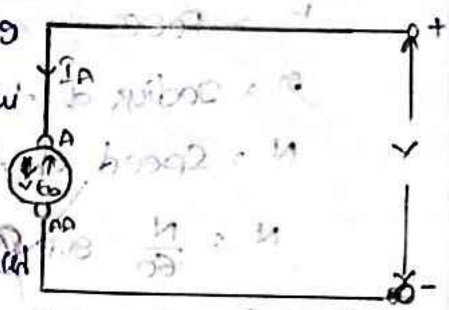
UNIT II

Performance of D.C Machines

Torque & Back-emf equations of D.C Motor :-

Back-emf :-



When the armature of a D.C motor rotates the conductor also rotates in the magnetic field. According to the Faraday's law of electro magnetic induction e.m.f is induced in the conductors whose direction as found by Fleming's right hand rule is in opposition to the applied voltage as shown in above fig. because of it's opposition direction it's referred to as Back emf "E_b". Opposite 'V' has to drive I_a against the opposing E.M.f E_b

$$I_a = \frac{\text{Net voltage}}{\text{Resistance}} = \frac{V - E_b}{R_a}$$

Where

R_a = Armature Resistance

Induced e.m.f (or) Back e.m.f

$$\therefore E_b = \frac{\phi Z N}{60} \times \frac{P}{A} \text{ Volts}$$

Back e.m.f depends upon armature speed. If speed is high E_B is high. Hence I_a is small. If speed is less, then E_b is less. Hence I_a is more current (or) high current flows to develope Torque.

Torque :-

Torque is defined as the twisting moment of a force about an axis.

Torque is the product of the force and the radius at which this force acts

Torque T = Force × radius N.

Torque equation of D.C. motor :-

let

T_g = Armature (or) Gross Torque (N-m)

= Force × radius

F = Force in Newtons

r = radius of the armature in m

N = Speed of the armature in r.p.m.

$N = \frac{N}{60}$ r.p.s

Work done / revolution = $F \times 2\pi r$ N-M

Work done/s = $F \times 2\pi r \times \frac{N}{60}$

$W/d = \frac{2\pi N}{60} \times (F \times r) = \frac{2\pi N T_g}{60}$ N-M/sec (or) J/s (or) Watts → ①

* The voltage equation of D.C. motor is given by

$V = E_b + I_a R_a$

Multiplying both sides on I_a

$V I_a = E_b I_a + I_a^2 R_a$

{Electrical I/P} = {Electrical power (or) Mechanical power developed} + {Armature Cu. losses}

Mechanical power developed = $E_b I_a$ → ②

∴ Equating equation ① & ② we get

$\frac{2\pi N T_g}{60} = E_b I_a = \frac{Z\phi N}{60} \times \frac{P}{A} \times I_a$

$T_g = \frac{1}{2\pi} \phi Z I_a \times \frac{P}{A}$ N-M

$$\boxed{T_g = 0.159\, \phi Z I_a \times \frac{P}{A}}\ \text{N-M}$$

φ = Flux per pole in wb
P = No. of poles
Z = No. of armature conductors
A = No. of armature paths
I_a = Armature current.

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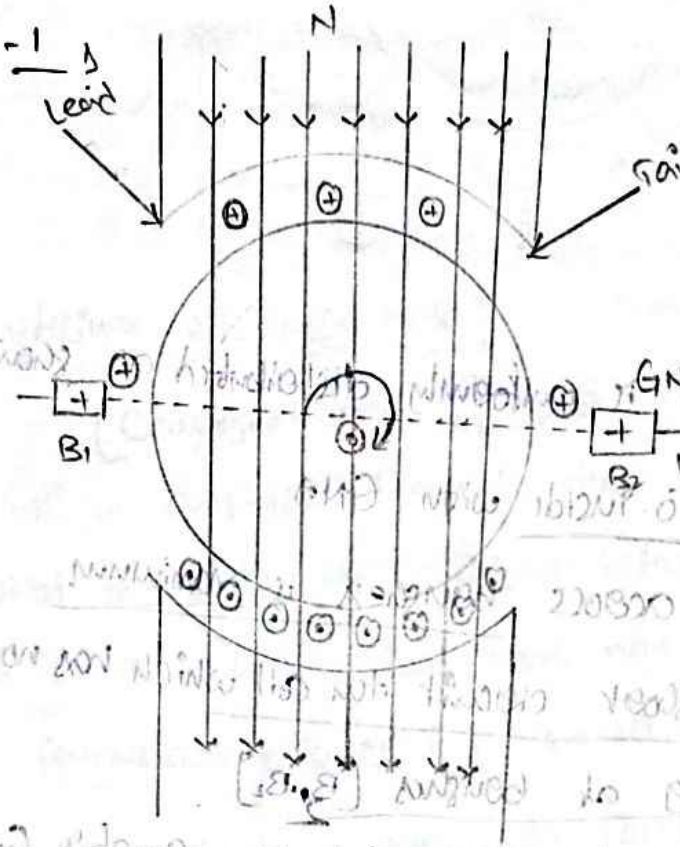
Armature Reaction :-

→ The effect of armature flux on the distribution of pole flux in the air gap is known as armature reaction.

i.e Armature reaction takes place in air gap

Condition - 1

Figure-1 :-



→ MNA :- Magnetic neutral axis (or) plane

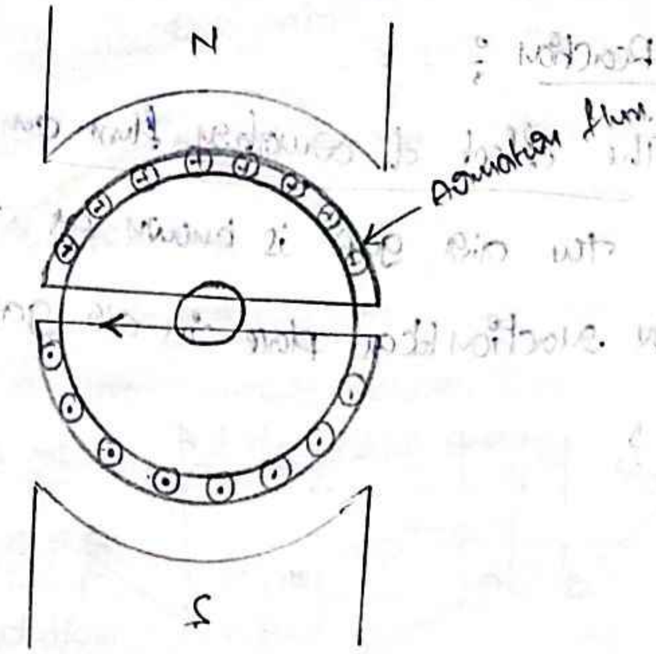
→ GNA :- Geometrical neutral axis (or) plane,

→ Condition 2 :-

→ When the armature is not loaded no current passes through the armature and no flux is produced by armature i.e, there is no armature reaction

→ The conditions under armature reactions are

Fig:- 2



1. The pole flux is uniformly distributed as show in fig(1)

2. The MNA co-incide with GNA

3. The voltage across brushes is maximum

4. The brush short circuit the coil which has no emf

5. No sparking at brushes [B_1, B_2]

6. When the armature is loaded the armature current carrying conductors and another flux is produced by armature flux

7. The armature flux is acting in the same direction with common pole flux at trailing pole tips and acting in opposite direction at leading pole tips

8. The fig (3) shows the resultant flux armature reaction. The trailing pole in strength and and leading poles are week and

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Figure-3:

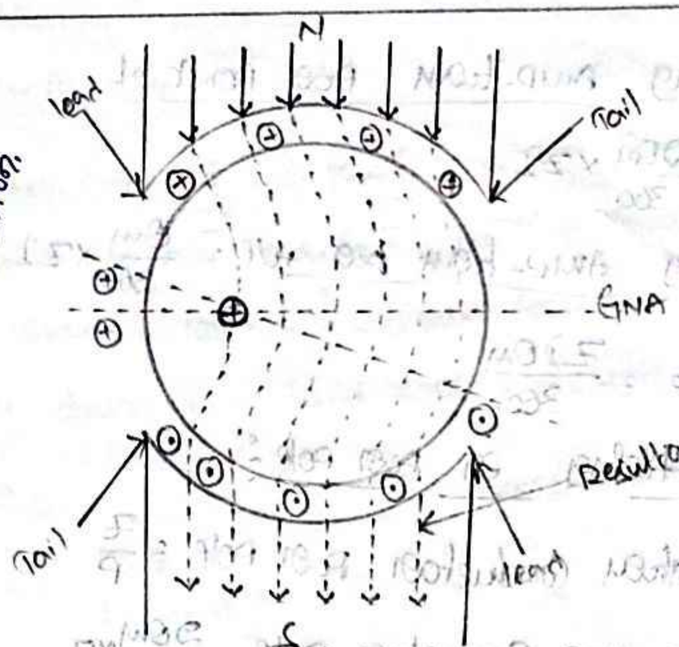

Fig shows Resultant flux armature reaction.

Demagnetising AT per pole :-

[Demagnetising AT per pole are neutralized by adding extra ampere turns to the main field winding.] it is essential to calculate the number before according further it should be remembered that the no. of turns are equal to half of conductors because two conductors constitute one turn.

Let Z = Total no. of Armature conductors

I = current in each conductor = $\frac{I_a}{2}$ per simple wave winding

$I = \frac{I_a}{P}$ per simple lap winding

Total no. of conductors in angles AOC & BOD is

$\frac{4\theta_m}{360} \times Z$

where θ_m = forward leading mechanical (or) Geometrical (or) Angular degrees

As two conductors constitute one turn

Total no. of turns in the angles = $\frac{2\theta_m}{360} \times ZI$

∴ Demagnetising Amp-turns per point of

Pole $= \frac{2\theta_m}{360} \times Z I$

Demagnetising Amp-turns per pole $= \frac{\theta_m}{360} \times Z I$

∴ $AT/Pole = \frac{Z I \theta_m}{360}$.

Cross magnetising AT per pole :-

Total armature conductor per pole $= \frac{Z}{P}$

Demagnetising per conductor pole $= \frac{2\theta_m}{360} \times Z$

Cross magnetising conductor per pole $= \frac{Z}{P} - Z \times \frac{2\theta_m}{360}$

$= Z\left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$ $Z\left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$

Cross-magnetising Amp conductor per pole

$= Z I \left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$

Cross-magnetising Amp turns per pole

$= Z I \left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$

ATc per pole

$= Z I \left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$

NOTE:- For neutralising demagnetising effects of an armature an extra no. of armature turns may be put on each point

∴ No. of extra turns per pole

$= \frac{ATd}{I_{sh}}$ → for shunt generator

$= \frac{ATd}{I_a}$ → for series generator

Here, I_{sh} is shunt current

I_a is Armature current

d is demagnetising.

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Problem on ATd, ATc per pole:

① A 8 pole lap connected D.C. shunt generator delivers an o/p of 240 A at 500V. The armature has 1408 conductors & 160 commutator segments. If the brushes are given a lead of 4 segments from the no-load neutral axis estimate the demagnetising and cross magnetising AT/pole.

Sol Given data:

P = 8

I = 240 A

V = 500 V

Z = 1408

Commutator segments = 160

Brush lead = 4 segment

$I = \frac{I_a}{P} = \frac{240}{8} = 30$ A

$\theta_m = \frac{4 \times 360}{160} = 9^\circ$

$AT_d/\text{pole} = \frac{ZI\theta_m}{360} = \frac{1408 \times 30 \times 9}{360} = 1056$

$AT_c/\text{pole} = ZI\left[\frac{1}{2P} - \frac{\theta_m}{360}\right] = 1408 \times 30\left[\frac{1}{2 \times 8} - \frac{9}{360}\right] = 1584$

② A 22.38 kW, 440V, 4 pole wave wound D.C shunt motor has 840 armature conductors and 140 commutator segments, its full load efficiency is 88% and the shunt field current 1.8 A. If the brushes are shifted backward through 1.5 segments from the geometrical neutral axis. Find the demagnetising and distorting amp-turns per pole.

Sol Given data:

Motor output = 22.38 kW

Voltage (V) = 440V

P = 4

Z = 840

Commutator segments = 140

I_{sh} = 1.8 A

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efficiency = 0.88

Motor input = $\frac{Output}{\eta} = \frac{22380}{0.88}$

Motor input current = $\frac{22380}{0.88 \times 440}$

Armature current (I_a) = $57.8 - 1.8 = 56A$

Current in each conductor = $\frac{I_a}{2} = \frac{56}{2} = 28A$

$$\theta_m = \frac{1.5 \times 360}{140} = \frac{27}{7}$$

Demagnetising AT/pole = $\frac{ZI\theta_m}{360} = \frac{840 \times 28 \times 27}{7 \times 360} = 252$

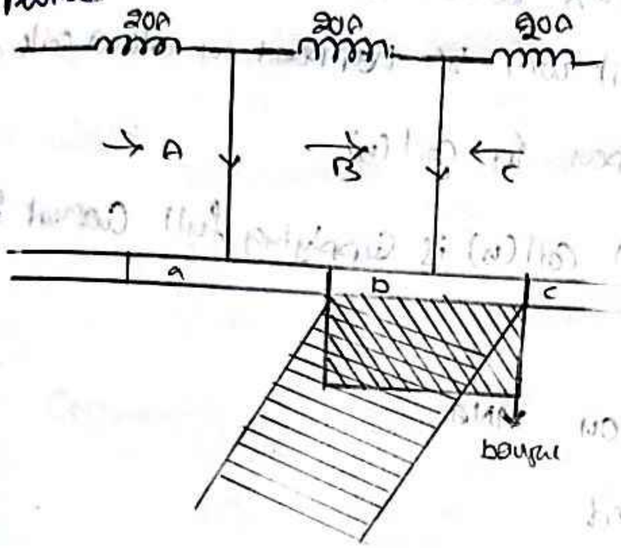
Cross magnetising AT/pole = $ZI\left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$

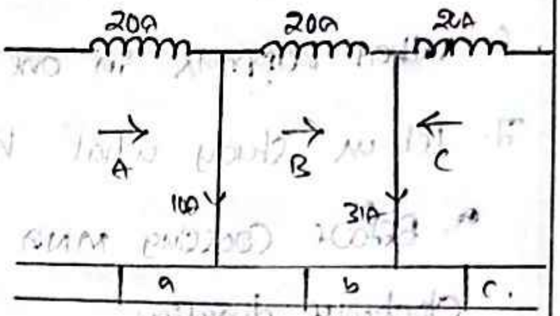
$$= 840 \times 28\left[\frac{1}{2 \times 4} - \frac{27}{7 \times 360}\right]$$

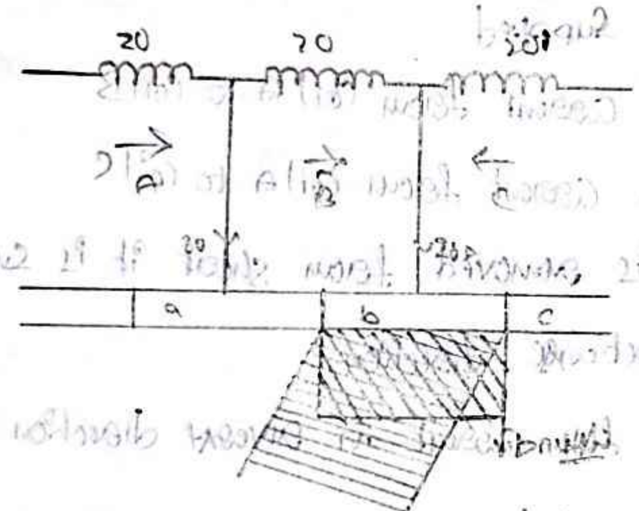
$$= 2688$$

Commutation:

Commutation means reverse of current this current in the armature coil reverse immediately after crossing MNA. The analysis gives the performance of armature during commutation period.







1. During the commutation period the following armature
2. All the coils sides under each pole carry same current in the same direction
3. Each coil is connected across adjacent segment the segments are insulated from the each other. the poles and brushes are in same position

4. The coils & segments rotate at a rated speed the brushes does two things

a. Collects current from coils through segments

b. It short circuit the coils which are on MNA

5. No voltage induces in coils which are on MNA

6. What happens in one coil will be happened in other coils also

7. Let us study what happen in coil (b)

a. Before crossing MNA in coil (b) is supplying full current in clockwise direction

b. When the coil (b) is on MNA

(i) No voltage is induced

(ii) No current is supplied

(iii) The brush take current from coil A to coil B

(iv) The brush take's current from coil A to coil C

c. After the coil is removed from short it is supplying current is anticlockwise direction

8. The coil B gives full current in reverse direction after crossing MNA. It is called

i. Smooth (or) Sparkless commutation

ii. Linear commutation

iii) Ideal (or) resistance commutation

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Reactance voltage :-

E = Self inductance × rate of change of current. self-inductance = L

current in a coil = I-(-I) = 2I

T_c = Commutation period = $\frac{Wb - Wm}{V}$

where

Wb = width of brush in cm;

Wm = width of mica

V = period velocity of commutator

Segments in cm

$$E = \frac{L \times 2I}{T_c}$$

for sinusodial commutator = 1.11·E.

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Problems :-

① Calculate reactance voltage for a machine having 55 Conductor Segments and Speed -900 rpm. if reactance inductance $L = 1.53 \times 10^{-6}$ width of brushes is 1.74 Cm, a Current having 270A.

Sol Given data :-

Inductance $L = 1.53 \times 10^{-6}$

Current $I = 270\,A$

Brushes width $W_b = 1.74$

$V = \frac{900}{60} \times 55 = 825$

$W_m = 0, \; W_b = 1.74$

$T_c = \frac{W_b - W_m}{V} = \frac{1.74 - 0}{825}$

$T_c = 2.1 \times 10^{-3}$ sec

$E = L \times \frac{2I}{T_c}$

$= 1.5 \times 10^{-6} \times \frac{2 \times 270}{2.1 \times 10^{-3}}$

$E = 0.039$

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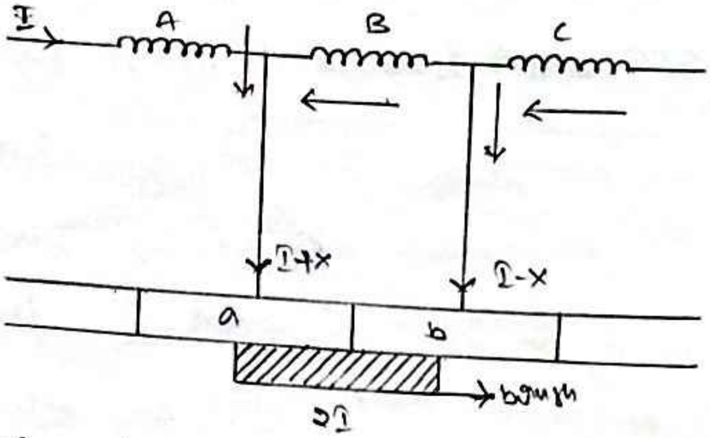
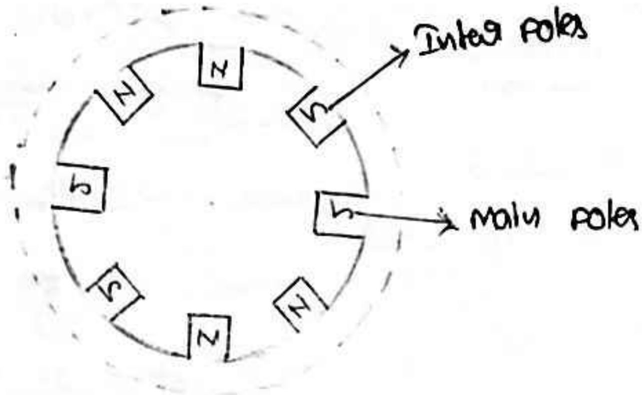
Methods of Improving Commutation :

(i) Resistance Commutation Method :



(ii) Emf Commutation using Interpoles :



→ Inter poles are connected to yoke

→ Inter poles polarity is same as main pole

→ So they produced some emf which neutralized the reaction voltage

→ It's another function is to neutralized

→ Compensation winding are coast when compared to the interpoles. So interpoles used.

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Characteristics of D.C. motor :-

The performance of a D.C. Motor can be judged from its characteristics curve known as motor characteristics

* Torque and Armature current characteristics (T_a/I_a)
* Speed and Armature current characteristics (N/I_a)
* Speed and Torque characteristic (N/T_a). It is also known as mechanical characteristic.

* Electrical characteristics (T_a/I_a) :-

$$I_a = I_L - I_{sh}$$

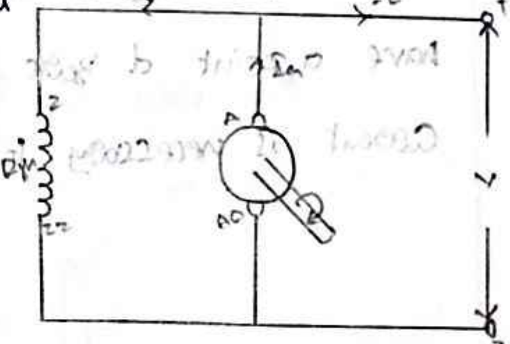
$$I_{sh} = \frac{V}{R_{sh}}$$

It will be seen that field current I_{sh} remain almost constant so flux ϕ which is proportional to I_{sh} will also remain constant.

We know that $T_a = \frac{1}{2\pi} \phi Z I_a \times \frac{P}{A}$

$$T_a \propto \phi I_a$$

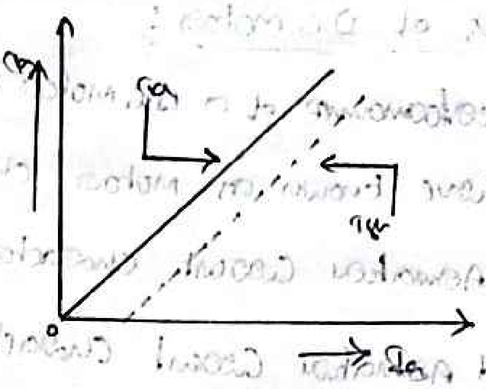
$$T_a \propto I_a \quad (\phi \text{ is constant})$$



⇒ The electrical characteristic i.e. the torque is proportional to the armature current I_a is practically a straight line from origin as shown in given fig.

The shaft torque (T_{sh}) verses I_a is also shown doted. It is clear that a large current is required to start heavy load.

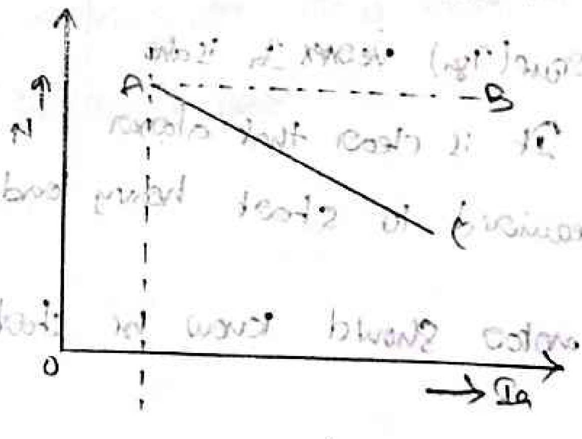
∴ Shunt motor should know be started with heavy load.



* The o/p (or) Horse power (HP) of the motor is dependent on the shaft torque as shown in above fig.

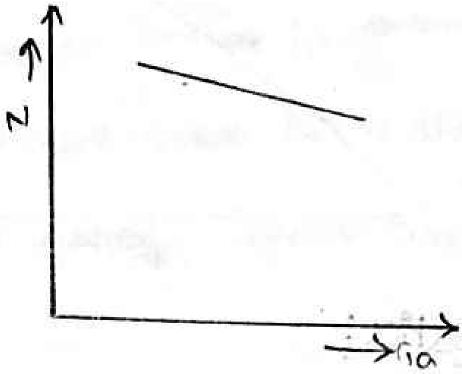
N/Ia Characteristics :

* The speed N of a motor is given by $N \alpha \frac{E_b}{\phi}$
* The flux ϕ and back emf E_b in a shunt motor are almost constant. under normal condition. Therefore speed of a shunt motor will remain constant as the armature current varies strictly speaking. when the load is increased ($E_b = V - I_a R_a$) and ϕ decreases due to the armature resistance drop and armature reaction respectively. However E_b decreases slightly more than ϕ so that the speed of the motor decrease slightly with load (linear). It may be noted that the characteristic doesnot have a point of zero armature current because a small current is necessary to maintain rotating of the motor at no-load



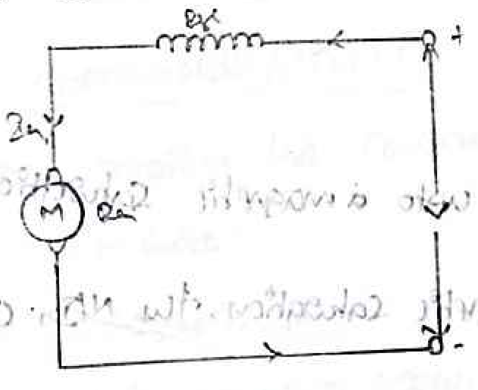
3. N/Ia Characteristics :-

This Curve is obtained by plotting the values of N & Ia for various armature currents as shown fig. It may be seen that speed falls some what as the load torque increases



Characteristics of D.C. Series motor :

The d.c. series motor is, the current passing through the field winding is the same as that in the armature. If the mechanical load on the motor increases the armature current also increases. The flux in a series motor increases with the increase in armature current and vice-versa



1. Ta/ Ia characteristics :

We known that
$T_a \propto \phi I_a$.

upto magnetic saturation $\phi \propto I_a$

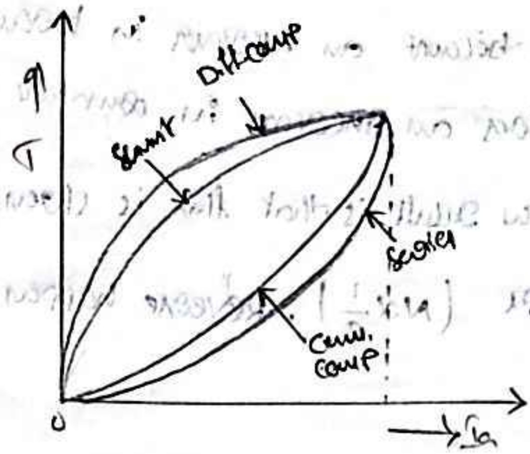
so that $T_a \propto I_a^2$

After magnetic saturation ϕ is constant. so that $T_a \propto I_a$

After magnetic saturation the armature torque is directly

Thus upto magnetic saturation

to the motor. The result is hence there is a decreases as load is rate at which the motor torque increases with load. Another draw back is weakening of flux with increase in load, speed is unstability



2. Speed & Armature current characteristics (N/Ia) :-

long shunt compound motor

$V = E_b + I_a(R_a + R_{se})$

$E_b = k\phi N$

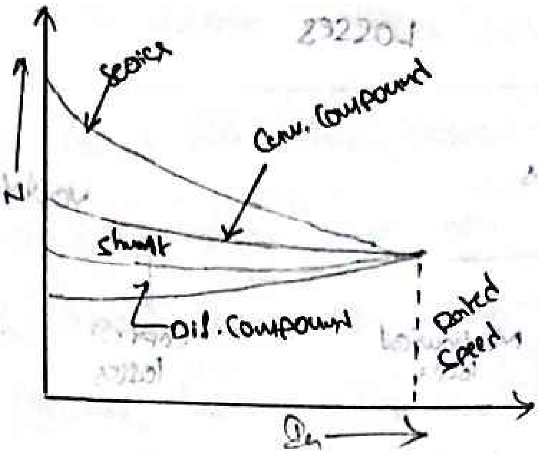
$= k(\phi_{sh} + \phi_{se}) N$

ϕ_{sh}, ϕ_{se} are flux due to I_{sh} & I_{se}

$$N = \frac{E_b}{k(\phi_{sh} + \phi_{se})} = \frac{V - I_a(R_a + R_{se})}{k(\phi_{sh} + \phi_{se})}$$

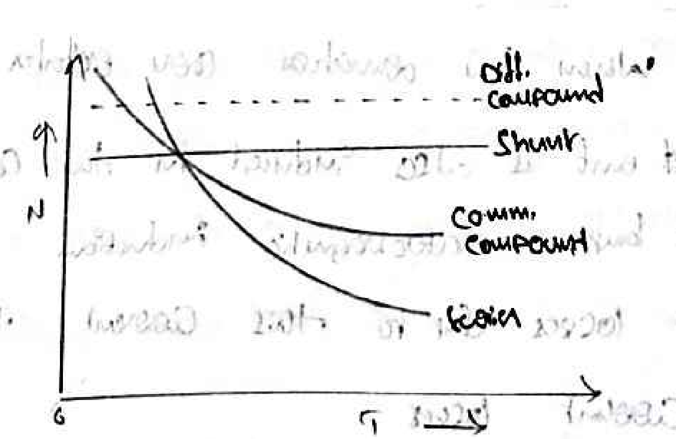
With increase in I_a, ϕ_{se} increases and $V - I_a(R_a + R_{se})$ decreases. Thus with the increase in I_a the speed drops at faster rate in cumulative compound motor than in shunt motor. If the shunt field is stronger than series field the curve tends to shunt motor curve and if series field is stronger than shunt field it tends to series field curve.

The comparision of characteristics



3. Speed & Torque characteristics (N/T) :-

Speed characteristics is also known as mechanical characteristic and is derived from speed-current & torque current characteristics. It is seen that an increase in torque increases the armature current and also the flux at the same time decreasing the speed rapidly in armature of compound motor. The decrease is more predominant than compound with shunt motor. Therefore the speed torque characteristics approaches the shunt motor characteristics if the shunt field is stronger. If the series flux is stronger than shunt flux speed torque characteristic approaches the series motor characteristics. Depending upon the relative strength of shunt and series fields the speed torque can occupy any position



Losses in D.C. Motor :

- Losses
  - Constant losses
    - Iron losses
      - Hysteresis losses
      - Eddy current losses
    - Mechanical losses
      - Friction losses
      - Windage losses
  - Variable losses
    - Copper losses
      - Armature copper losses
      - Shunt copper losses
      - Series copper losses
    - Stray load losses

Iron losses :

As the armature core is made up of iron & it rotates in the magnetic field, a small current gets induced in the core itself too. Due to this current, eddy current loss & hysteresis loss occurs in armature core.

Hysteresis loss

It is due to the reversal of magnetisation of armature core. The loss depends on the volume and grade of iron, frequency of magnetic reversals and value of flux density. Hysteresis loss is given by

$$W_h = \eta B_{max}^{1.6} f V \text{ watts}$$

Eddy current loss :

When the armature core rotates in the magnetic field, an emf is also induced in the core, according to the Faraday's laws of electromagnetic induction.

→ Power losses due to this current is known as eddy current losses

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Eddy Current losses : $K B^2 t^2 V B_m^2$ watts:

Copper losses:

The Copper losses are the losses taking place due to the current flowing a winding. There are basically Armature and field winding. The copper losses are proportional to the square of the current flowing through this winding.

* Armature copper losses : $I_a^2 R_a$
* Shunt field copper losses : $I_{sh}^2 R_{sh}$
* Series field copper losses : $I_{se}^2 R_{se}$

In a compound D.C machine both shunt & series field copper losses are present an addition to the copper losses. There exist brush contact resistance drop. This drop is usually include in the armature copper losses. The copper losses reduced 30-40% full load losses

Mechanical losses:

This losses consist of frictions, windage losses. Some power is devided required over come mechanical frictions, windage resistance at this shaft

Stray losses:

In addition to the losses stated above there are be small losses present which are called as stray losses.

This losses are to the design & modeling of the machine most of the times stray losses assumed to 1% of the full load losses

 Total losses = constant losses + variable losses

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Efficiency (η) :

It is the ratio of output of machine to input of machine

$$\%\eta = \frac{\text{Output}}{\text{Input}} \times 100$$

Efficiency when running as Motor :

Input $= P_i = VI$

$I_a = I_L - I_{sh}$

Copper losses $= I_a^2 R_a$

Constant losses $= W_c$

$$\eta_m = \frac{O/P}{I/P} \times 100 = \frac{I/P - \text{losses}}{O/P} \times 100$$

$$= \frac{VI - (I_a^2 R_a + W_c)}{VI} \times 100$$

$$\eta_m = \frac{VI - \{(I_L - I_{sh})^2 R_a + W_c\}}{VI} \times 100$$

Efficiency when running as generator :

$I_a = I_L + I_{sh}$

$$\eta_g = \frac{O/P}{I/P} \times 100$$

$$= \frac{O/P}{O/P + \text{losses}} \times 100$$

$$= \frac{VI}{VI + I_a^2 R_a + W_c} \times 100$$

$$\therefore \%\eta_g = \frac{VI}{VI + (I_L + I_{sh})^2 R_a + W_c} \times 100$$

Applications of D.C. Motors:

1. Shunt Motor:

* For driving constant speed line shafting
* Lathe machines
* Centrifugal pumps
* Blowers & fans
* Reciprocating pumps

2. Series Motor:

* For traction system
* Electric locomotives
* Trolley cars
* Cranes & hoists & conveyors

3. Cumulative compound:

* Rolling mills, Ice machines
* Punching presses
* Air compressor
* For intermittent high-torque load

4. Differential compound:

These are not in common use. Limited uses for experimental research & laboratory purpose.

Key points :-

Kirchhoff's current law [KCL]:-

"The algebraic sum of all the current meeting at a point in an electrical network is zero."

Sum of Incoming currents = Sum of outgoing currents

Kirchhoff's voltage law :- [KVL]

"In a closed path (or) mesh, the algebraic sum of the products of currents and resistances in each of the conductor plus the algebraic sum of the emfs in that path is equal to zero."

Formulas :-

EMF Equation of D.C. Generator :-

Generated e.m.f $E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$ volts

For lap winding :- $[\because P = A]$

$$E_g = \frac{\phi Z N}{60} \text{ volts}$$

For wave winding :-

$$E_g = \frac{\phi Z N P}{120} \text{ volts}$$

D.C. Series Motor :-

$I_a = I_{se} = I_L = I$

$V = E_g - I_a(R_a + R_{se})$

$P_g = E_g \cdot I_a$

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D.C. Shunt Motor:

$I_a = I_L + I_{sh}$

$I_{sh} = \frac{V}{R_{sh}}$

Voltage $V = E_g - I_a R_a$

Generated emf $E_g = V + I_a R_a +$ Brush contact drop

Long shunt compound Generator:

$I_a = I_{se} = I_L + I_{sh}$

$I_{sh} = \frac{V}{R_{sh}}$

$V = E_g - I_a(R_a + R_{se})$

$E_g = V + I_a(R_a + R_{se})$

$P_g = E_g \cdot I_a$

Short shunt compound generator:

$I_L = I_{se} = I_a - I_{sh}$

$I_{sh} = \frac{V + I_{se} R_{se}}{R_{sh}}$

$V = E_g - I_a R_a - I_{se} R_{se}$

$E_g = V + I_a R_a + I_{se} R_{se}$

Torque equation of D.C motor:

$T_g = \frac{1}{2\pi} \phi Z I_a \times \frac{P}{A}$ N-M

$T_g = 0.159 \phi Z I_a \times \frac{P}{A}$ N-M

Demagnetising Amp-turns/poles $= \frac{Z I_c \theta_m}{360}$

Cross-magnetising Amp-turns/pole $= Z I \left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$

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