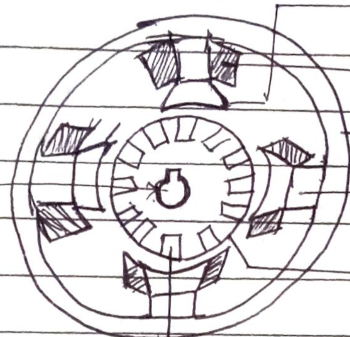
DC GENERATORS
MODULE - 4



Yoke :-

* It is the outermost cylindrical part.
* It acts as supporting frame
* It provides the path for magnetic flux.
* It is made up of cast iron, cast steel or forged steel.

POLES :-

* The pole cores are fixed inside the yoke
* By attaching pole shoe, the end of the pole is made to have a cylindrical surface.
* It is made up of cast steel or forged steel
* Each pole carries a field coil.

FIELD COILS :-

* The field coils are wound on pole cores. and are supported by pole shoes.
* All coils are identical
* They are connected in series. Such that on excitation by a dc source, alternate N and S Poles are made.

ROTOR :-

* The rotor is the inner cylindrical part having armature and commutator brush arrangement.
* It is mounted on the shaft.

ARMATURE :-

* Consists of steel laminations of 0.4 - 0.6mm thick insulated from one another.
* The purpose of lamination is to reduce the eddy current.
* The slots are stamped on the pheriphery of the laminations to accomodate the armature winding.
* The slots carry the armature winding.

COMMUTATOR :-

* It consists of a large number of wedge shaped copper segments or bars, assembled side by side to form a ring.
* Segments are insulated by Mica sheet
* Commutator is a part of the rotor.

BRUSHES :-

* Two stationary brushes, made of carbon are pressed against the commutator with the help of a spring fitted in a brush-gear

2. EMF equation for a DC generator :-

P = Number of poles

ϕ = magnetic flux per pole

Z = Total number of conductors.

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A = number of parallel path
N = rotational speed of rotor be N rpm.

Induced emf gets induced in the conductor according to Faraday's law of electromagnetic induction. Hence the average value of emf induced in each armature conductor is,

$$e = \text{rate of cutting the flux} = d\phi/dt$$

consider one revelotion of conductor. In one revolution, conductor will cut total flux produced by the poles. while time required to complete one revolution is 60/N seconds as speed is N rpm.

$$e = \frac{\phi P}{\frac{60}{N}} = \frac{\phi P N}{60}$$

The total Z conductors with A parallel path, hence Z/A number of conductors. are always in series.

$$E = \phi P \frac{N}{60} \times \frac{Z}{A} \text{ volts.}$$

$$\boxed{E = \frac{\phi PNZ}{60A}}$$

4. PRINCIPLE OF A DC MACHINE AS A GENERATOR :-

* Generator works on the principle of dynamically induced emf.
* It is based on the Faradays law of electromagnetic induction.

* The magnitude of induced emf in a conductor is propotional to the rate of change of flux associated with the conductor. The mathematical equation is,

$$e \propto \frac{d\phi}{dt}.$$

* So a generating action requires following basic components to exist (i) The conductor or a coil (ii) flux (iii) The relative motion between conductor and flux.

* The armature is rotated with the help of some external device. Such an external device is called prime mover. eg:- diesel engine, steam engine,
* The necessary magnetic flux is produced by current carrying winding which is called field winding.
* The direction of the induced emf is given by Flemming's right hand rule.
* $E = Bl(V \sin\theta)$ Volts

B = magnetic field density
l = length of the conductor
$V \sin\theta$ = component of velocity.

* The enduced emf is purely sinusoidal (ie) alternating
* To have dc voltage a device is used in a dc generators to convert the alternating emf to unidirectional emf. This device is called commutator.

5. TYPES OF DC GENERATORS:-

1) Permanent Magnet generators.
2) Seperately excited generator.
3) Self excited generator.

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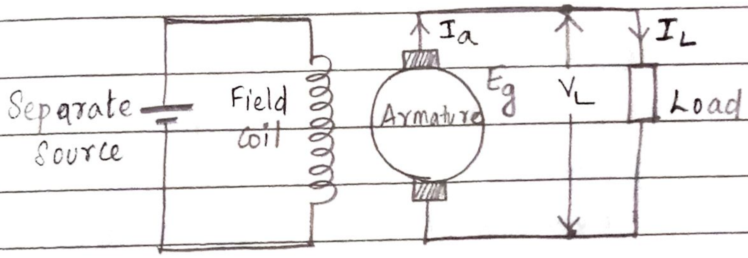
5. (i) permanent magnet generator:- Using a permanet magnet
(ii) Seperately excited generators:- Using some external source to excite the field coil.

(iii) Self-excited generators:- Using the armature supply to excite the field coils.

6. Seperately excited Generators:-



The field coils are excited from a storage battery or from a seperated dc source.

(i) $I_a = I_L = I$

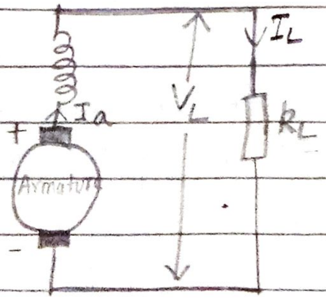
(ii) $V = E - I_a R_a$.

(iii) Power developed $= EI$

(iv) Power delivered $= VI$

7. What are the types of self-excited generators.

(a) Series-wound Generators.
(b) Shunt-wound Generators.
(c) Compound-wound Generators.
 (i) short-shunt compound generator
 (ii) long-shunt compound generator.



SERIES-WOUND.

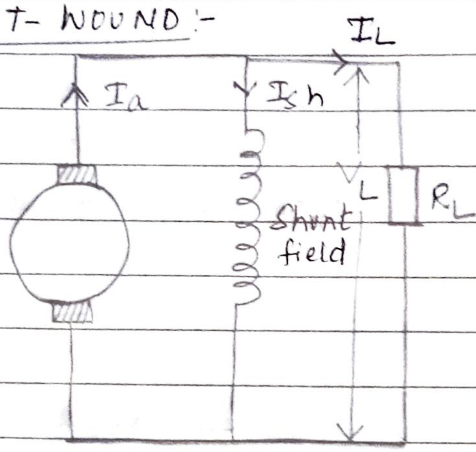
(i) $I_a = I_{se} = I_L = I$

(ii) $V = E - I(R_a + R_{se})$

(iii) Power developed $= EI$

(v) Power delivered $= VI$

SHUNT-WOUND :-



(i) $I_{sh} = V / R_{sh}$

(ii) $I_a = I_{sh} + I_L$

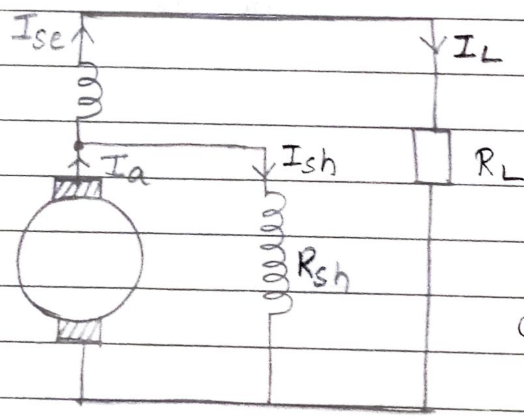
(iii) $V = E - I_a R_a$

(iv) Power developed $= E I_a$

(v) Power delivered $= V I_L$

COMPOUND WOUND :-

SHORT SHUNT COMPOUND WOUND :-



(i) $I_{se} = I_L$

(ii) $I_{sh} = (V + I_{se} R_{se}) / R_{sh}$

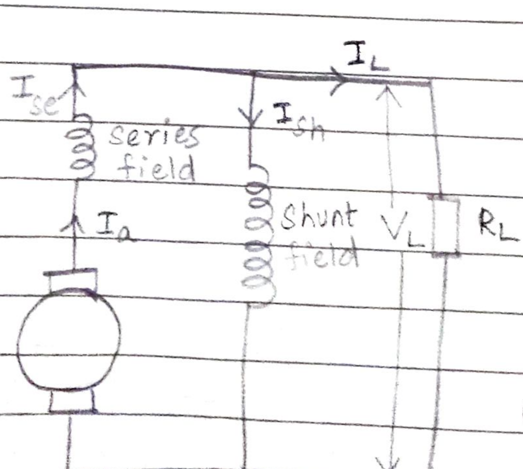
(iii) $I_a = I_{sh} + I_L$

(iv) $V = E - I_a R_a - I_{se} R_{se}$

(v) Power developed $= E I_a$

(vi) Power delivered $= V I_L$

LONG-SHUNT COMPOUND WOUND :-



(i) $I_a = I_{se} = I_{sh} + I_L$

(ii) $I_{sh} = V / R_{sh}$

(iii) $V = E - I_a R_a - I_a R_{se}$

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

(iv) Power developed $= E I_a$

(v) Power delivered $= V I_L$

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PROBLEM.

(1) A 4-pole generators with wave wound armature has 51 slots, each having 24 conductors, the flux per pole is 0.01 wb. At what speed must the armature rotate to give a induced emf of 220V. what will be the voltage developed if the winding is lap and armature rotates at same speed.

given :-

$P = 4$; (wave) $A = 2$

Slots = 51

Conductors/slot = 24

$Z = 51 \times 24 = 1224$

$E_g = 220V$

$\phi = 0.01$ wb/pole

$$E_g = \frac{P\phi ZN}{60A} = \frac{4 \times 0.01 \times 1224 \times N}{60 \times 2}$$

$N = 539.22$ rpm.

$N = 539.22$ rpm.

when winding is lap connected.

$$E_g = \frac{P\phi ZN}{60A} = \frac{4 \times 0.01 \times 1224 \times 539.22}{60 \times 4}$$

$E_g = 110$ V

(2) A 30kW, 300V DC shunt generator has armature and field resistance of 0.05 ohms and 100 ohms respectively. calculate the total power developed by armature when it delivers full output power.

$I_L = \frac{P_{out}}{V_t} = \frac{30 \times 10^3}{300} = 100A$

$I_{sh} = V_t / R_{sh} = \frac{300}{100} = 3A$

$I_a = I_L + I_{sh} = 103A$.

$E = V_t + I_a R_a$.

$= 300 + (103 \times 0.05)$

$= 305.15V$

Total power developed by the armature $= E I_a$

$= 305.15 \times 103$

$= 31.43 W.$

3) The emf generated in the armature of a shunt generator is 625V, when delivering its full load current of 400A to the external circuit. The field current is 6A and the armature resistance is 0.06Ω. what is the terminal voltage.

given :-

$E_g = 625V$

$I_L = 400A$

$I_{sh} = 6A$

$R_a = 0.06\Omega$

$I_a = I_L + I_{sh} = 400 + 6 = 406A$.

$V = E_g - I_a R_a$

$= 625 - (406 * 0.06) = 600.64V$.

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4) An 8 pole generator has a 500 armature conductor and has useful flux per pole of 0.065 wb. what will be the emf generated if it is lap connected and runs at 1000 rpm. what must be the speed at which it should be driven to produce the same emf if it is wave wound.

given data :-

$P = 8$

$Z = 500$

$\phi = 0.065$ wb.

$N = 1000$ rpm.

$$E_g = \frac{P\phi Z N}{60A} = \frac{8 \times 0.065 \times 500 \times 1000}{60 \times 8}$$

Lap winding $P = A = 8$

$$E_g = 541.67V$$

When wave connected, speed is,

$$N = \frac{60 A E_g}{\phi Z P} = \frac{60 \times 2 \times 541.67}{0.065 \times 500 \times 8} = 250 \text{ rpm.}$$

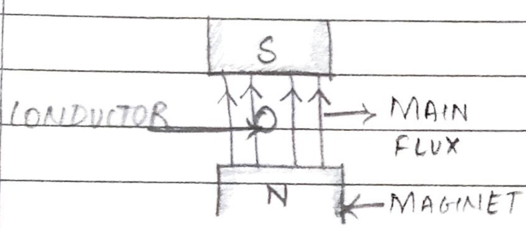
DC MOTOR.

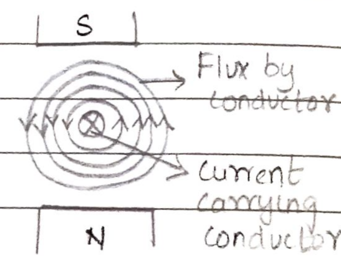
1. Principle of operation of dc Motor:-

* Principle :-

When a current carrying conductor is placed in a magnetic field it experiences a mechanical force.

* Consider a single conductor placed in a magnetic field.





* This conductor is excited by a separate supply so that it carries a current in a particular direction.

* The current carrying conductor produces its own magnetic field around it, hence this conductor also produces its own flux.

* direction of this flux is given by right hand thumb rule.

* Now there are two fluxes present.

1) The flux produced by the permanent magnet called main flux.

2) The flux produced by the current carrying conductor.

* Here on one side of the conductor, both the fluxes are in the same direction. There is gathering of fluxes.

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* On the other side the two fluxes are in the opposite direction. Hence there is cancellation of fluxes on the other side.
* This flux distribution exerts a mechanical force on the conductor
* Due to this, overall armature experiences a twisting force called torque and armature of the motor starts rotating.
* The magnitude of the force experienced by the conductor in a motor is given by

$$F = BIl \text{ Newtons}$$

B = Flux density due to the flux produced by the field winding

l = Active length of the conductor

I = Magnitude of the current passing through the conductor.

* The direction of such force (ie) the direction of rotating of a motor can be determined by Fleming's left hand rule.

2. What is back emf? explain the significance of a back emf.

In a dc motor, when motor starts rotating the armature conductors rotate in the flux produced by the field windings.

* Thus the armature conductors cut the flux and there is an induced emf in the rotating armature conductors according to Faraday's law of electro magnetic induction.
* According to the lenz law this induced emf in the armature always acts in the

Opposite direction to the cause producing it which is the supply voltage.

* This emf tries to set up a current through the armature which is in the opposite direction to that, which supply voltage is forcing through the conductor.

* So as this emf always opposes the supply voltage, it is called back emf and denoted as E_b. Though it is denoted as E_b, basically it gets generated by the generating action hence its magnitude can be determined by the emf equation as

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

Significance of back emf :-

* In case of a dc motor, supply voltage V has to overcome back emf E_b which is opposing V and also various drops as armature resistance drop $I_a R_a$, brush drop etc.

* Hence the voltage equation of a dc motor can be written as.

$$V = E_b + I_a R_a + \text{Brush drop}$$ and neglecting brush drop.

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

3. What is the power equation of DC motor?

* The voltage equation of a dc motor is given by

$$V = E_b + I_a R_a .$$

*multiplying both sides of the equation of a dc motor

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

VI_a = Net electrical power input to the armature measured in volts.

$I_a^2 R_a$ = Power loss due to the resistance of the armature called armature copper loss.

So the difference between VI_a and $I_a^2 R_a$ (ie) input - losses gives the output of armature.

* $E_b I_a$ is called the electrical equivalent of gross mechanical power developed by the armature. This is denoted by P_m.

* power input to armature - armature copper loss = Gross mechanical power developed in armature.

4. Torque equation of a DC motor:-

*The turning or twisting force about an axis is called torque.
* Consider a wheel of radius 'R' meters acted upon by a circumferential force newton.
* The wheel is rotating at a speed of N rpm. Then its angular speed is

$$\omega = \frac{2\pi N}{60} \text{ rad/sec}$$

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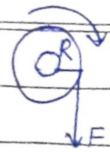


* So work done in one revolution is

W = F x distance travelled in one revolution

$= F \times 2\pi R$

* P = power developed = $\frac{\text{work done}}{\text{time}} = \frac{F \times 2\pi \times R}{\text{time for 1 rev}}$

$$= \frac{F \times 2\pi \times R}{\left(\frac{60}{N}\right)} = F \times R \times \left(\frac{2\pi N}{60}\right)$$

* $P = T \times \omega$

T = Torque in Nm

ω = Angular speed in rad/sec.

* T_a be the gross torque developed by the armature of the motor. It is called armature torque.

* The gross mechanical power developed in the armature is $E_b I_a$, as seen from the power equation

* So if speed of the motor is N rpm. then

Power in armature = armature torque $\times \omega$

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

* But E_b in a motor is given by $E_b = \frac{\phi P N Z}{60}$

$$\frac{P\phi Z N}{60} = T_a \times \frac{2\pi N}{60}$$

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

$$T_a = 0.159\ \phi I_a \frac{PZ}{A}\ Nm.$$

* This is the torque equation of dc motor.

5 Explain about the different types of torque in a dc motor.

a) * The Mechanical power developed in the armature is transmitted to the load through the shaft of the motor.

* It is impossible to trasmit the entire power developed by the armature to the load. This is because while transmitting the power through the shaft, there is a power loss due to friction, windage and the iron loss.

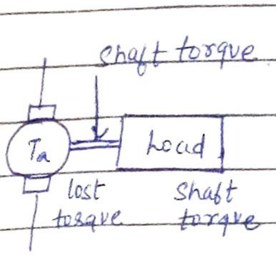
* The torque required to overcome these losses is called lost torque, denoted as T_f. These losses are also called stray losses.

* The torque which is available at the shaft for doing the useful work is known as load torque or shaft torque denoted as T_{sh}

$$T_a = T_f + T_{sh}$$

* The shaft torque magnitude is always than the armature torque ($T_{sh} < T_a$)

* The speed of the motor remain the same all along the shaft say N rpm. Then the



Product of shaft torque T_{sh} and the angular speed ω rad/sec is called power available at the shaft (ie) net output of the motor.

* The maximum power a motor can deliver to a load safety is called output rating of a motor. Generally it is expressed in HP. It is called HP rating of motor.

$$\text{Net output of motor} = P_{out} = T_{sh} \times \omega.$$

6. No load condition of a motor ? explain ?

* On no load, the load requirement is absent $T_{sh} = 0$.
* This does not mean that motor is at halt. The motor can rotate at a speed say N_0 rpm, on no load. The motor draws a armature current of I_{a0}

$$I_{a0} = \frac{V - E_{b0}}{R}$$

where E_{b0} is the back emf on no load, proportional to speed N_0.

* Now armature torque T_a for a motor is

$$T_a \propto \phi I_a.$$

* As flux is present and armature current is present hence T_{a0} (ie) armature torque exist on no load.

* Now, $T_a = T_f + T_{sh}$ but no load $T_{sh} = 0$

* So no load motor produces a torque T_{ao} which satisfies the friction, windage and iron losses of the motor.

Power developed ($E_{bo} \times I_{ao}$) = Friction, windage and Iron losses.

E_{bo} = Back emf on no load.

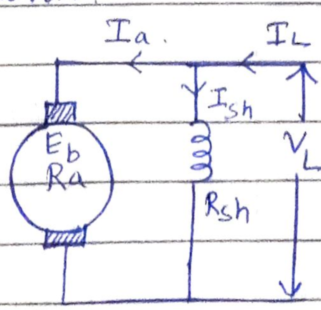
I_{ao} = Armature current drawn on no load.

The component of stray losses (ie) $E_{bo} I_{ao}$ is practically assumed to be constant through the load on the motor is changed from zero to the full capacity of the motor.

7. What are the different types of dc motor?

- DC motor
  - DC shunt motor
  - DC series motor
  - DC compound motor
    - long shunt motor
    - short shunt motor

DC shunt motor :-

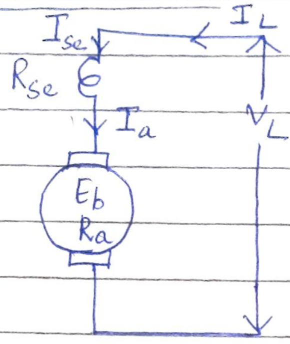


$$I_L = I_a + I_{sh}$$

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

$V = E_b + I_a R_a$

DC Series motor :-

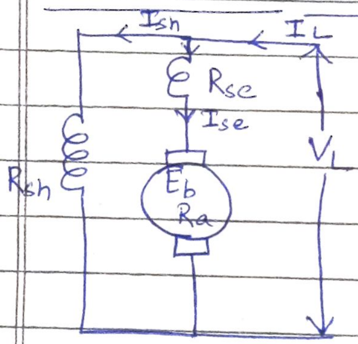


$I_a = I_{se} = I_L$

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

DC compound motor :-

Long shunt DC compound motor :-

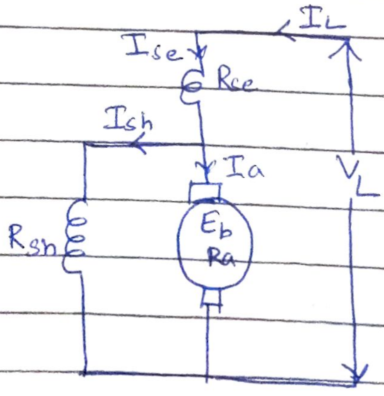


$I_L = I_a + I_{sh}$

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

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

Short shunt DC comopound motor :-



$I_L = I_{se}$

$I_L = I_{sh} + I_a$

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

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

$I_{sh} = \frac{V_L - I_L R_{se}}{R_{sh}}$

$I_{sh} = \frac{E_b + I_a R_a + V_{brush}}{R_{sh}}$

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8. Explain the speed and torque equations

* The torque is given by

$$T \propto \phi I_a$$

* $0.159\left(\frac{PZ}{A}\right)$ is constant for a given motor
* Now ϕ is the flux produced by the field winding and is proportional to the current passing through the field winding.

* $\phi \propto$ field

* For a dc shunt motor, I_{sh} is constant as long as supply voltage is constant. Hence flux ϕ is also constant.

* $T \propto I_a$ for shunt motor
* For a dc series motor, I_{se} is same as I_a. Hence flux ϕ is proportional to the armature current I_a.

$$T \propto I_a \phi \propto I_a^2$$

* Similarly as $E_b = \frac{P\phi NZ}{60A}$ we can write the

Speed equation.

$$E_b \propto \phi N$$

(ie) $N \propto \frac{E_b}{\phi}$

$$E_b = V - I_a R_a$$

* So far shunt motor as flux ϕ is constant

$$N \propto V - I_a R_a.$$

* While for series motor, flux ϕ is proportional to I_a

$$N \propto \frac{V - I_a R_a - I_a R_{se}}{I_a}.$$

9. Explain the characteristic of Dc motor.

The performance of dc motor under various conditions can be Judged under the following characteristic.

(i) Torque - Armature current characteristics (T Vs I_a)

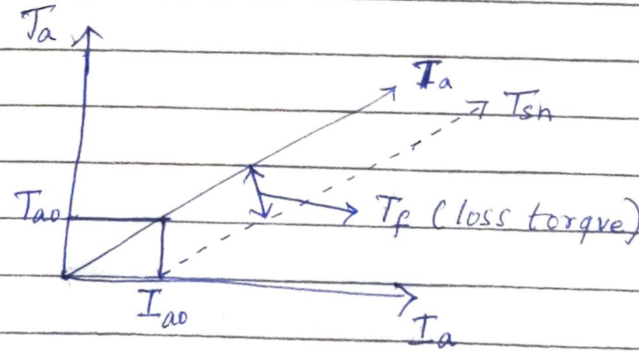
(ii) Speed- armature current characteristis (N Vs I_a)

(iii) Speed- Torque characteristic (N Vs T).

Characteristic of dc shunt motor :-

(i) Torque - armature current characteristics
For a constant values of R_{sh} and supply voltage V, I_{sh} is also constant, hence flux is also constant

$$T_a \propto I_a$$



* So as load increases, armature current increases, encreasingly the torque developed linearly.

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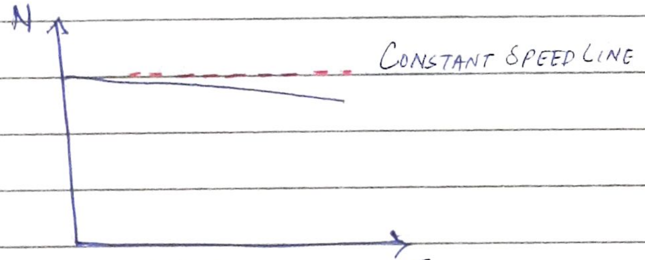
Speed- armature current characteristics :-

* From the speed equation we get .

$$N \propto V - I_a R_a$$

* 'Ra' is very small, hence Ia Ra drop is small, hence drop in speed is also not significant .
* This makes these motors as constant-speed motors



N Vs Ia

Speed-torque characteristics :-

* The characteristic is similar to speed-armature current characteristics as torque is proportional to the armature current .
* The curve shows that the speed

characteristic of dc Series motor :-

Torque - armature current characteristics :-

* For the series motor the series field winding is carrying the entire armature current .

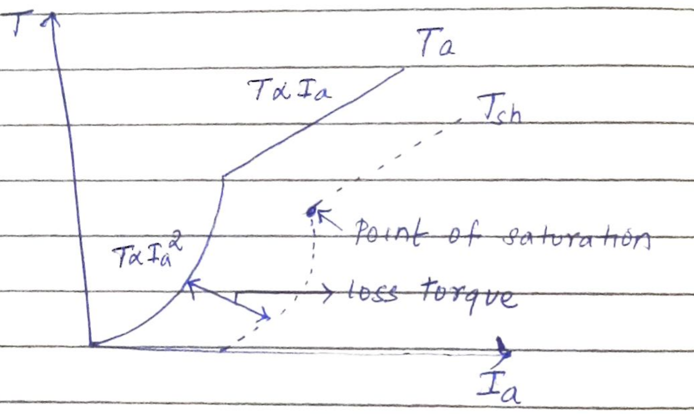
$$T \propto \phi I_a .$$

$$T \propto I_a^2$$

* The speed equation reduces to .

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

* As load increases, the armature current increases and the torque produced increases proportional to the square of the armature current upto a certain limit.
* As the entire I_a passed through the series field there is a property of an electromagnet called saturation, may occur.
* Saturation means though the current through the winding increases, the flux produced remains constant. Hence after saturation the characteristics takes the shape of straight line as flux becomes constant.



(ii) Speed - armature current characteristics :-

* From the speed equation we get,

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a - I_a R_{se}}{I_a}$$

as $\phi \propto I_a$ in case of series motor.

* The value of R_a and R_{se} are so small that the effect of change in I_a on speed over rides the effect of change in $V - I_a R_a - I_a R_{se}$ on the speed.

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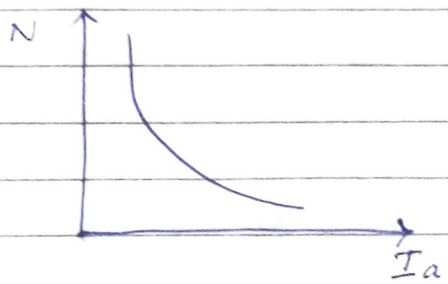
* Hence the speed equation, $E_b \simeq V$ and can be assumed constant

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

* So speed - armature current characteristics is rectangular hyperbola type



(iii) Speed - Torque characteristics :-

* In case of series motor

$$T \propto I_a^2$$

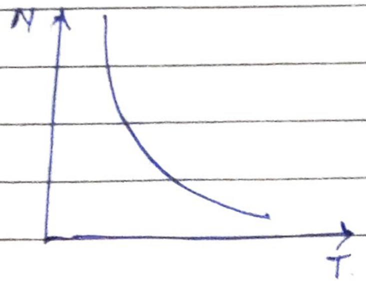
$$N \propto \frac{1}{I_a}$$

* Hence we write,

$$N \propto \frac{1}{\sqrt{T}}$$

* Thus a torque increases when load increases, the speed decreases.

* On no-load, torque is very less and hence speed increases to dangerously high value.



10. Explain why series motor is never started on no-load.

* It is seen earlier that motor armature current is decided by the load
* on high load or no load, the armature current drawn by the motor is very small.
* In case of a dc series motor, $\phi \alpha I_a$ and on no load as I_a is small hence flux produced is also very small.
* According to speed equation, $N \alpha \frac{1}{\phi}$ as E_b is almost constant.
* So on very light load or no load as flux is very small, the motor tries to run at dangerously high speed which may damage the motor mechanically.
* This can be seen from the speed-armature current and the speed torque characteristic that on low armature current and low torque condition motor shows a tendency to rotate with dangerously high speed.
* This is the reason why series motor should never be started on light loads or no load conditions.

11. Application of DC motor :-

Type of motor	characteristics	Application
Shunt motor	* speed is fairly constant * Medium starting torque	1) Blower + fan 2) centrifugal and reciprocating Pump 3) Lathe machine 4) Machine tools 5) Milling machine 6) Drilling machine

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Type of Motor	Characteristics	Application
series	* High starting torque * No-load condition is dangerous. * variable speed	* cranes * Hoists, Elevators * Trolleys * conveyors. * Electric locomotives.
Commulative Commpound	* High starting torque * No-load condition is allowed	* Elevators * Rolling mills * Punches * shears * Heavy Planers
Differential compound	* speed increases as load increases	Not suitable for practical application

PROBLEMS.

1 A 4 pole DC shunt motor takes 22.5A from 250V supply $R_a = 0.5\Omega$, $R_{sh} = 125\Omega$ and the armature is wave wound with 300 conductors. If the flux per pole is 0.02wb, calculated the speed, torque and power developed.

given data

$P = 4$

$I_L = 22.5A$

$V = 250V$

$R_a = 0.5\Omega$

$R_{sh} = 125\Omega$

Wave wound, $A = 2$

$Z = 300$

$\phi/\text{pole} = 0.02wb$.

$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2A$

$I_a = I_L - I_{sh} = 22.5 - 2 = 20.5A$

$E_b = V - I_a R_a = 250 - (20.5 * 0.5)$

$= 239.75V$

$E_b = \frac{P\phi Z N}{60A}$ where $Z = 300$ $A = 2$ $\phi = 0.02Wb$

$239.75 = \frac{4 \times 0.02 \times 300 \times N}{60 \times 2}$

$N = \frac{239.75 \times 60 \times 2}{4 \times 0.02 \times 300}$

$N = 1199$ rpm

Torque $T = 0.159 \phi I_a \frac{PZ}{A}$

$T = 39.114$ N/m

Power developed $= P = E_b I_a = 02 \times 20.5$

$P = 4.9$ kW.

2\. A 200V, 4 pole lap wound DC shunt motor has 800 conductors on its armature, the resistance of the armature winding is 0.5 ohms and that of field winding is 200Ω the motor takes a current of 21A, the flux per pole is 30mwb. Find the speed and torque developed by motor.

given data:-

$V = 200V$

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$P = 4$

Lap wound $A = P = 4$

$Z = 800$

$R_a = 0.5\Omega$

$R_f = 200\Omega$

$I_L = 21A$

ϕ/pole $= 30$ mWb $= 30 \times 10^{-3}$ wb.

$I_{sh} = V/R_{SH} = 200/200 = 1A$

$I_a = I_L - I_{sh} = 21 - 1 = 20A$

$E_b = V - I_a R_a = 200 - (20 * 0.5) = 190V$

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

$$190 = \frac{30 \times 10^{-3} \times 800 \times N \times 4}{60 \times 4}$$

$$N = \frac{190 \times 60 \times 4}{30 \times 10^{-3} \times 800}$$

$N = 475$ rpm.

Torque $T = 0.159 \, \phi I_a \frac{PZ}{A}$

$$= 0.159 \times 30 \times 10^{-3} \times 20 \times \frac{4 \times 800}{4}.$$

$T = 76.32$ Nm.

3. A DC shunt motor takes an armature current of 110A at 480V. The armature resistance is 0.2Ω. The machine has 6 poles and armature is lap connected with 864 conductors. The flux per pole is 0.05wb. Calculate the speed and torque developed by the armature.

given data :-

$I_a = 110 A$

$V = 480 V$

$R_a = 0.2 \Omega$

$P = 6$

lap winding, $A = P = 6$

$Z = 864$

ϕ/pole = 0.05 wb

$E_b = V - I_a R_a$

$= 480 - (110 \times 0.2) = 458 V$

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

$$458 = \frac{0.05 \times 864 \times N \times 6}{60 \times 6}$$

$$N = \frac{458 \times 60 \times 6}{0.05 \times 864 \times 6} = 636 \text{ rpm}.$$

$$T = 0.159 \times \phi I_a \times \frac{PZ}{A}$$

$$= 0.159 \times 0.05 \times 110 \times \frac{6 \times 864}{6}$$

$T = 755.5 \text{ Nm}$

4. 220V Series motor is taking a current of 40A, resistance of armature 0.5Ω, resistance of series field is 0.25Ω. calculate the voltage at the brushes, Back emf, Power wasted in armature and power wasted in series field.

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Voltage at brushes $= V - I_a R_{se}$

$= 220 - (40 \times 0.25) = 210V$

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

$= 220 - (40 (0.5 + 0.25)) = 190V$

Power wasted in armature $= I_a^2 R_a$

$= 40 \times 40 \times 0.5 = 800W$.

Power wasted in Field $= I_a^2 R_{se}$

$= 40 \times 40 \times 0.25 = 400W$.