repulsion will be produced and the rotor will rotate in the clockwise direction. The motor is called repulsion motor since the forces produced on the armature are repulsion forces. If the brush axis is shifted by an angle α in the counter-clockwise direction the rotor will rotate in the counter-clockwise direction. Therefore, the direction of rotation depends on the direction of brush shift.



The starting torque developed by repulsion motor will depend on the amount of brush shift (α).



The motor will operate with:

1- Speed varies with changing load, becoming dangerously high at no-load.

2- Low power factor expect at high speeds.

3- Sparking at the brushes.

Compensated Repulsion motor:

It is repulsion motor with an additional stator winding called compensating winding which will (1) improve the p.f. (2) provide better speed regulation. This winding is much smaller than the stator winding and is wound in the inner slots of the main poles and is connected in series with the armature through an additional set of brushes placed at right angles to the usual short-circuited brushes.