# Unit - IV ⇒ DC generator, DC motors & AC generators

## Unit IV — D. C. Motor

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EEE
MSRIT

19 Pages
L Section
2015 April 18

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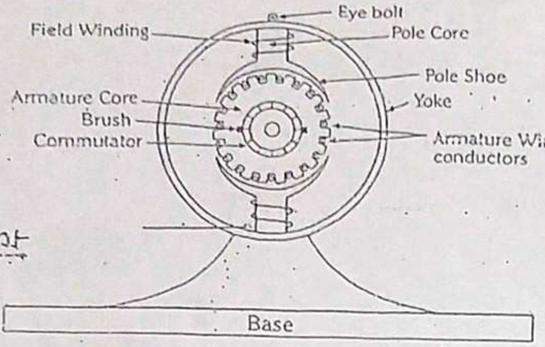
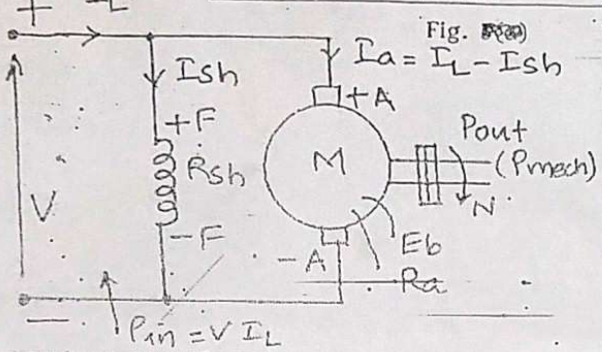
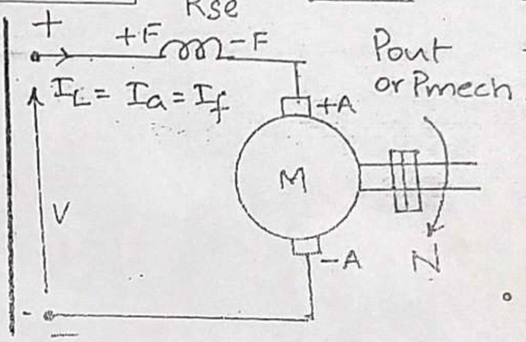



Fig.

D.C. Shunt Motor




D.C. Series Motor




An electric motor is a machine which converts electrical energy into mechanical energy. Construction of DC generator / motor is the same. Generally we call them as D.C Machine.

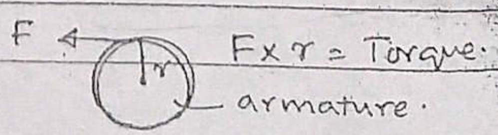
In D.C. Motor – Power input Electrical
Power output Mechanical.

A DC Machine can work as motor or Generator depending upon the type of input. (Electrical or mechanical) given.

D.C. Motor :- it works on the principle that when a current carrying conductor is placed in a magnetic field, it experience a mechanical force, whose direction is given by Flemings left hand rule. working :-

Thumb: ↑ motion.
→ field (fore finger)

Force x radius of armature = Torque due to which the armature rotates.



Explain the significance of back emf in d.c. motors. Page(02) 4 marks.

Q3)

* $Eb = \frac{\phi Z N}{60} \frac{P}{A}$ ∴ $Eb \propto N$

* $T_a = \frac{(Eb\, Ia) \times 60}{2\pi N}$ ∴ $Eb \propto T$

* If $Eb = 0$, $T = 0$, $N = 0$: the motor can not rotate. Therefore no motoring action. No outp

* $Ia = \frac{V - Eb}{Ra}$, $Ra << 1\Omega$

* When $Eb = 0$, $Ia \propto V$, starting currt will very high, if no starting resistance provided, armature winding will burn out.

* As the back emf increases, speed, torque increases.

Q.2) ~~Back emf (Eb)~~

When the armature is connected across dc supply & the field excited, the armature start rotating due to its driving torque. (F×r)

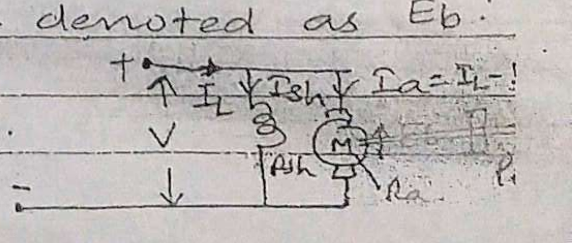
When a currt carrying conductor is placed in a magnetic field, it experience a force tending the armature to ratate

This rotating armature conductors, cut the magnetic field, therefore an emf is induced in the armature conductors. The induced emf acts in opposite direction the applied voltage V. & is known as back emf or counter emf. denoted as Eb.

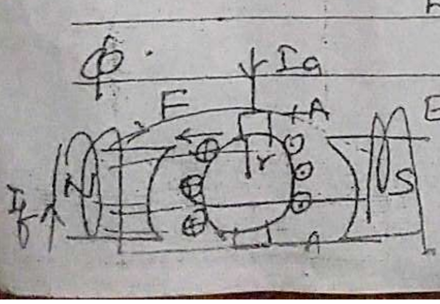
$Eb = \frac{\phi Z N}{60} \frac{P}{A}$ volts

$Ia = I_L - Ish$

$\phi$.



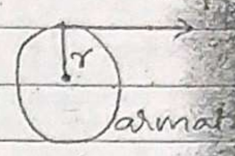

$Eb < V$



**Q8. Derive the torque equation of DC Motor.**

$T \propto \phi I_a$.

Ans: Torque is the turning or twisting moment of a force about an axis.




It is the product of force & the radius (r) at which this force acts.

$T_a = (F \times r)$ Nw-m.

work done by this force in 1 revolution } = Force × distance

$= F \times 2\pi r$

$= 2\pi T_a$ joules

Power developed by the armature } = workdone in 1 sec

$= 2\pi T_a \cdot \frac{N}{60} = \frac{2\pi N T_a}{60}$ joules/sec

= Watts

Electrical equivalent of power $= E_b I_a$ Watts

$$\frac{2\pi N T_a}{60} = E_b I_a.$$

$$= \left(\frac{\phi Z N}{60} \frac{P}{A}\right) I_a$$

$$\therefore T_a = \left(\frac{\phi Z N}{60} \frac{P}{A}\right) I_a \times \frac{60}{2\pi N}$$

$$= \boxed{\frac{1}{2\pi} \frac{ZP}{A} \phi I_a} \text{ Nw-m.}$$

$$T_a = K \phi I_a$$

$$\boxed{T_a \propto \phi I_a} \text{ Nw-m.}$$

before pole saturation.

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Note:

Series Motor $\phi \propto I_a$ ; $\therefore T_a \propto I_a^2$

shunt Motor $\phi$ is constant ; $T_a \propto I_a$.

$$\boxed{T_a = (E_b I_a)\frac{60}{2\pi N}}$$

**Shaft Torque Tsh**

is the actual torque available at the shaft.

$T_{sh} < T_a$ because of Iron & mechanical losses.

$T_L$ = Torque lost due to Iron & mechanical losses.

Power out of Motor $= \frac{2\pi N T_{sh}}{60}$ watts.

$\therefore T_{sh} = \frac{\text{Pout of motor in watts} \times 60}{2\pi N}$

P in Watts $\rightarrow$ $T_{sh} = \frac{P_{out} \times 60}{2\pi N}$ Nw m.

P in HP $\rightarrow$ $T_{sh} = \frac{(P_{out} \text{ in HP} \times \cancel{735.5}\ 746)}{2\pi N}$ Nw-m.

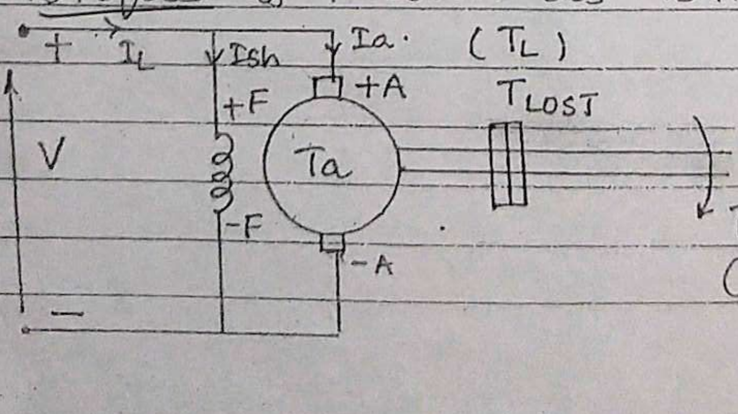
$T_a - T_{sh} = T_L$

1 HP = 735.5 watts in metric system

= 746 ✓ in British system.

Brake horse power BHP.

The horse power developed by the shaft torque is known as BHP.



Q3) Derive the speed eqn of DC Motor.

$$E_b = V - I_a R_a$$

$$E_b = \frac{\phi Z N}{60} \frac{P}{A} \quad ; \quad N = \frac{E_b \times 60 \times A}{\phi Z P}$$

$$N = K \frac{E_b}{\phi}$$

$$\boxed{N \propto \frac{E_b}{\phi}}$$

Speed of a dc motor is directly proportional to back emf & inversely to the flux.

In a dc motor, let $N_1$, $E_{b1}$, $\phi_1$ be the initial speed, back emf, flux & $N_2$, $E_{b2}$, $\phi_2$ be the final speed, back emf, flux, then,

$$N_1 \propto \frac{E_{b1}}{\phi_1} \rightarrow (1) \qquad N_2 \propto \frac{E_{b2}}{\phi_2} \rightarrow (2)$$

P $\leftarrow$ $\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \cdot \frac{\phi_1}{\phi_2}}$ general speed equation of DC Motor.

Shunt motor:

$I_{sh} = \frac{V}{R_{sh}}$ V, $R_{sh}$ constant, $\therefore$ $I_{sh}$ constant, flux ($\phi$) constant.

$$\boxed{\therefore \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}}$$

NOTE: If the armature reaction weakens the field or there is any reduction in flux or change in flux, then we've to use general speed eqn (P) for shunt Motor.

$$N_2 = E_{b2} \cdot \phi_1$$

## series Motor

In series motor $\phi \propto I_a$

$I_L = I_a = I_{se} = I_f$ = current.

$\therefore \phi \propto$ current

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \cdot \frac{\phi_1}{\phi_2}$$

$$= \frac{E_{b2}}{E_{b1}} \cdot \frac{I_{a1}}{I_{a2}}$$

$$= \frac{E_{b2}}{E_{b1}} \cdot \frac{I_{L1}}{I_{L2}}$$

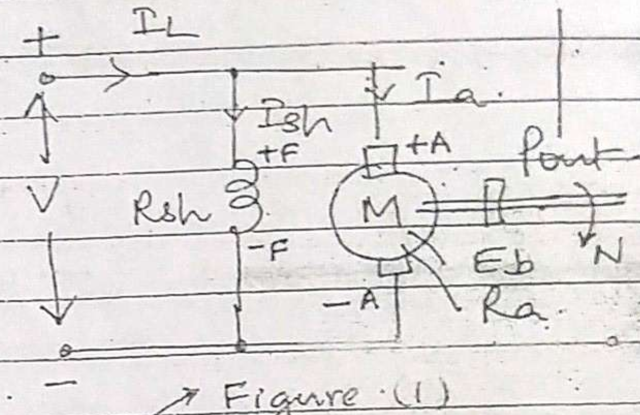



Figure (1)

**working of a D.C. Motor**. Refer fig (1)

When a D.C. Motor is connected across a DC supply, field excited, armature carries currt $I_a$. They experience a force tending the armature to rotate. ( $F \times r = T_a$ )

Each conductor experience a force, collectively produce a driving torque; Twisting moment. Force X radius of armature = Torque.

→ Force $F = B I_a l$ newton

$B$ = flux density of magnetic field Wb/m²

$I_a$ = armature current in amps.

$l$ = length of armature conductor in metres.

## classification of D.C. Motors.

(1) D.C. shunt motor (2) D.C. Series Motor

(3) D.C. compound Motor.

- cumulatively compounded Mr.
- Differentially compounded Mr.

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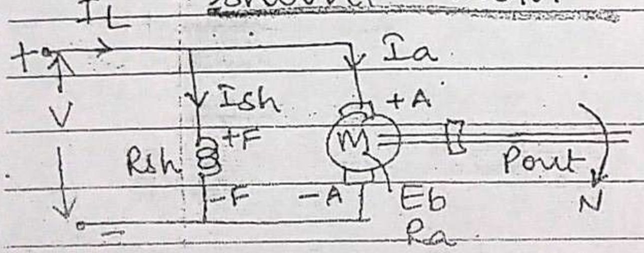
96) characteristics of D.C. Motors.

1) Ta Vs Ia — Torque Vs Ia or T Vs load.
2) N Vs Ia — speed Vs Ia (speed Vs load)
3) N Vs Ta → mechanical characteristics.

shunt Motor.




Ta Vs Ia chs

Electrical chs:

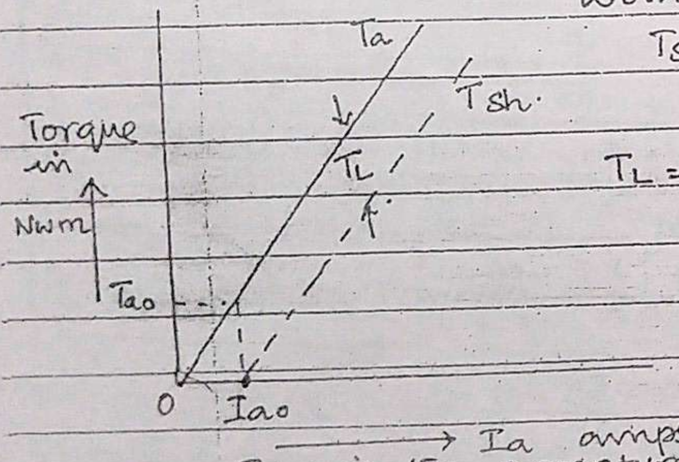
$$T_a = \frac{1}{2\pi} \frac{ZP}{A} \phi I_a$$

$$T_a \propto \phi I_a$$

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

V, Rsh constant, Ish constant hence ($\phi$) is constant.

$T \propto I_a$ shape is a straight line passing through origin. Torque increases linearly with Ia. As $I_L \uparrow$ $I_a \uparrow$ $T \uparrow$




$T_{sh} < T_a$ due to friction & windage (mechanical losses)

$T_L$ = Torque lost

Ia = armature current

Ta = Torque dev in armature.

N = Primemover speed or armature speed.

Iao is the armature currt at no load.

* shunt motor has medium starting torque hence doesnot suit, where very large loads are required to be started.
* ie shunt motor should never be started on heavy loads.

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N Vs Ia chs. Shunt Motor.

$E_b = V - I_a R_a$.

$N \propto \frac{E_b}{\phi}$  $I_L \uparrow$ $I_a \uparrow$ $\underset{drop}{(I_a R_a)} \uparrow$ $E_b \downarrow$. $N \downarrow$.

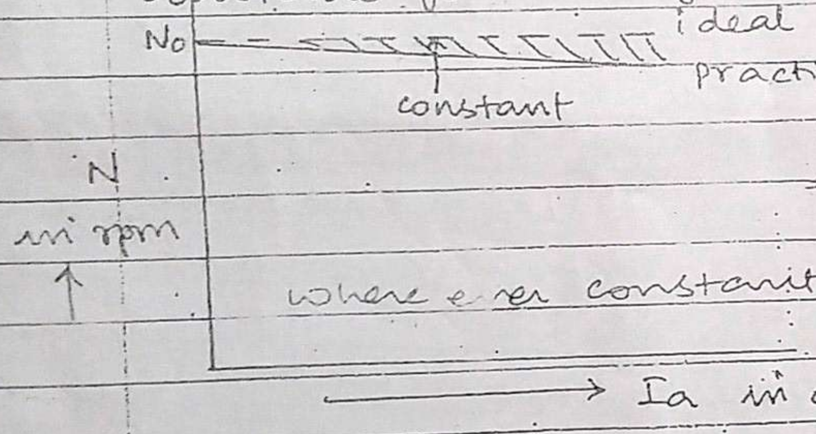
As. (load increases)

$\phi$ constant for shunt motor.

$\therefore N \propto E_b$

$N \propto V - I_a R_a$.

As $I_a \uparrow$ $I_a R_a \uparrow$ $E_b \downarrow$ speed decreases. But $I_a R_a$ drop is very small compared to V. Hence decrease of speed is very small so shunt motor may be considered as constant speed motor. shunt motors are suitable for driving shafting, machine tools, Lathes, wood working machines.

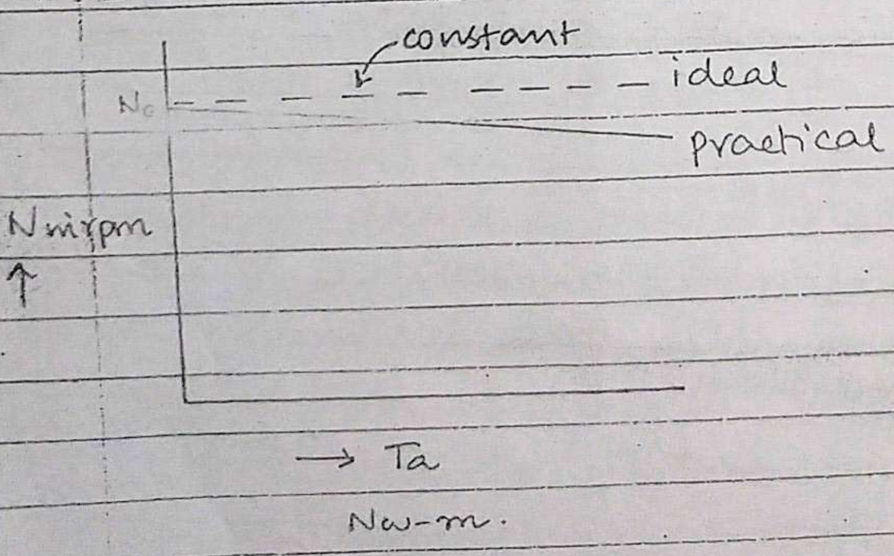



$N_o$ = no load speed of motor.

where ever constant speed is required, shunt mtrs are employ

(3) N Vs Ta chs: Shunt Motor.

Ta $\propto$ Ia hence N Vs Ta is $\parallel^r$ to N Vs Ia chs as shown above.



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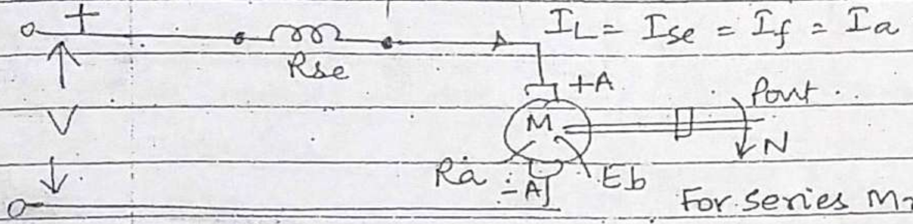
## Series Motor. T Vs Ia chs.



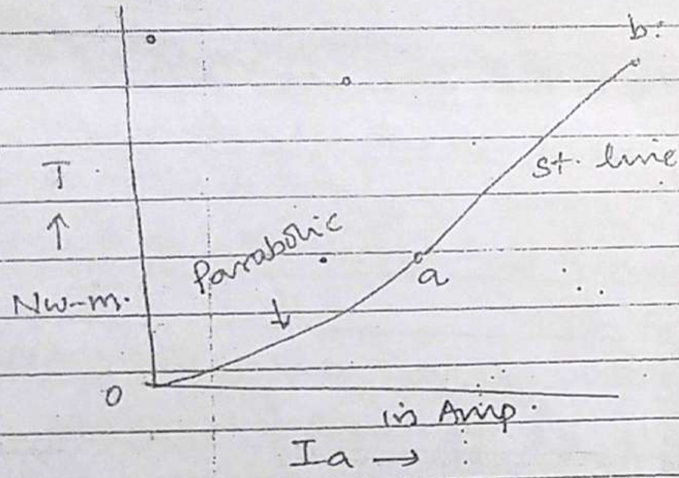

For series Mr, series field winding is connected in series with the armature.

$\therefore \phi \propto I_a$ ; $T \propto \phi I_a$ , $\phi \propto I_a$. of Poles.

As load ↑, Ia↑ ∴ $T \propto I_a^2$ ↑ before saturation, shape will be parabolic. (oa).

after saturation of poles, $\phi$ remain constant, $T \propto I_a$, shape will be st. line (ab)

(Tst) starting torque of DC motor is very high




saturation of pole mean though the currt through the field winding increases flux remains constant. so we say after Saturation of poles, $\phi$ is constant.

on heavy loads, a series motor exerts a $T \propto I_a^2$. Hence where large starting torque is required series motors are preferred

* for accelerating heavy masses quickly on hoist, electric train etc. series motors are used.

* Series Motors develop high torque at low speed.

Ra, Rse are so small, $\therefore E_b \propto V$ | $N \propto \frac{V - I_a R_a}{\phi}$

V constant.

$\therefore N \propto 1/\phi$.

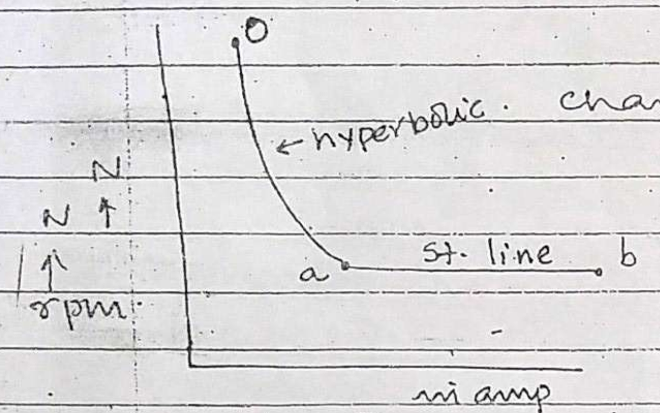


## N Vs Ia Series Motor

$N \propto \frac{E_b}{\phi}$. $\phi \propto I_a$ in series Motor.

$\boxed{N \propto \frac{1}{I_a}}$

Shape'll be hyperbolic (o a) before saturation of poles.




change in Eb is small $\therefore N \propto \frac{1}{\phi}$.

$N \propto \frac{1}{I_a}$. of poles

* After saturation flux become constant hence speed is also constant (ab).

(1) Ia ↑ Ia(Ra+Rse) ↑, N ↓

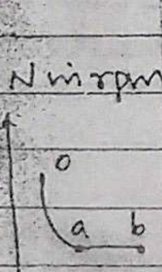
(2) Ia ↑ N ↓; $\phi$ is Large

when load is heavy, Ia is large, hence N is low.

when load current & hence Ia when fall to a very low value, speed becomes dangerously high & the motor may fly off due to centrifugal force. [illegible] Series motor never be started at noload [illegible] ad}.

Series motor is considered as a variable speed motor. because as the load increases, the speed decreases over a wide range.

## N VS Ta chs of Series Motor.




Series Mr develop high torque at low speed & vice versa. This is because an increase in torque, requires an increase in Ia, which is also the field current, hence $\phi$ is more, $N \propto \frac{1}{\phi}$, $N \propto \frac{1}{I_a} \rightarrow (2)$

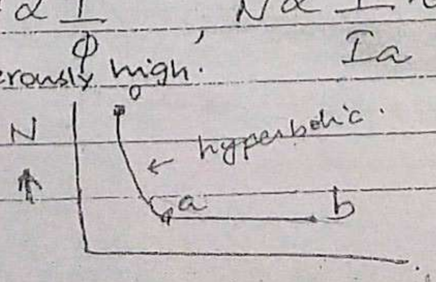
$T_a \propto I_a^2$

$I_a \propto \sqrt{T_a}$.

* on noload, T is less, N ↑ dangerously high.

$T_a \propto I_a^2 \rightarrow (1)$

or $I_a \propto \sqrt{T_a}$




$N \propto \frac{1}{\sqrt{T_a}} \rightarrow (3)$

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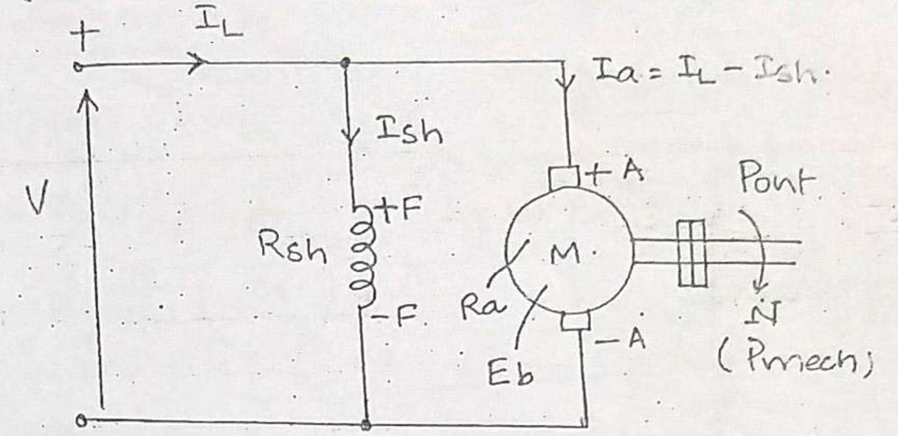



D.C. shunt Motor.

Power developed in the armature = $E_b \cdot I_a$ watts

If the field winding is connected in parallel with the armature, it is known as D.C. Sh. Mr.

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

$I_a = I_L - I_{sh}$

$E_b < V$

$E_b = V - I_a R_a - B.D.$

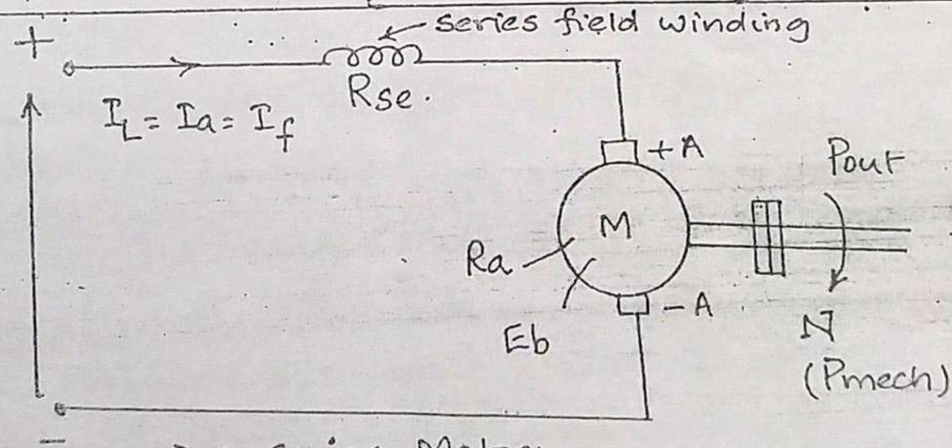
$I_L$, $I_L = \frac{P_{in}}{V}$

$I_L = \frac{P_{out}}{V \cdot \eta}$

$\eta$ = efficiency of Mr.

BD = Brush

Power dev in arm = $E_b I_a$ Watt




D.C. Series Motor.

$E_b = V - I_a R_{se} - I_a R_a - B.D.$

or

$E_b = V - I_L R_{se} - I_L R_a - B.D.$

Power developed in the armature = $E_b \cdot I_a$ Watts.

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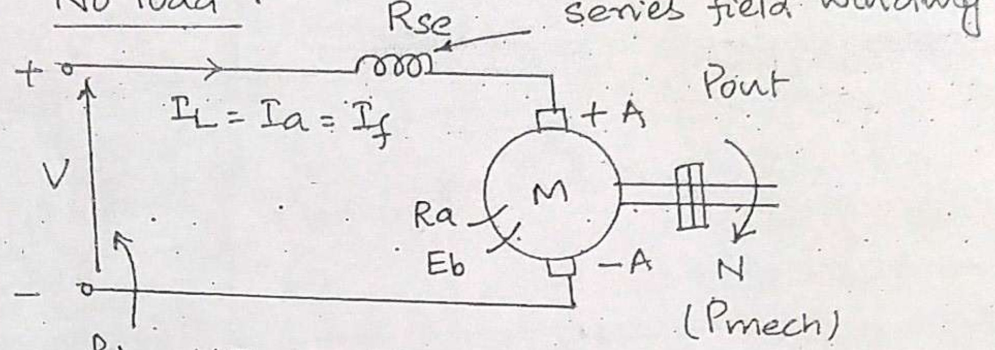
## Why Series Motor is never started on No load ? (or light load)




$P_{in} = V I_L$ watts.

In series motor $I_L = I_a$.
on no load $I_a$ is (very) very small. $\boxed{\phi \propto I_a}$ Therefore flux ($\phi$) is also very small.

$\therefore \quad N \propto \frac{1}{\phi}$ $\qquad$ $\because N \propto \frac{E_b}{\phi}$

$E_b = V - \underbrace{I_a(R_{se} + R_a)}_{\text{neglected}}$

$E_b \propto V$ → constant

when $\phi$ is v small, N will be dangerously high, which may damage the motor mechanically.

This is the reason why series motor should never be started on light loads or no load conditions.

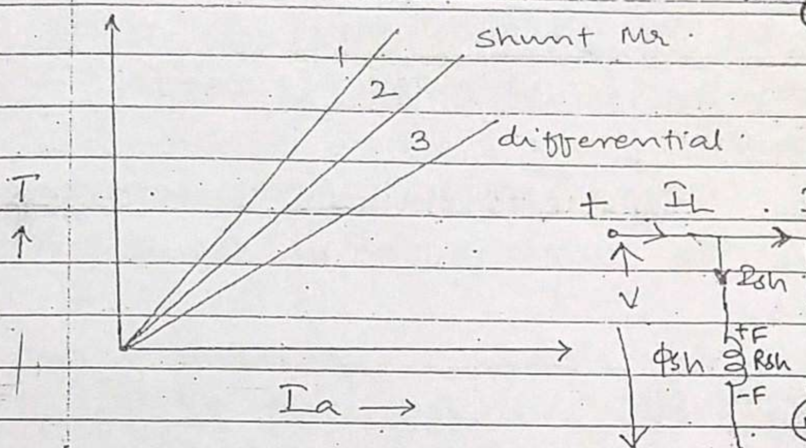
$\phi = 0$
$N = \infty$

---

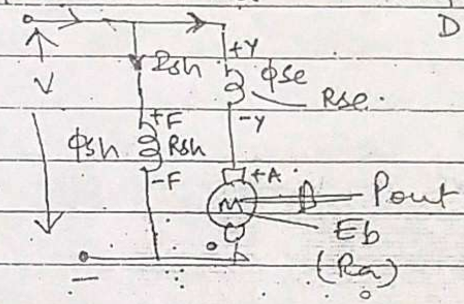
$R_{se}$ = Series field resistance
$R_{sh}$ = Shunt field resistance.
$I_a$ = armature current
$I_L$ = current drawn from supply.
$E_b$ = back emf.
$R_a$ = armature resistance.
$V$ = Supply Voltage.
$N$ = Speed of armature in rpm.

## (IX) T Vs Ia chs of DC compd motor.






Differtially compounded DC Motor.




$T \propto \phi I_a$

<u>Cumulatively compounded Motor</u>

$\phi_{Resultant} = (\phi sh + \phi series) > \phi sh$

differentially compounded Motor

$\phi_{Resultant} = (\phi sh - \phi se) < \phi sh$

As $I_L \uparrow$ $I_a \uparrow$ $\phi se \uparrow$ $\phi$ resultant $\uparrow$ $T \uparrow$ in <u>cumulatively compounded DC Motor.</u>

<u>In " " " starting torque is more than that of a DC Sh. Mr.</u>

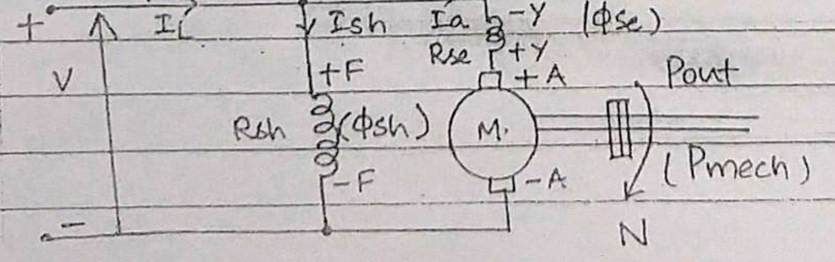
& less than " " Series Mr.

At low speed, T is high.

In differential

as $I_L \uparrow$ $I_a \uparrow$ $\phi se \uparrow$ $\phi$ resultant $\downarrow$ $T \downarrow$

<u>Cumulatively compounded DC Motor.</u>



## D.C. compound Motor.

- Compound motor characteristics basically depends on the fact whether the motor is cumulatively compounded or differtially compounded.
- All the characteristics of the compound motor are the combination of shunt & series motor chs.
- Cumulatively compounded motor is capable of developing large amount of Torque at low speeds just like series motor. However it is not having a disadvantage of series motor even at light or no load.
- In cumulative

$$\phi \text{ Resultant} = \phi sh + \phi se.$$

$$\phi \text{ Resultant} > \phi sh.$$

$$N \propto \frac{1}{\phi}$$

∴ cumulative compd Mr can run at a reasonable speed & will not run at dangerously high speed at no load or light load like series Mr.

- In differential compd Mr

$$\phi \text{ Resultant} = \phi sh - \phi se.$$

$$\therefore \phi \text{ Resultant} < \phi sh$$

$$N \propto \frac{1}{\phi}$$

As the load increases, $\phi$ Resultant decreases, thus the Mr runs at a higher speed

- This property is dangerous on full load, Mr may run at dangerously high speed. so this Mr is generally not used in practice.

08

Applications Page (15)

Shunt Motors :- constant speed ↕ Medium starting torque

Blowers, fans, centrifugal & reciprocating pumps, lathes, Machine tools, for constant speed line shafting.

Series Motors : (variable speed, high Tstart

Traction purposes (Electric)

electric locomotives

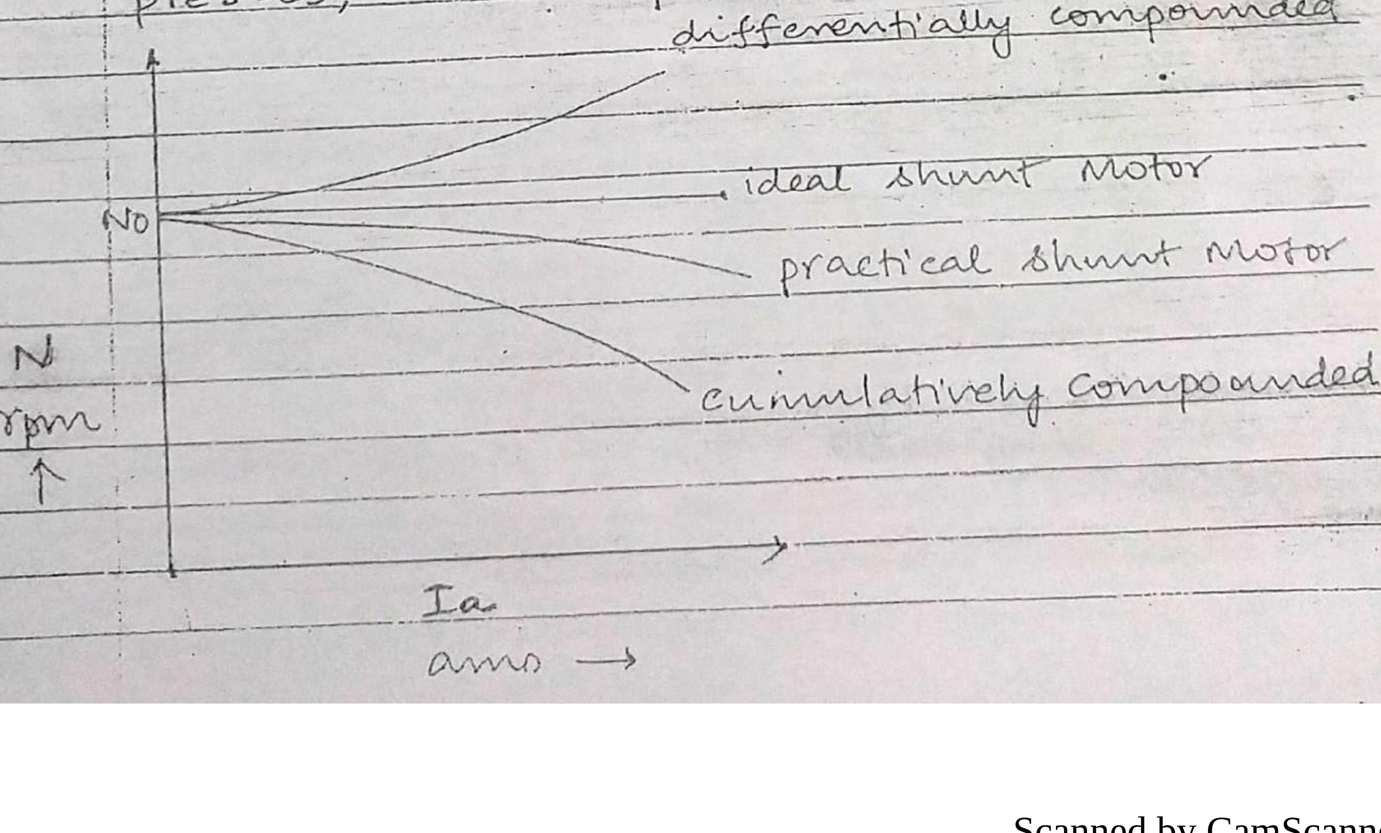
Trolley cars, Hoists, cranes, trams.

conveyors.

compound Motors (variable speed, high Ts

cumulative compd Mr.

Elevators conveyors, high torque loads of intermittent nature, punches, shears, heavy machine tools, Heavy planers. Rolling mills, Ice machines, printing presses, Air compressors.



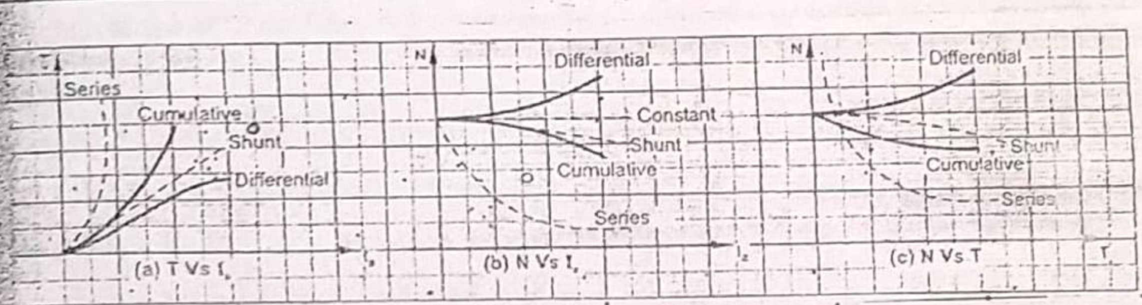



Fig. 8.24.1 Characteristics of compound motor

## Applications of D.C. Motors

> *State the applications of d.c. shunt and series motors.*

Jan.-04, 06, 07, 08, 10; Feb.-05; July-05, Marks 2

| Types of motor | Characteristics | Applications |
|---|---|---|
| Shunt | Speed is fairly constant and medium starting torque. | 1) Blowers and fan<br>2) Centrifugal and reciprocating pumps<br>3) Lathe machines<br>4) Machine tools<br>5) Milling machines<br>6) Drilling machines |
| Series | High starting torque. No load condition is dangerous. Variable speed. | 1) Cranes<br>2) Hoists, Elevators<br>3) Trolleys<br>4) Conveyors<br>5) Electric locomotives |
| Cumulative compound | High starting torque. No load condition is allowed. | 1) Rolling mills<br>2) Punches<br>3) Shears<br>4) Heavy planers<br>5) Elevators |
| Differential compound | Speed increases as load increases. | Not suitable for any practical application |

Table 8.25.1 Applications of d.c. motors

## Necessity of Starter

> *Explain the necessity of starter for a d.c. motor. With a neat sketch explain the working of three point starter for a d.c. motor.*

[redacted]

- The starter is not required to start a d.c. motor but it enables us to start the motor in a

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- At the starting instant the speed of the motor is zero, (N = 0). As speed is zero, there cannot be any back e.m.f. as $E_b \propto N$ and N is zero at start.

$\therefore$ $E_b$ at start = 0

- The voltage equation of a d.c. motor is, $V = E_b + I_a R_a$

So at start, $V = I_a R_a$ as $E_b = 0$

$$\therefore \quad I_a = \frac{V}{R_a} \quad \text{... At start}$$

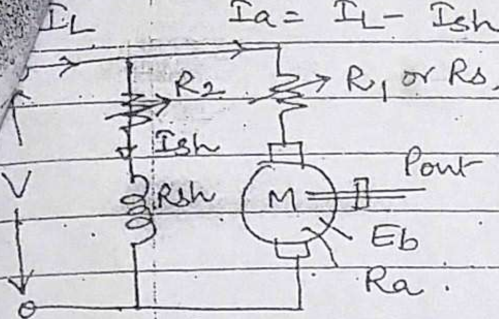
Ra

- Generally motor is switched on with normal voltage and as armature resistance is very small, the armature current at start is very high.
- So at start, motor is showing a tendency to draw an armature current which is 15 to 20 times more than the full load current.
- Such high current drawn by the armature at start is highly objectionable for the following reasons :
  1. It may affect the performance of the other equipments connected to the same line.
  2. Such excessively high armature current, blows out the fuses.
  3. A large armature current flowing for a longer time may burn the insulation of the armature winding.
- To restrict this high starting armature current, a variable resistance is connected in series with the armature at start. This resistance is called starter or a starting resistance. So starter is basically a current limiting device.
- In the beginning the entire resistance is in series with the armature and then gradually cuts off as motor gathers speed, producing the back e.m.f.
- In addition to the starting resistance, there are some protective devices provided in starter.

### 8.26.1 Three Point Starter

- The Fig. 8.26.1 shows three point starter.
- The starter is basically a variable resistance, divided into number of sections. The contact points of these sections are called studs and brought out separately shown as OFF, 1, 2, ... upto RUN.
- There are three main points of this starter :
  1. 'L' → Line terminal to be connected to positive of supply.
  2. 'A' → To be connected to the armature winding.
  3. 'F' → To be connected to the field winding.
- Point 'L' is further connected to an electromagnet called Overload Release (OLR). The second end of 'OLR' is connected to a point where handle of the starter is pivoted.

Explain the need of starter for DC Motors.




$E_b = V - I_a R_a - BD$

$$I_a = \frac{V - E_b}{R_a}$$

V = Supply voltage
Eb = back emf
Ra = armature resistance.

When the motor is at rest, no Eb developed. Now, if full supply voltage V is applied across the stationary armature, it draws a very large current because Ra is very small. ($R_a << 1\Omega$)

Say $V = 440$, $R_a = 0.25\Omega$, ∴ starting curr through armature $= 440/0.25 = 1760$ Amp. This excessive current will blow out fuses & prior to that, it will damage commutator, brushes & armature windings. To avoid this a resistance $R_1$ is connected in series with the armature. It is known as starting resistance ($R_T$)

$R_1$ limits the current during starting period.

Starting resistance is variable, it is slowly & gradually cut out as the motor gains speeds & develops Eb; which then regulates the speed.

$T_a \propto \phi I_a$

Starter is necessary to limit the starting current.

$$E_{b1} = \frac{\phi PN_1Z}{60A} = \frac{50 \times 10^{-3} \times 6 \times 1200 \times 492}{60 \times 6} = 492 \text{ V}$$

A 6 pole dc shunt motor has a lap connected armature with 492 conductors. $R_a = 0.2$, $\phi = 50$ mwb. The Motor runs at 20 rev/sec when it is connected to a 500V supply for a particular load. what will be the speed of the motor when the load is reduced by 50%. neglect contact drop (Brush drop BD)

$$E_{b1} = V - I_{a1}R_a$$

$$\therefore \quad I_{a1} = \frac{V - E_{b1}}{R_a} = \frac{500 - 492}{0.2} = 40 \text{ A}$$

Now load is reduced by 50% i.e. $T_2 = 0.5\ T_1$.

$$T \propto \phi I_a \propto I_a \qquad \therefore \phi \text{ constant for shunt motor}$$

$$\therefore \quad \frac{T_1}{T_2} = \frac{I_{a1}}{I_{a2}}$$

$$\frac{1}{0.5} = \frac{40}{I_{a2}}$$

$$\therefore \quad I_{a2} = 20 \text{ A}$$

$$\therefore \quad E_{b2} = V - I_{a2}R_a = 500 - 20 \times 0.2 = 496 \text{ V}$$

Now $\quad N \propto \frac{E_b}{\phi} \propto E_b$

$$\therefore \quad \frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}}$$

$$\therefore \quad N_2 = \frac{E_{b2}}{E_{b1}} \times N_1 = \frac{496}{492} \times 1200 = 1209.756 \text{ r.p.m.}$$

$$\therefore \quad N_2 = \frac{1209.756}{60} = 20.1626 \text{ revolutions per second}$$

## Review Questions

1. *Explain with a neat sketch, the construction of a d.c. machine.*
2. *Which part of a d.c. machine is laminated ? Why ?*
3. *What is the basic nature of the induced e.m.f. in a d.c. generator ? What is the function of a commutator.*
4. *What is the difference between lap type and wave type of armature winding ?*
5. *Derive from first principles an expression for the e.m.f. of a d.c generator.*
6. *State the different types of d.c. generators and state the applications of each type.*
7. *In a particular d.c. machine, if P = 8, Z = 400, N = 300 r.p.m. and $\phi$ = 100 mWb, calculate generated e.m.f. if winding is connected in (i) Lap fashion (ii) Wave fashion.*

(Ans. : (i) 200 V (ii) 800 V)

Page (01) | KN Prasanna
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# D.C. Machine

DC generator — DC Motor.

DC generator is a machine which converts mechanical energy to electrical energy.

construction of DC Machine.

construction of DC generator/DC Motor

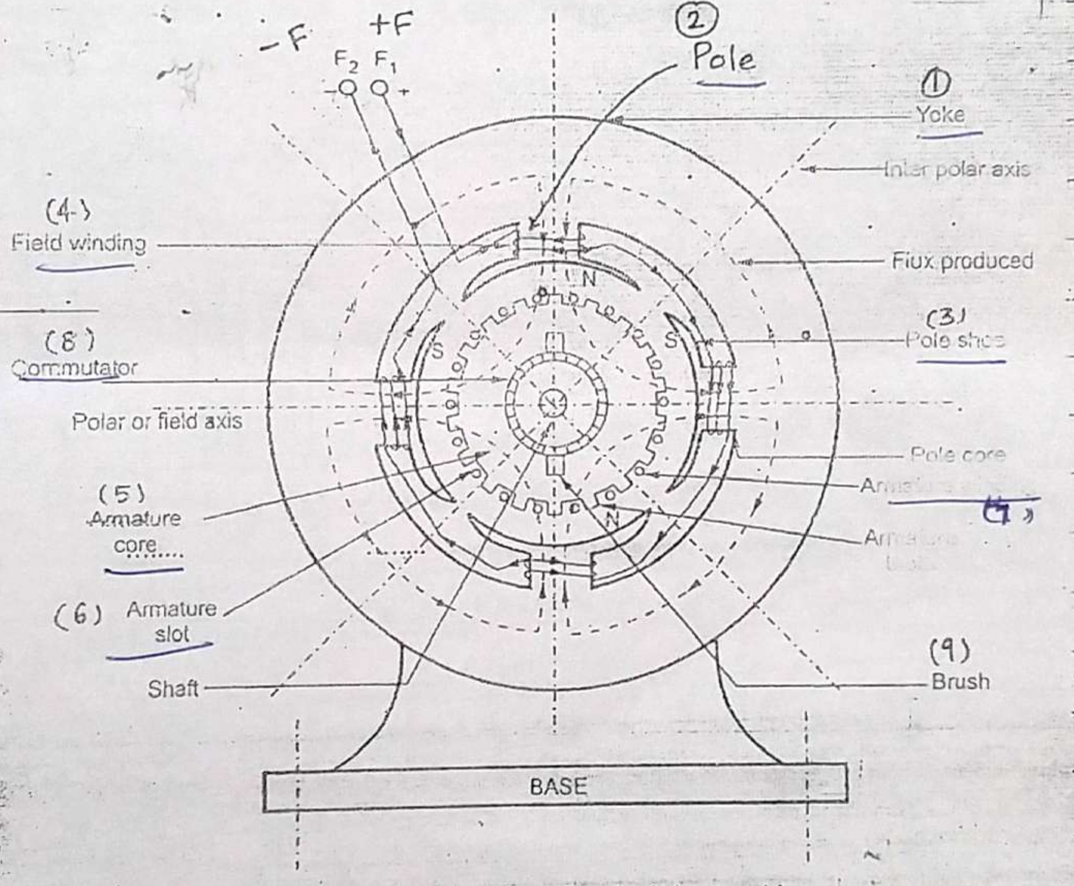
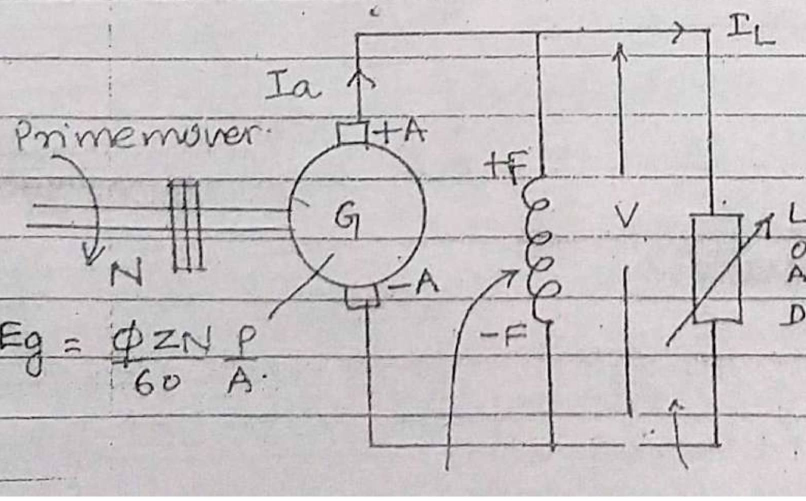



Fig. 8.3.1 A cross-section of typical d.c. machine




$$E_g = \frac{\phi Z N}{60}\frac{P}{A}$$

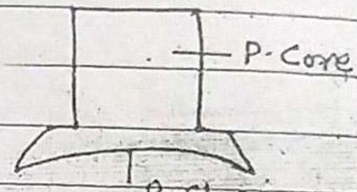
Power Generated in armature = $E_g I_a$ watts

$P_{in} = P_{mech}$

Power out = Electrical

## Main Parts of D.C. Machine.

1) Yoke
2) Main Poles North pole | South pole
   Pole core, pole shoe
   Field windings
3) Armature
   " windings
4) commutator
5) Brushes
6) shaft.
7) Terminal box
8) lifting eye.




Stationary part
Yoke, pole, field winding
Rotating Part
shaft, armature, commutator

Yoke : It is the outer most cover of DC M/c. It is cylindrical in shape. It is made up of cast iron for small m/cs & cast steel for large m/c's.
It has 2 main functions
1) It provides mechanical support to the poles as well as acts as a protective cover for the machine.
2) It provides a low reluctance path to magnetic flux.
Flux is carried by the yoke between North pole and South pole.
North pole and South pole

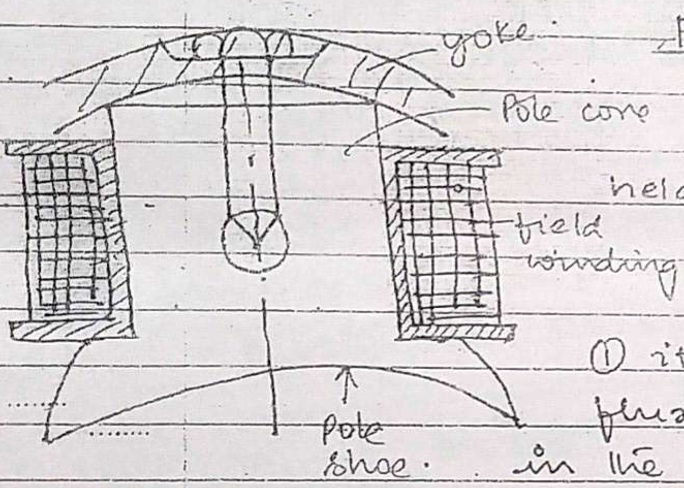
Main poles, pole shoe, field windings

Main Poles :-

They are made up of cast steel or wrought iron.

Poles will be laminated to reduce eddy current loss.

Poles are fixed to yoke by means of nut & bolt.




pole supports the field windings

The laminations are ~~held~~ held together by end plates, rivets

pole shoe has 2 functions

(1) it spread out the magnetic flux over a large area ~~in~~ in the air gap

(2) It supports field coils.

when direct current is passed through the field windings, the pole becomes electro magnet & produces the main flux

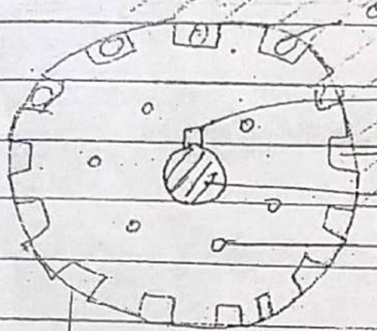
NOTE: Minimum number of poles is 2.

The ~~design~~ no: of poles required depends on the speed of armature & the o/p of the machine (output)

$$E_g = \frac{\phi Z N}{60} \frac{P}{A} \text{ Volts}$$

$$E_g \propto P$$

Armature:- It is the rotating part of DC Machine.




It consists of armature core & armature windings. It is cylindrical in shape. armature core is made of high permeability & low loss silicon steel. arm core is laminated.

armature slots are cut uniformly on the outer periphery of the armature core. Armature conductors are placed these slots.

The use of high grade silicon steel reduces the hysterisis loss.

armature conductors are insulated ones

armature laminations are keyed to the shaft. So when the shaft rotate, armature conductors also rotate.

Through the ventilating duct, free air can circulate & cool the armature.

armature windings is of 2 types lap & wave

In wave, the no: of ||el path = 2

ie A = 2

for lap A = P

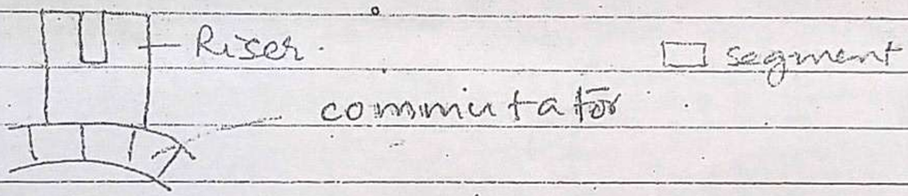
P = no of poles.

Commutator:-

The main function of the commutator is to collect current induced in the arm winding & convert it from ac to dc. ingr action.

It's cylindrical in shape.
It has no: of segments, each segment is seperated from one another using mica insulation.

Commutr is mounted on the shaft armature conductors are connected to commutator through risers.




Brushes:- The main function of the brushes is to collect D.C. current from the commutator & deliver it to external load circuit.

Brushes are made up of carbon.
They are rectangular in shape.

Shaft & bearings.

The armature core & commutator are mounted on a suitable shaft, shaft is mechanically coupled to a prime mover.

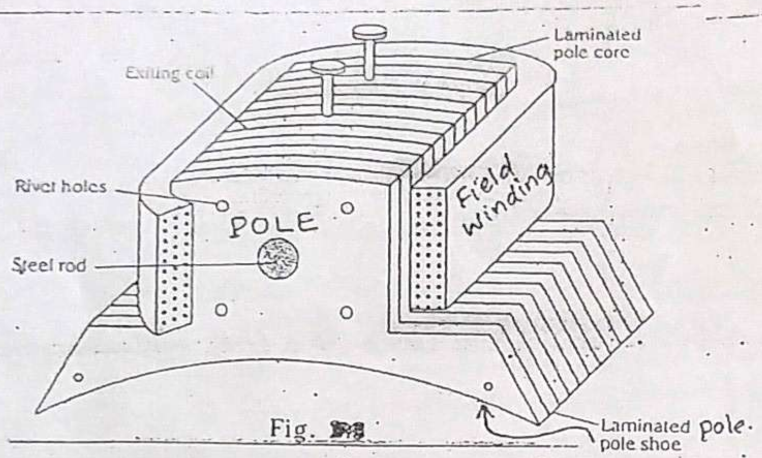



Fig.

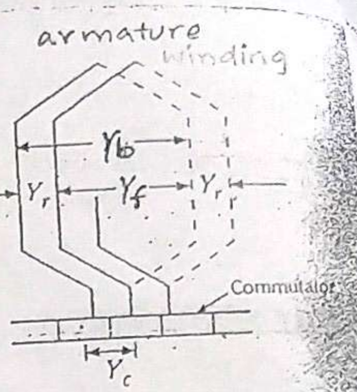
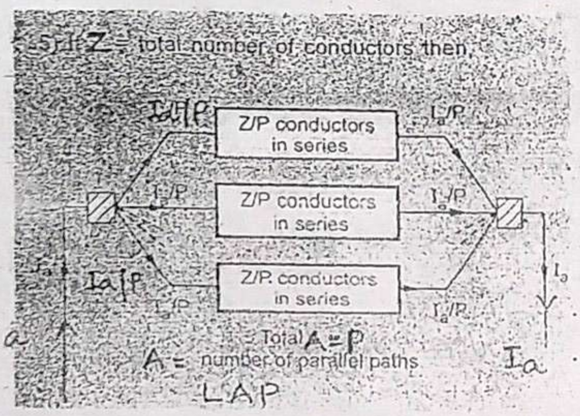
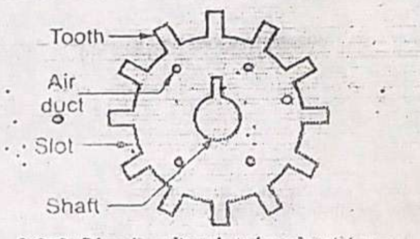



Fig. Lap winding




Single circular lamination of armature core

D.C. Machines

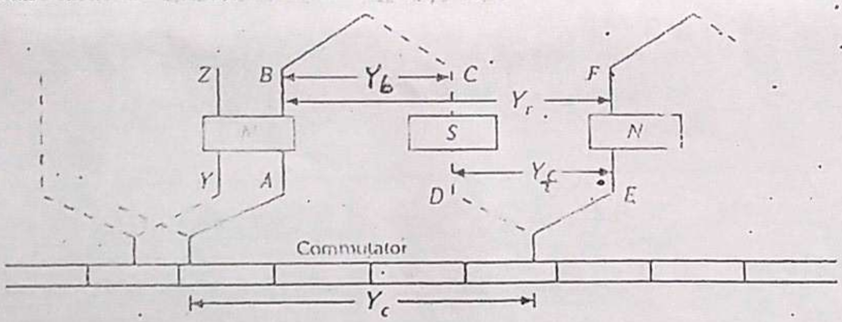
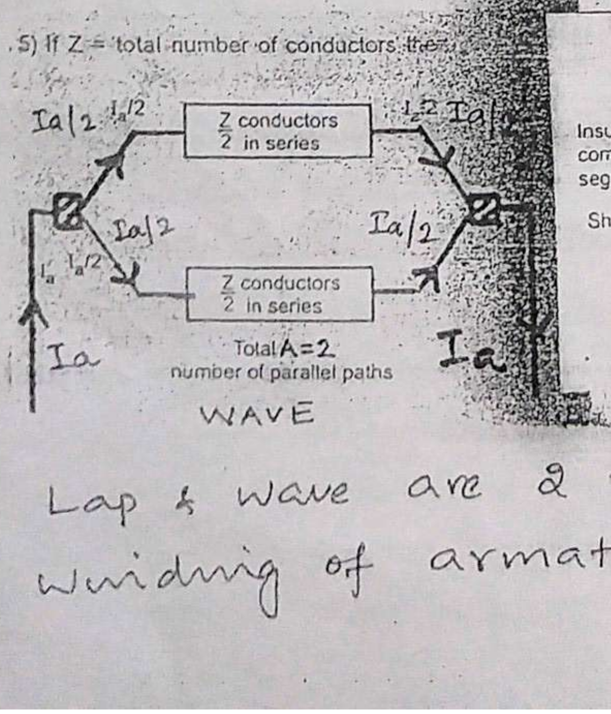



Fig. Wave winding



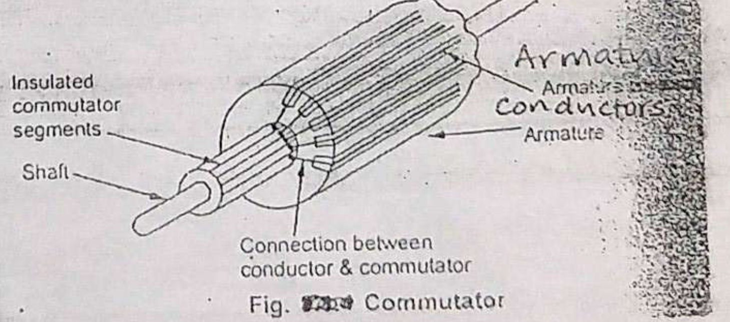
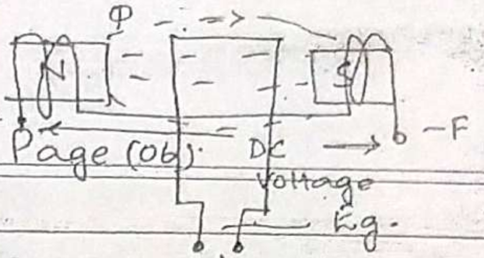




Fig. Commutator

Lap & wave are 2 fashions of DC winding of armature.

DC Gr → armature is rotating
field is Stationary.

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## Q. working principle

DC generator works on the principle of electromagnetic Induction

Whenever a conductor is rotated in a magnetic field such that it cuts across lines of flux, an emf is induced in the conductor.

Armature is rotated inside a magnetic field with the help of prime mover, an emf is induced in it & if the conductor forms a closed circuit, current will flow in it. The nature of emf induced is dynamically ~~induced emf~~. D.C Generator.

UQ ## EMF equation of DC gr

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

. Flemings right hand Rule.

Z = Total number of armature conductors

$\phi$ = flux per pole in weber.

N = Speed of armature or prime mover speed in rpm.

P = no: of poles.

A = no: of ||el paths.

A = 2 wave winding

A = P for lap "

flux cut by one conductor in 1rev $= d\phi = P\phi$

Time taken by the conductor to make 1rev $\} = dt = \frac{60}{N}$ sec

Average emf induced / conductor $= \frac{d\phi}{dt}$

N rpm → 60 sec
60 sec

No: of conductors / ||el path = Z/A

There are Z no: of armature conductors arranged in A no: of ||el paths.

Voltage generated across the gr terminals } = $E_g = \frac{\phi Z N}{60} \frac{P}{A}$.

A = 2 wave winding.
A = P. lap winding.

emf induced per ||el path } = emf induced/conductor × no: of condtrs/||el path

$$E_g = \frac{\phi Z N}{60} \cdot \frac{P}{A}.$$

$E_g$ = no load voltage
= open ckt emf
= generated emf.

NOTE : The direction of induced emf is according to Flemings right hand rule.

* DC gr works on the principle of Faradays laws of Electromagnetic induction

* The nature of emf induced is dynamically induced emf.

## D.C. Generator

1. The D.C. Gr works on the principle of dynamically induced emf.
- The direction of induced emf in a gr is given by Flemings right hand rule.
- The nature of current flowing in the armature of a d.c. gr is ac.
- The function of commutator is to covert ac to dc emf
- Brushes are made of carbon.
- $E_g = \frac{\phi Z N}{60} \frac{P}{A}$    $A = 2$ wave winding, $A = P$ lap
- Power in the armature = $E_g \cdot I_a$ Watts.
- emf induced per parallel path = emf induced/conductor × number of conductors/parallel path.

---

### Theory Questions:

1. With a neat diagram, explain the constructional features of a D.C. Machine.
2. Explain the principle of operation of a D.C. Generator.
3. Obtain the emf equation with usual notations.
4. What are the main parts of D.C. Machine its function and the material used.

KN Prasanna
EEE

# Alternator. (A.C. generator)

## Synchronous Generator.

It is an a.c. machine which converts mechanical energy to electrical energy.

Power input = P mech (HP)

Power output = P elec (KW / KVA)

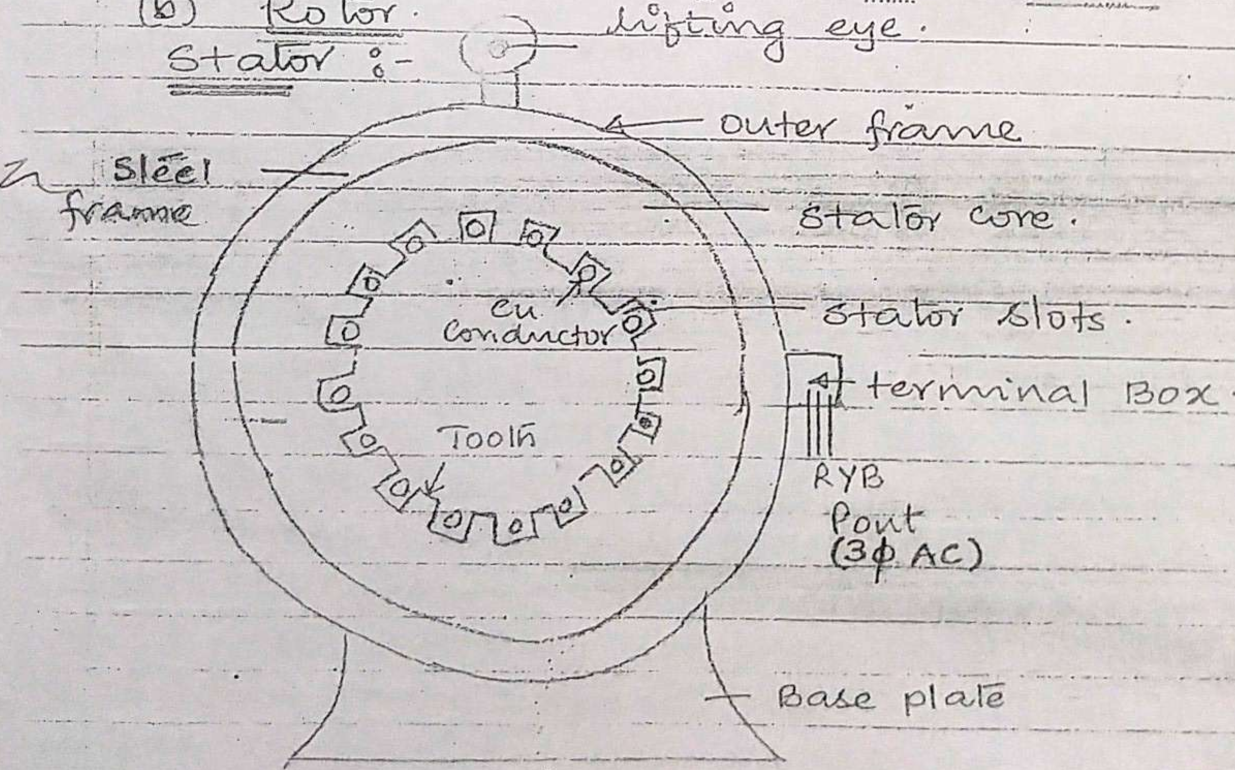
It works on the principle of electromagnetic induction. For the generation of voltage, three things are essential. a mag field, conductors, & relative motion betwn the two. In alternator the field system is rotating & the conductors are stationary. where emfs are induced.

## Construction:

Parts of Alternator

An Altr consists of 2 Parts (a) Stator (b) Rotor.

### Stator :-



2 Stator

It is the outer covering of the machi and is cylindrical in shape, made of mil steel. stator core is made of no: of lamminations & are insulated (varnished) from one another & pressed together to form the core. The lamminations will reduce the eddy current losses & silicon steel will reduce hysteresis losses. on the inner periphery of the stator core, uniform slots are cut to house the stator conductors. stator is the stationary part. The stator conductors are 3φ ac. windings. The ending terminal (ER, Ey, EB) of the 3φ winding is brought out & connected in the terminal box from where the generated power is taken out.

3 Rotor :- There are 2 types of rotor

a) Salient pole (projecting pole)

b) Non Salient pole (smooth cylindrical type)

Rotor is the rotating part. It is cylindrical in nature & is made of cast steel

→ Salient pole Rotor. (projecting pole)

This type of rotor is used in low & medium speed Altrs (300 to 600) rpm). These Rotor have large diameter & short axial length. The main poles are rigidly fixed & the rotor core by means of bolts & nuts by rivets. The prime movers used to drive this rotor are water turbines & I.C. Engines.

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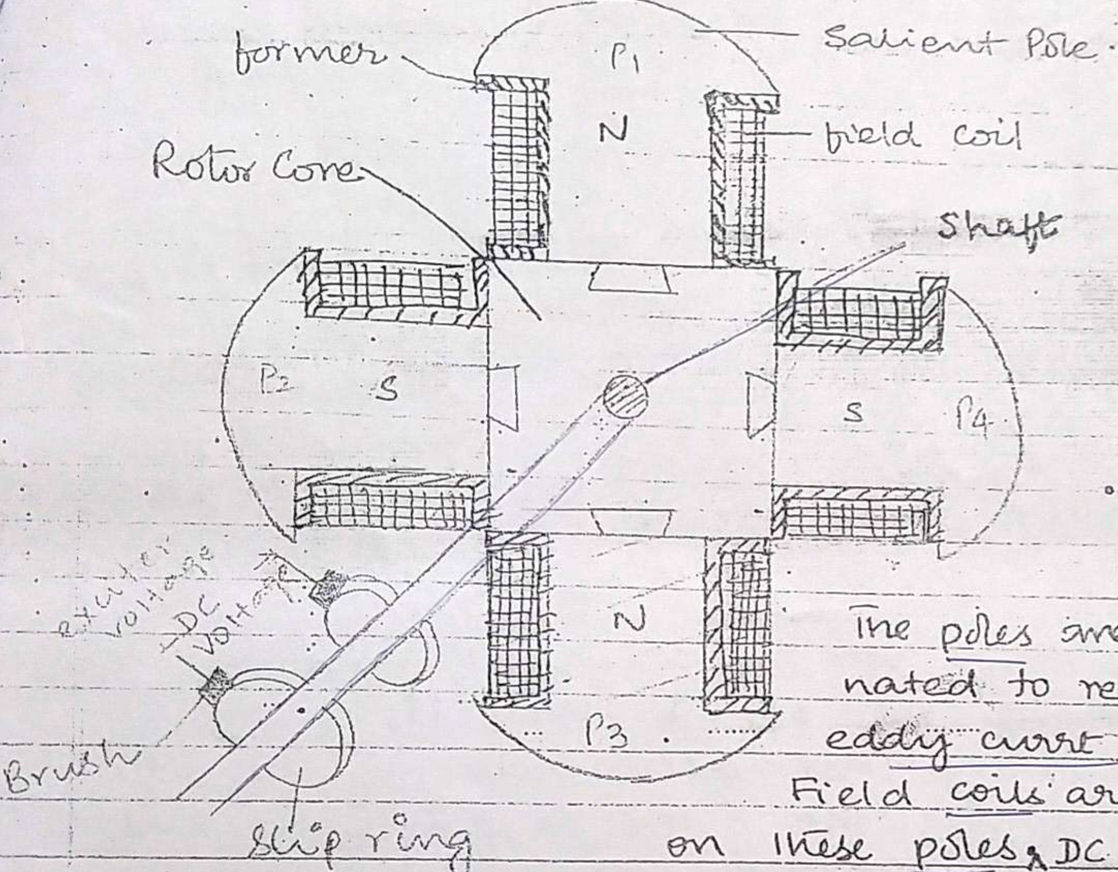
## Salient Pole Rotor




The poles are laminated to reduce eddy currt losses. Field coils are wound on these poles, DC voltage is fed to the field coils through 2 carbon brushes which slide on 2 slip rings fixed to the shaft of the alternator.

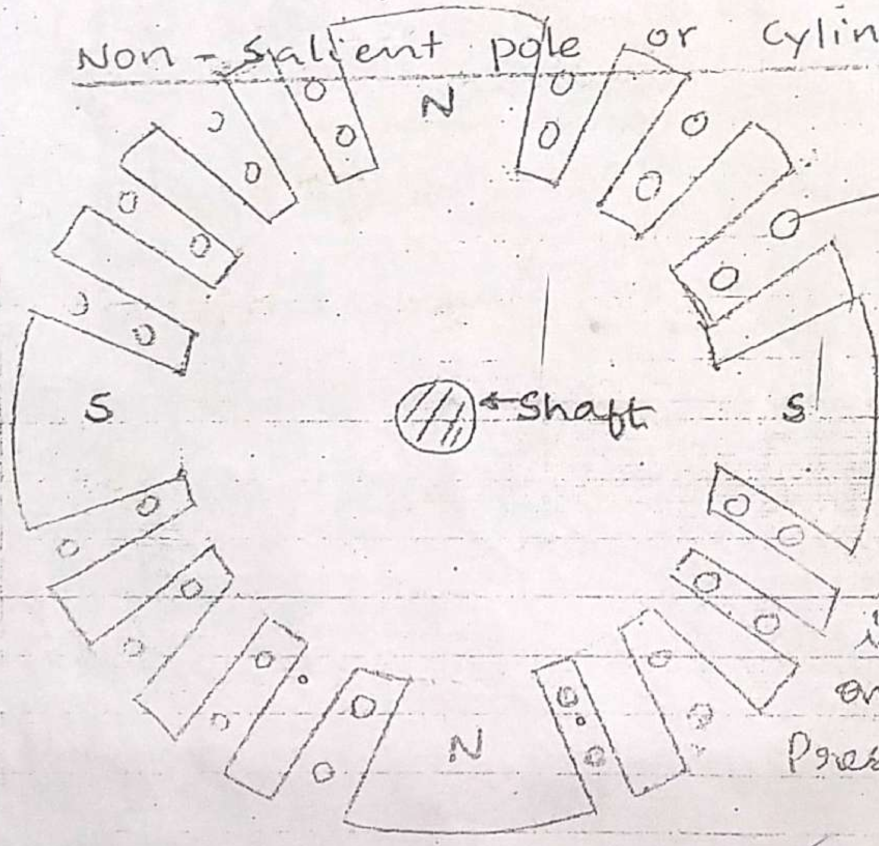
These rotors cannot run at high speeds. In practice, these rotors are driven by hydraulic turbines which run at low speeds. It usually rotate on horizontal axis.

The field coils are wound on the pole core & all field coils are joined in Series. The ends of the field windings are permanently joined to 2 insulated cu slip rings.

These are used in hydro electric grs.

Smooth cylindrical OR.

Non-Salient pole or cylindrical




The rotor consist of steel laminations which are insulated from one another & pressed together.

The rotor core is cylindrical in nature, having no: of slots on its outer periphery, for accomodating the field windings. The field magnets are cut out of the rotor core as shown in fig slots are provided in between the poles. This type of rotor is driven by a steam turbine electric motors. & rotate at very high speed 1500 to 3000 rpm. This is a high speed Altr so known as Turbo Altrs. This rotor is designed to have 2 or 4 poles. It usually rotate on a vertical axis.

These rotors have small diameter & large axial length. This type of rotor construction gives better balance & quitter operation, windage losses will be less.

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# 3 phase Alternator (Synchronous Generator)

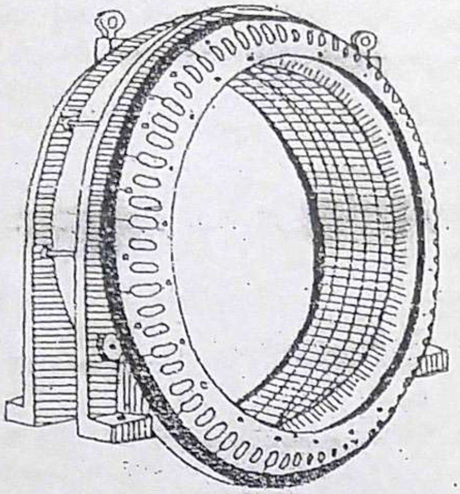
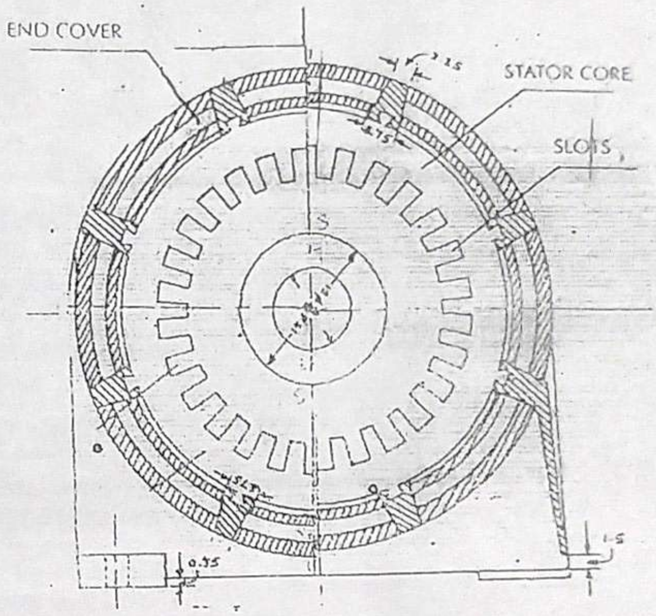
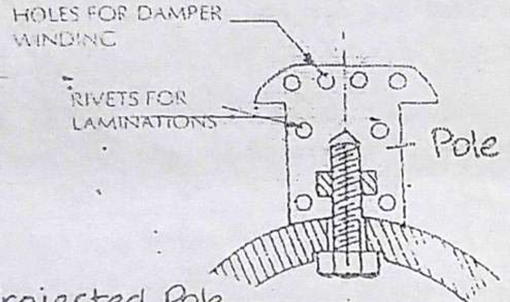


Fig. : STATOR OF AN ALTERNATOR.

## 3 phase Alternator Stator



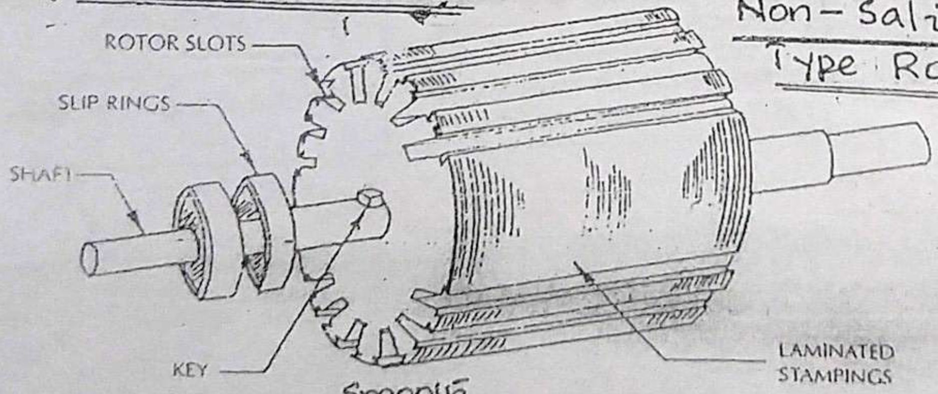

Projected Pole Type Rotor

Rotor.
Fig. : SALIENT POLE

rotor.

## Alternator - Rotor -

Non - Salient Type Rotor.




Smooth

Fig. : CYLINDRICAL ROTOR OR WOUND ROTOR

Page(06)

Q 7 (a) With necessary sketches distinguish between salient pole and cylindrical pole type synchronous generators and when these are preferred. (7 marks)

Ans :

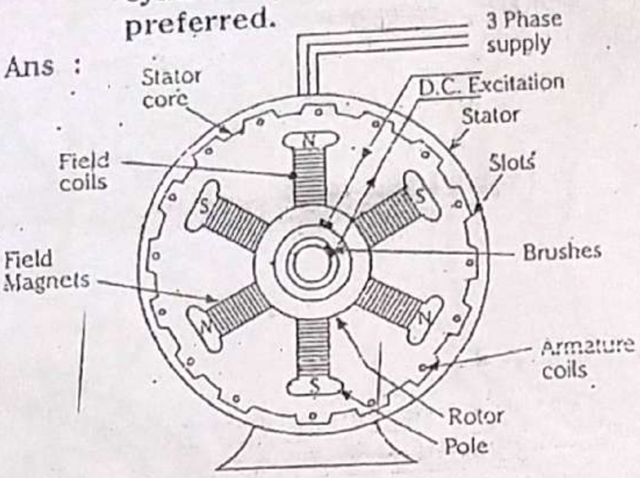



Fig. 7(a)

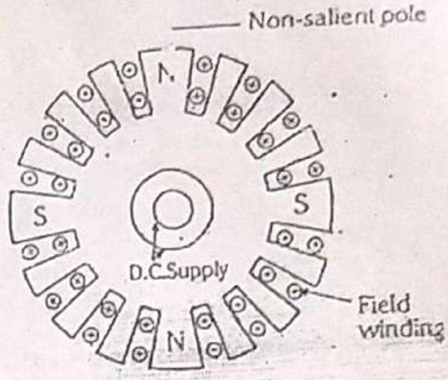



Fig. 7(b)

In the case of both the salient pole and cylindrical pole type synchronous generators, these is no differences as far as stators are concerned. However, the rotors are differently constructed.

The differences between salient and cylindrical types of rotor are given below in tabular form :

| Sl.No. | Salient Pole Type | Cylinderical Pole Type |
|---|---|---|
| 1 | They have large diameter and short axial length | Very small diameter and very long axial length |
| 2 | Preferred for low speed alternators | Preferred for use in very high speed turbo-alternators |
| 3 | The poles project from the surface | A portion of the cylinder acts as poles; hence poles are non-projecting |
| 4 | Mechanically weak | Mechanically robust |
| 5 | For the same size, the rating is smaller than for the cylindrical type | For the same size, the rating is higher than for the salient pole type |
| 6 | Its air-gap is non-uniform | Its air-gap is uniform due to the smooth cylindrical periphery |
| 7 | The pole faces are provided with slots to provide damper windings to prevent hunting | Damper windings are not necessary |
| 8 | Prime-movers used are hydraulic turbines and diesel engines | Prime movers used are steam turbines |

The Altr works on the principle of

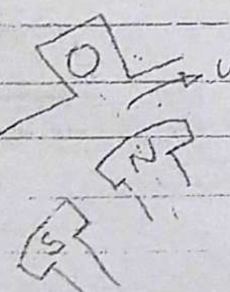
**Working:** Electromagnetic Induction.

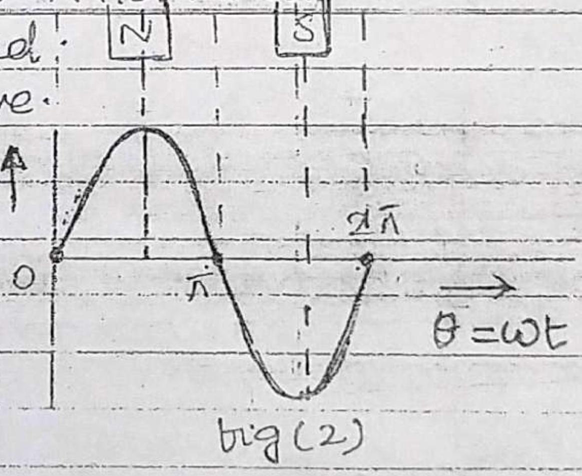
The rotor maintains uniform airgap betwn the stator & rotor.

The field windings of the rotor are supplied with D.C. voltage; hence a magnetic field sets up. The rotor is rotated by a prime mover, stator conductors are stationary. The flux produced by rotor poles, sweeps across the stator conductors & hence an emf is induced in them. This is alternating in nature. The frequency of the induced emf depends up on the no: of poles (P) and prime mover speed (N) rpm. $\boxed{f = \frac{PN}{120}}$. There is a relative motion between the conductors and the flux, hence emf is induced in the conductors.

Q: Derive an equation for the frequency of induced emf in the Alternator in terms of no: of poles & speed.

$f = \frac{PN}{120}$ derive.






fig(2)

P = No: of poles

f = frequency of generated emf

N = Rotor speed in rpm.

Consider a single conductor placed in the slot of the stator as shown in fig.

Let the rotor with alternate North & South poles N & S. rotate with an angular velocity $\omega$ in the clockwise direction.

+ve ½ cycle of emf is induced in the conductor, when the north pole N sweeps across the conductor. -ve ½ cycle of emf is induced when the south poles S sweeps across it & hence, one cycle of emf is induced in the conductor, when one pair of poles sweeps across it as shown in fig (2).

60 sec → N rev

1 sec → $\frac{N}{60}$ rev

No: of cycles of emf induced in one revolution $\} = \frac{P}{2}$

No. of revolutions per sec $\frac{N}{60}$

frequency f = cycles/s

N r.p.m → 60 sec

$\left(\frac{N}{60}\right)$ r.p.s

f = no: of cycles of emf induced / rev * no: of rev/sec.

$$= \frac{P}{2} * \frac{N}{60} = \frac{PN}{120} \text{ cycles/sec. or Hz.}$$

**U.S.** Derive an expression for the emf induced in an Alternator.

$$E_{ph} = 4.44 \, f \, \phi \, T_{ph} \, K_p \, K_d$$

$Z_{ph}$ = no: of stator conductors per ph

P = no: of poles.

$\phi$ = flux per pole in wb.

f = freq.cy of induced emf in Hz.

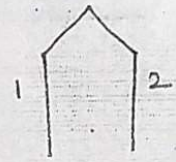
## Derive an expression for the emf induced in an Alternator.

$E_{ph} = 4.44\, f\, \phi\, T_{ph}\, K_w$

$Z_{ph}$ = number of stator conductors / phase.
$P$ = number of poles.
$\phi$ = flux per pole in weber.
$f$ = frequency of induced emf in Hz.
$T$ = number of Turns.

$Z_{ph} = 2\, T_{ph}$

or $T_{ph} = \frac{Z_{ph}}{2}$




1 turn = 2 conductors.

$N$ = rotor speed in rpm

flux cut by 1 conductor in 1 revolution $\Big\} = d\phi = P\phi$ wb

Time taken for 1 revolution $= dt = \frac{60}{N}$ sec.

average emf induced in 1 conductor $\Big\} = \frac{d\phi}{dt} = \frac{P\phi \times N}{60}$ volts

$N$ rev → 60
∴ 1 rev → $\frac{60}{N}$ sec

$= \frac{P\phi}{60}\left(\frac{120f}{P}\right) = 2 f \phi$ volts.

The average emf induced in Z no: of stator conductors $\Big\} = 2 f \phi (Z_{ph})$
$= 2 f \phi (2 T_{ph})$
$= 4 f \phi\, T_{ph}$ volts.

for a sinusoidal wave, $E_{rms} = 1.11\, E_{ave}$.

∴ rms value of emf induced per phase =
$E_{ph} = 4.44 f \phi\, T_{ph}$ volts.

$E_{ph} = 4.44 f \phi\, T_{ph}\, K_w$ Volts where $K_w$ is the winding factor.

$\lambda$ connected $3\phi$ Altr. $E_L = \sqrt{3}\, E_{ph}$

$\Delta$ connected $3\phi$ Altr $E_L = E_{ph}$

Note:

- The machine generating ac emf are called Alternators. The Alternators work at a specific constant speed called synchronous speed ($N_s$) and hence in general ~~Called~~ Alternators are also called as Synchronous generators.
- The main difference between D.C. Generator and Alternator is that in Alternators the field is rotating while armature (stator windings) are stationary & commutator is absent.
- In DC Generator, field is stationary, armature is rotating.

- Why A.C. Generators (Alternators) are called as Synchronous Generators?

For fixed no: of poles, Altr. has to be rotated at a particular speed to keep the freqcy of the generat emf const. at the required value; Such a speed is called Synchronous speed ($N_s$).

$$N_s = \frac{120f}{P}$$ where f is the required frequency.

- Note: Minimum number of poles can be 2, hence maximum value of $N_s$ = 3000 rpm, for a frequency of 50 Hz.

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NOTE

- The field winding of an Altr is excited by DC voltage.
- In Altrs field rotates.
- Salient pole ~~Altr~~ Rotor has low / medium speed. [300 to 600 rpm].
- non salient pole ~~Altrs~~ Rotors are used for high speed Altrs. 1500 – 3000 rpm.
- Salient pole rotors have large diameter and smaller axial length.
- Non salient pole rotor have small diameter & large axial lengths.
- Air gap is non uniform in salient pole rotors.
- Air gap is uniform in non salient pole " rotors.
- synchronous speed $N_s = \frac{120f}{P}$

**Example 10.10 :** *A 24-pole turbo alternator has a star connected armature winding with 144 slots and 10 conductors per slot. It is derived by a low speed Kaplan turbine at a speed of 250 revolutions per minute. The winding has full-pitched coils with a distribution factor of 0.966. The flux per pole is 67.3 mWb. Determine,*

*i) The frequency and the magnitude of the line voltage.*

*ii) The output kVA of the machine if the total current in each phase is 50 A.*

(Feb. - 2006, Marks - 8)

**Solution :** P = 24, slots = 144, 10 conds/slot, $N_s$ = 250 r.p.m., full pitch coils $K_c$ = 1, $K_d$ = 0.966, $\phi$ = 67.3 mWb.

i)
$$N_s = \frac{120f}{P} \text{ i.e. } f = \frac{N_s \times P}{120} = \frac{250 \times 24}{120} = 50 \text{ Hz}$$

$$Z = \text{slots} \times \text{conds/ slot} = 144 \times 10 = 1440$$

$$Z_{ph} = \frac{Z}{3} = \frac{1440}{3} = 480$$

$$T_{ph} = \frac{Z_{ph}}{2} = 240$$

$$\therefore \quad E_{ph} = 4.44\, K_c K_d\, \phi\, f\, T_{ph} = 4.44 \times 1 \times 0.966 \times 67.3 \times 10^{-3} \times 50 \times 240$$

$$\therefore \quad E_{ph} = 3463.8287 \text{ V}$$

$$E_{line} = \sqrt{3}\, E_{ph} = 5999.527 \text{ V} \approx 6 \text{ kV}$$

ii)
$$\text{Output kVA} = \sqrt{3}\, V_L I_L / 1000 \quad \text{.. 1/1000 for expressing in kVA}$$

For star $\therefore$ $I_L = I_{ph}$ = 50 A given, $V_L = E_{line}$ = 6 kV

$$\therefore \quad \text{Output kVA} = \frac{\sqrt{3} \times 6 \times 10^3 \times 50}{10^3} = 519.615 \text{ kVA}$$

Theory.

## ~~Review~~ Questions

1. *Discuss the advantages of rotating field type of alternators.*
2. *Explain in detail the constructional features of a three phase alternator.*
3. *List the differences between salient type and non-salient type of rotor construction.*
4. ~~*With the help of neat sketches, explain the various types of windings used in alternators.*~~
5. *Derive the generalized expression for an induced e.m.f. per phase in three phase alternator.*
6. ~~*Define and state the expressions for*~~
   ~~*a) Pitch factor*~~ *b)* ~~*Distribution factor*~~
7. *A 3 phase, 12 pole, star connected alternator has 72 slots and 6 conductors per slot. If it is driven at 500 r.p.m., calculate the induced e.m.f. per phase. Assume coil span as 150° electrical and flux per pole 40 mWb.* (Ans. : 596.53 V)

hw

## Review Questions

1. *Explain the principle of working a single phase transformer.*
2. *Explain the construction of a single phase transformer.*
3. *Discuss the difference between core type and shell type of construction.*
4. *Derive from the first principles, the e.m.f. equation for a transformer.*
5. *State the relationships between voltages and currents on primary side and secondary side of a single phase transformer.*
6. *What is kVA rating of a transformer ?*
7. *Explain the various features of an ideal transformer.*
8. *What is the difference between ideal transformer and practical transformer ?*
9. *Write a note on various winding parameters of a transformer.*
10. *Define regulation, stating an expression to obtain it.*
11. *Enumerate the various losses in a transformer. How these losses can be minimised.* %
12. *What do you understand by efficiency of a transformer ?*
13. *Derive the condition for maximum efficiency.* home Work Problems.
14. *A 600 kVA, single phase transformer has an efficiency of 94 % both at full load and half load at unity power factor. Determine its efficiency at 75 % of full load at 0.9 power factor.* hw

    (Ans. : 93.722 %)
15. *The magnetic material used for a transformer has an iron loss of 75 W at 25 Hz while 165 W at 40 Hz when flux density in the core remains same. If the transformer is connected to 60 Hz supply, what will be the new eddy current loss, hysteresis loss and iron loss?* hw

    (Ans. : 270 W, 67.5 W, 337.5 W)
16. *In a 25 kVA transformer the iron loss and full load copper loss are 350 W and 400 W respectively. Calculate the efficiency of the transformer at i) Half load at unity p.f. and ii) 3 / 4th th full load at 0.8 p.f. lagging.* hw

    (Ans. : 96.525 %, 96.308 %)
17. *The required no load ratio in a single-phase 50 Hz core type transformer is 6000/150 V. Find the number of turns per limb on the high and low voltage side if the flux is to be about 0.06 Wb.* hw

    (Ans. : 225.225 turns, 5.63 turns)
18. *A 50 kVA single phase transformer has 600 turns on primary and 40 turns on the secondary. The primary winding is connected to the 2.2 kV, 50 Hz supply. Calculate :* hw

    *i) Secondary voltage on no load ii) Full load primary and secondary currents*

    (Ans. : 146.67 V, 22,727 A, 340.909 A)