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Dc Motor:

Principle of operation:-

A machine that converts electrical energy into mechanical energy is known as motor.

Its operation is based on the principle that when a current current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.

The magnitude of the force is given by

$$F = BIL \text{ newtons.}$$

Where $B \rightarrow$ magnetic flux density wb/m²

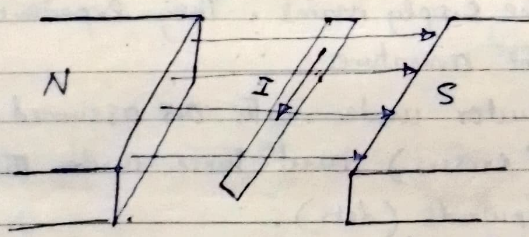
$I \rightarrow$ current carried by the conductor

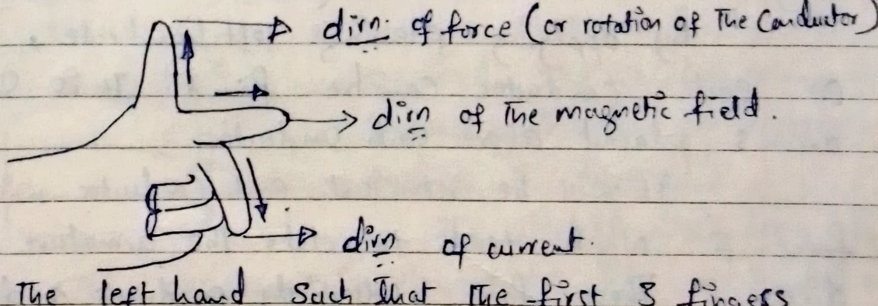
$L \rightarrow$ length of the conductor lying in the magnetic field.

The dir of the force is given by Fleming's left hand rule.

—— ☆ ——

Fleming's left handrule:-





Strech the left hand such that the first 3 fingers (i.e Thumb, fore finger & middle finger) are mutually ⊥ar to each other then thumb points the dirn of force (or rotation of the conductor), the fore finger points dirn of the magnetic field and the middle finger points the dirn of current.

Apply FLH rule to this fig, it is clear that the force acting on the conductor vertically upwards.

[illegible]

— A —

How the armature rotates?

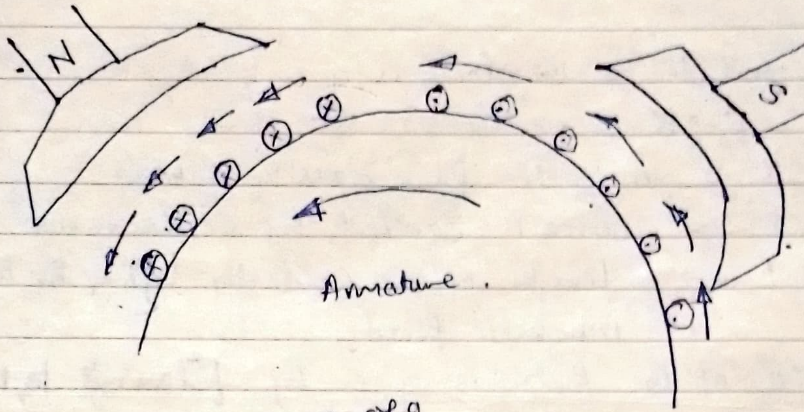


Fig shows a part of a multipolar dc motor. When its field magnet are excited and its armature conductors are supplied with currents from the supply mains, they experiences a force tending to rotate the armature.

Armature conductor under north are assumed to carry current downwards (crosses) and those under the south pole carry the current upwards (dots).

By applying Fleming's left hand rule, the dirn. of force on each conductor can be found. It is shown by small arrows placed above each conductor.

It will be seen that each conductor will experiences a force F which tends to rotate the armature in the anticlockwise dirn. These force collectively produces a driving torque which sets the armature rotating.

When the conductor under the south pole will carry the current upwards due to the rotation of the armature that conductor comes under influence of north pole at that instant the current in that conductor reverses its dirn from upwards to down ward and the dirn of force on the conductor remains the same.

— A —

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Back emf or counter Emf :-

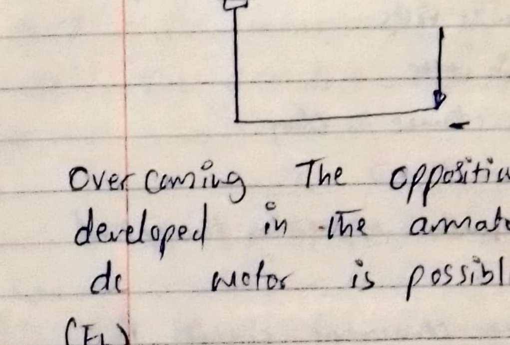
As soon as the supply is given to the dc motor, the armature of the motor starts rotating. The rotating armature cuts the magnetic flux produced by the poles, an emf will be induced in the armature conductor according to Faraday's laws of electromagnetic induction. The induced emf in the conductor acts against to the applied voltage V (in accordance with the lenz's law) and hence it is known as back or counter emf (E_b)

Since the back emf generated in the armature, the expression for back emf is same as that of expression for generated emf in a generator

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

The back emf is always less than the applied voltage (V). although this difference is very small when the motor running under normal condition.

Significance of back emf :-



As the armature rotates back emf (E_b) opposes the applied voltage as shown in fig. The applied voltage has to force the current through the armature against the back emf.

The electric work done in overcoming the opposition is converted into mechanical energy developed in the armature. So the energy conversion in a dc motor is possible due to the production of back emf (E_b).

∴ net voltage a/c the armature circuit = $V - E_b$

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

Since V and R_a are usually (Constant) fixed, the value of E_b determine the current drawn by the motor.

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

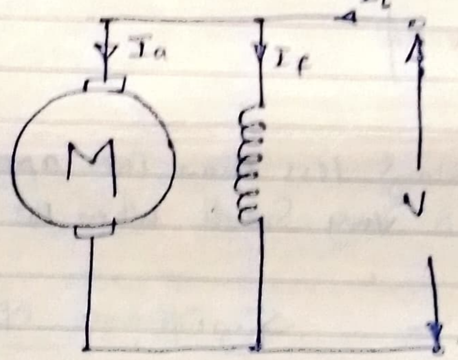
$$E_b \propto \phi N$$

If speed is high, E_b is max and the motor will draw less armature current.

If speed is low, E_b is small and the motor will draw large armature current. [illegible] presence of [illegible] which develops more torque. Hence the presence of back emf makes the dc motor a self regulating mc.

— A —

Voltage equation of a motor.



The voltage V applied across the motor [illegible] the back emf [illegible]

Consider a dc shunt motor as shown in fig.

let V = applied voltage in volts

E_b = back emf in volts

R_a = armature resistance in Ohm

I_a = armature current.

Since back emf (E_b) acts in opposition to applied voltage (V).

The net voltage a/c the armature circuit is $(V - E_b)$

The armature current I_a is given by

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

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Or $\boxed{V = E_b + I_a R_a}$ → (1)

Eq(1) is known as the voltage eqn of the motor

If the brush drop is considered then the voltage eqn becomes

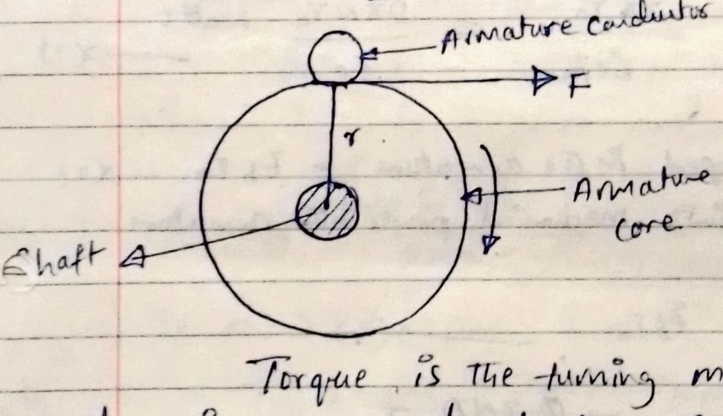
$$\boxed{V = E_b + I_a R_a + B.D}$$

$\times^{ly}$ eq(1) by I_a on both side

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

Where $V I_a$ → electrical I/P to the armature in watts
$E_b I_a$ → power developed in the armature in watts
$I_a^2 R_a$ → Armature cu loss.

Torque of a DC Motor.



Torque is the turning moment of a force about an axis and is measured by the product of force and radius of the armature at right angles to which the force acts.

$$T = F \times r \quad N\text{-}m.$$

In a dc motor, each conductor is acted upon by a circumferential force F at a distance 'r'. The radius of the armature. Hence each conductor exerts a torque, tending to rotate the armature. The sum of the torque, due to all armature conductors is known as gross torque (or armature torque)

Expression for torque of a dc motor:-

let

$Z \rightarrow$ no. of conductors on the armature
$P \rightarrow$ no of pole
$\phi \rightarrow$ flux/pole in wb
$N \rightarrow$ Speed in rpm
$A \rightarrow$ no of parallel path
$I_a \rightarrow$ armature current
$r \rightarrow$ radius of the armature in m
$T_a \rightarrow$ Armature torque N-M

Work done in one revolution of the armature

$= \text{Force} \times \text{distance travelled.}$

$= F \, 2\pi r$ joules.

$= (F \times r) \, 2\pi$

$= 2\pi T_a$

$\therefore$ power developed in the armature.

$$= \frac{\text{Work done}}{\text{time taken}} \text{ in watts.}$$

$$= \frac{2\pi T_a}{60/N} = \frac{2\pi N T_a}{60} \text{ watts} \longrightarrow (1)$$

We also have,

Power developed in the armature $= E_b I_a \longrightarrow (2)$

The Electrical power converted into mechanical power in the armature.

$(1) = (2)$

$$\frac{2\pi N T_a}{60} = E_b I_a \longrightarrow (3)$$

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

Newton meter

$$T_a = \left(\frac{PZ}{2\pi A}\right) \phi I_a, \ N\text{-m}$$

$$T_a = \frac{0.159 ZP}{A} \phi I_a \quad N\text{-m}$$

$$T_a = \left(\frac{0.159}{9.81}\right) \phi Z I_a \left(\frac{P}{A}\right) = 0.0162 \, \phi Z I_a \left(\frac{P}{A}\right) \text{kg-m}$$

Also in (3)

$$T_a = \frac{E_b I_a}{\left(\frac{2\pi N}{60}\right)} = 9.55 \left(\frac{E_b I_a}{N}\right) \ N\text{-M.}$$

Shaft torque:

The net torque which is available at the shaft the some part of it is lost for doing usefull work is known as shaft torque.

All the torque developed in the armature is not available at the shaft as some part of it is lost for compensating mechanical losses.

Hence the difference of T_a and T_{lost} is available at the shaft.

Hence, $T_{sh} = T_a - T_{lost}$.

Types ~~of~~

$$\text{Out put} = T_{sh} \times 2\pi N \text{ watts}$$

Where T_{sh} is in N-m and N is in rps.

$$\therefore T_{sh} = \frac{\text{o/p in watts}}{2\pi N} \text{ N-m}$$

If N is in rpm then

$$T_{sh} = \frac{\text{o/p in watts}}{\frac{2\pi N}{60}} \text{ N-m}$$

$$= \left(\frac{60}{2\pi}\right) \frac{\text{o/p in watts}}{N} \text{ N-m}$$

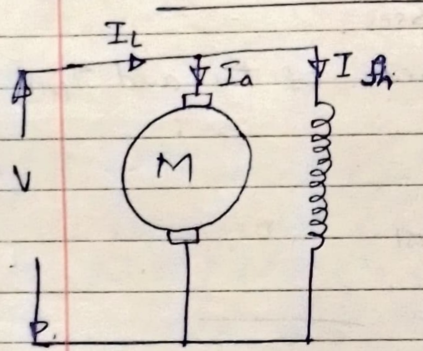
$$T_{sh} = 9.55 \frac{\text{o/p in watts}}{N} \text{ N-m}$$

Type of DC Motor:-

Similar to generator, The dc motor also classified into 3 types

(1) Shunt wound
(2) Series wound
(3) Compound wound.

(i) Shunt wound:-

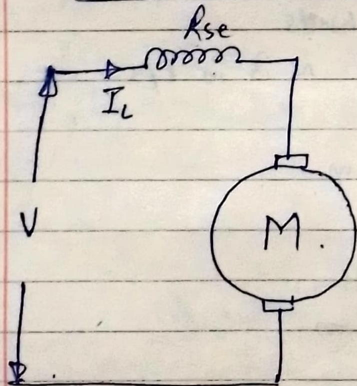


$E_b = V - I_a R_a$.

$I_a = I_L - I_{sh}$

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

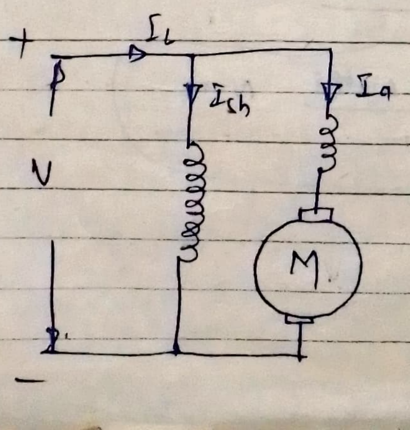
(ii) Series wound motor:-



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

$I_L = I_{se} = I_a$.

(iii) Compound motor:-



$E_b = V - I_a R_a - I_a R_{se}$

$I_a = I_L - I_{sh}$.

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

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Speed of a Dc motor:-

From the voltage equation of a motor we get

$E_b = V - I_a R_a$

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

$\frac{\phi Z N P}{60 A} = V - I_a R_a$

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

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

$\therefore N = K\left(\frac{E_b}{\phi}\right)$

It shows that speed is directly proportional to the back emf E_b and inversly proportional to the flux.

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

For series motor:-

let N_1, I_{a_1}, ϕ_1 be the speed, armature current, and flux/pole in the first case.

let N_2, I_{a_2}, ϕ_2 be the speed, armature current and flux/pole in the second case.

Then using the above relation we get

$N_1 \propto \frac{E_{b_1}}{\phi_1}$ → (1) where $E_{b_1} = V_a - I_{a_1} R_a$

Also $N_2 \propto \frac{E_{b_2}}{\phi_2}$ → (2) where $E_{b_2} = V - I_{a_2} R_a$

Sulekha

$\therefore$ (2/1) $\therefore \boxed{\dfrac{N_2}{N_1} = \dfrac{E_{b_2}}{E_{b_1}} \times \dfrac{\phi_1}{\phi_2}} \longrightarrow (A)$

Before Saturation of the magnetic poles

$\phi \propto I_a$.

$$\therefore \boxed{\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{I_{a_1}}{I_{a_2}}}$$

(ii) <u>For Shunt motor:</u>

In this case the Same equation applies

i.e (A) $\Rightarrow \dfrac{N_2}{N_1} = \dfrac{E_{b_2}}{E_{b_1}} \times \dfrac{\phi_1}{\phi_2}$

For Shunt motor flux practically remains Constant So that $\phi_1 = \phi_2$.

$$\therefore \boxed{\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}}}$$

<u>Dc Motor charecteristics:-</u>

The performance charecteristics of all types of Dc motor are listed below.

(i) <u>Torque v/s armature current charecteristics:-</u>

(T_a v/s I_a)

It is a plot b/w armature torque v/s armature current. It is also known as the electrical char.

(ii) <u>Speed and armature current I_a</u> i.e (N v/s I_a)

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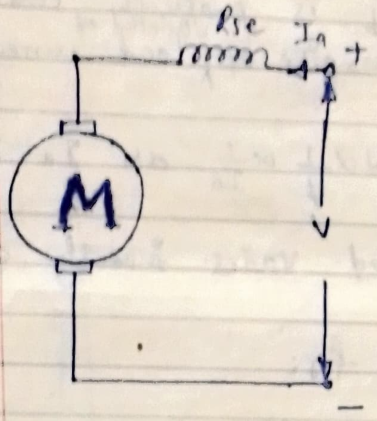
(iii). Speed v/s torque charecteristics :-

N v/s T_a

It is also known as a mechanical char.

(B) Charecteristics of Series motor :-

(i) Armature torque v/s armature current (T_a v/s I_a)
or electrical char.



For Series motor,

$T \propto \phi I_a$

Since $\phi \propto I_a$ before saturation

$\therefore \boxed{T \propto I_a^2}$

Therefore, as I_a increases, T_a increases as square of I_a.

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

Thus upto saturation the torque is proportional to square of the armature current. Thus T_a v/s I_a curve is upto magnetic saturation is a parabola. i.e curve as shown in fig.

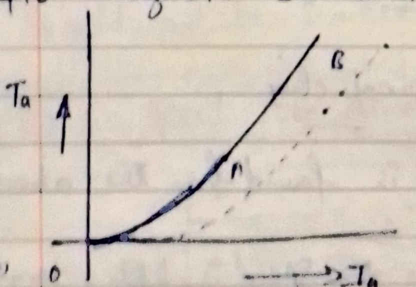


fig (a)

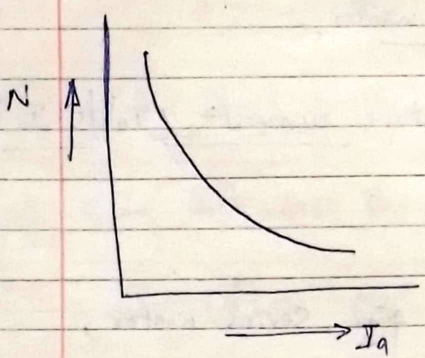
However after magnetic saturation, the torque is directly proportional to the armature current.
$\therefore$ T_a v/s I_a is almost a straight line (curve AB)

The shaft torque T_{sh} is less than the armature torque because of stray losses, a dotted 6 curve depicting it in fig (a).

Hence at ~~[struck out]~~ heavy load, the torque of a dc series motor will be very high before magnetic saturation.

∴ The Series motor are used in the application to accelerate heavy masses quickly i.e in case of electric locomotives, Cranes & hoists, conveyors, etc.

⇒ **Speed v/s Armature current char:** (N v/s I_a)



We have

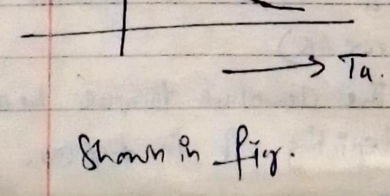
$$N \propto \frac{E_b}{\phi}$$

Since the drop in armature and series field is small, E_b is pratically constant inspite of variation of load current.

Hence $N \propto \frac{1}{\phi} \propto \frac{1}{I_a}$ as I_a increases ϕ also increases, Hence speed varies inversly as armature current as shown in fig.

When load is heavy, I_a is large, hence speed is low. When the load is very small, I_a is small & ϕ is also small and hence speed becomes dangerously high. Hence series motor should never be started without some mechanical load on it, otherwise ~~it may~~ it may develop excessive speed and get damaged due to heavy centrifugal forces so produced.

3) **N v/s Ta or mechanical char**



It is found from the above char

When the speed is high, torque is low and vice versa.

and the relation b/w the two as shown in fig.

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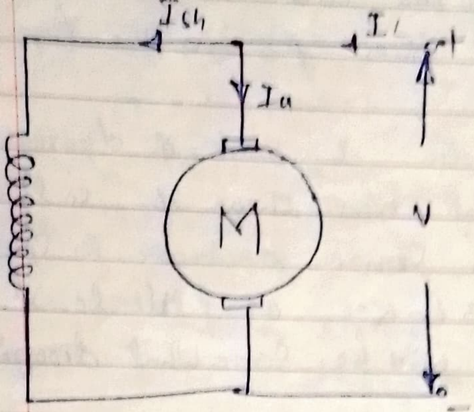
Char of Shunt motors.



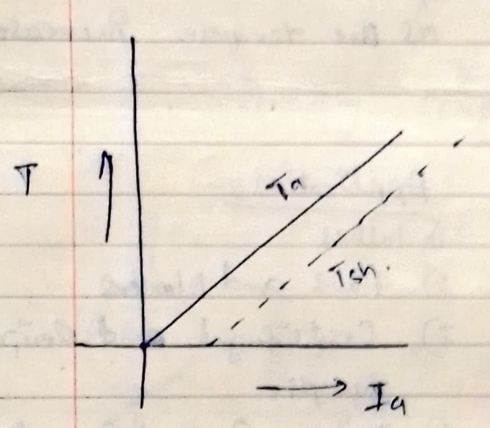
From fig.

$I_L = I_a + I_{sh}$

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

So the field current is constant, and hence the flux in a Shunt motor is practically constant.

(i) Ta v/s Ia char:



For a dc motor we have,

$T_a \propto \phi I_a$

Since flux is constant for Shunt motor

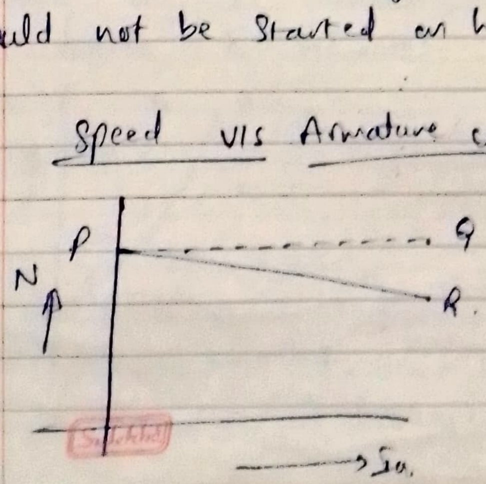
$T_a \propto I_a$.

Hence Ta v/s Ia char is a st. line passing through the origin as shown in fig.

and the Shaft torque which is less than the armature torque and is as shown in the fig.

It is clear from the fig that, a larger armature current is required to start a heavy load. Hence Shunt motors should not be started on heavy load.

(ii) Speed v/s Armature current char.



For dc motor we have

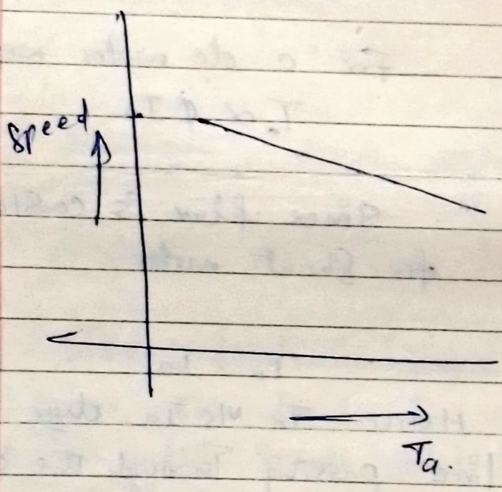
$N \propto \frac{E_b}{\phi}$

The flux ϕ and back emf E_b is almost Constant in a Shunt motor under normal load condition.

Therefore the speed of the Shunt motor ~~is almost~~ will remains Constant as the armature current varies. and is shown by dotted lines AB in the fig.

At large (or heavy) loads, both E_b and ϕ decreases, but E_b decreases somewhat more than ϕ, so that all considered, there is some decrease in speed, The drop ranging from 5 to 15% of full load. Thus actual speed curve will be somewhat drooping as shown by line AC.

3) N/Ta char.



This curve is obtained by plotting N V/S Ta for various armature currents. It may be seen that speed falls somewhat as the torque increases

Application:-
1) lathes
2) Fans and Blowers.
3) Centrifugal and Reciprocating pumps.
4) Driving Constant Speed line Shafting.

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