For a long shunt compound motor,

$$V_t = E_a + I_a(r_a + r_{se}).$$

and $E_a = K_a \phi \omega_m$

$$= K_a(\phi_{sh} + \phi_{se})\,\omega_m$$

$$\therefore \quad \omega_m = \frac{1}{K_a(\phi_{sh} + \phi_{se})} \times \left[V_t - I_a(r_a + r_{se})\right]$$

With increase of $I_a$, $\phi_{se}$ increases. So, denominator increases, but numerator decrease of speed eqn.. Thus, with increase in $I_a$, the speed drops at a faster rate in cumulatively compounded motor than in a shunt motor.

Now, $T \propto \phi I_a$

$$\propto (\phi_{sh} + \phi_{se}) I_a.$$

With increase in $I_a$, $\phi_{se}$ increases and the torque increases.

**Applications:-** Cumulatively compounded motors, with relatively large series m.m.f. are used for heavy machine tools and in other applications where the starting torque requirements are not ~~unduely~~ unduly high and where the no load speed must be kept at a definite and safe value. They are used in conjunction with fly wheels, for driving intermittent loads like shears, punches, presses etc..

**Speed control of d.c. motors:-**

It is known that, the speed is given by,

$$N = \frac{K(V - I_a R_a)}{\phi}$$

So, the speed can be controlled by varying —

(i) resistance $R_a$ of armature circuit

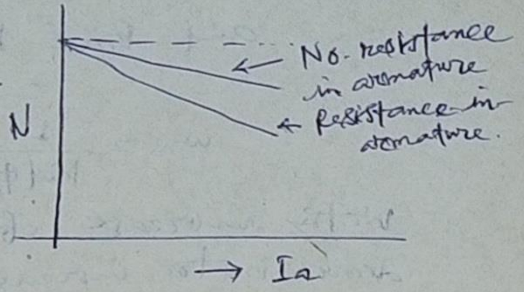
(ii) the field flux

(iii) the applied voltage.

(i) **Armature resistance control:-** In this method, a resistance R is provided in series with the armature of the motor, the field circuit is applied with normal voltage. Due to the voltage drop in the resistance R when the armature current flows through it, the applied voltage across the armature is decreased and hence, the speed decreases.

Let, $N_1$ = Speed of the motor without any external series resistance.

$N_2$ = Speed with external resistance R.




$$\therefore N_1 \propto \frac{V - I_a R_a}{\phi}$$

$$N_2 \propto \frac{V - I_a(R_a + R)}{\phi}$$

$$\therefore \frac{N_2}{N_1} = \frac{V - I_a(R_a + R)}{V - I_a R_a}$$

The efficiency of motor is reduced, as there is always certain losses taking place in the series resistance. In this method-

(a) the speed regulation is very poor and

(b) the series resistance R must have sufficient current rating to take-up the rated and even overload currents of the motor, thus making it bulky and expensive.

In this method, the torque is constant, hence HP is proportional to the speed. This type is applied in cement kilns, conveyors, textile and printing machines, gear pumps, hoad lifts etc..

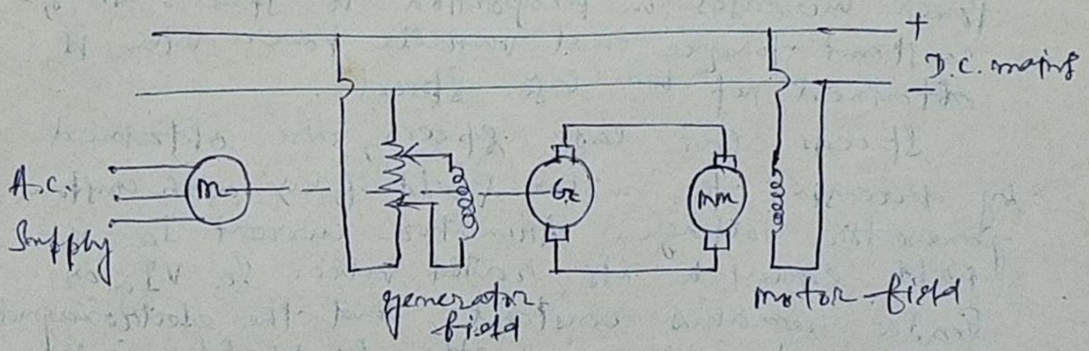
(ii) Field Control:- For shunt and compound motors, a variable resistance is placed in series with the shunt field and the field is weakened by increasing the resistance, resulting in increase of speed. Since, torque is proportional to flux per pole, any increase in speed, due to reduction in the field flux, automatically results in a decrease in torque, in fact, the increase in speed is completely balanced by the decrease in torque and the power developed by the armature remains constant. This type of control results in constant H.P., typical applications of this are in machine tools and winding machines.

In series machines, the field can be weakened by connecting a variable low resistance, called diverter, in parallel with the field. As in the case of shunt motors, here also the field control increases the speed of operation only at the expense of torque.

For both shunt and series motor control, the counter e.m.f. $E_a$ remains substantially constant, because a decrease in field flux is compensated by a corresponding increase in speed. If the armature current $I_a$ is kept equal to the motor rated current for its full utility, the power output $E_a I_a$ remains approximately constant and for this reason field flux speed control method may be called a constant power drive method.

(iii) <u>Voltage control method</u>:- In this method, the shunt field of the motor is connected permanently to a fixed exciting voltage, but the armature is supplied with different voltages. The armature speed will be approximately proportional to these different voltages.

<u>Ward Leonard System</u>:-




M—G — Motor driven generator set

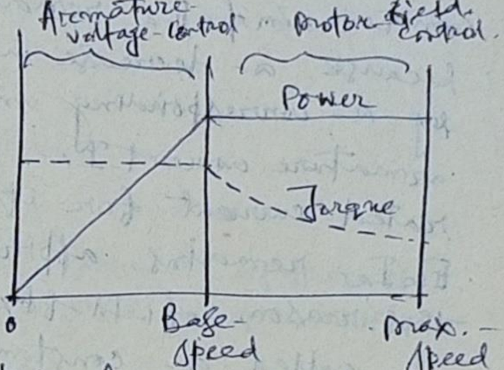
M—M — Main motor

MM → Separately excited d.c motor

G → Separately excited generator driven by a three phase driving motor.

By controlling the field of the generator, the desired voltage across the main motor terminals is obtained. The main motor field is supplied with full voltage independently of the armature. The generator field is fed from a potential divider so that the field current and hence, the terminal voltage of the generator can be varied from +V to −V, thus making the speed of the main motor to be controlled in either direction of rotation.

In order to achieve wider speed control range, speeds below base speeds are obtained by voltage control and above the base speed, by field flux control. For better utility of motor m-m, its current $I_a$ is maintained equal to its rated current during its speed control.




Up to base speed, speeds are obtained by increasing the generator out put voltage, with constant motor field flux. Since, the speed control is carried out with rated current $I_a$ and with constant motor field flux $\phi$ a constant torque up to base speed is obtained. Power increases in proportion to speed. Thus, constant torque and variable power drive is obtained up to base speed.

Speeds above base speed, are obtained by decreasing the motor field flux with constant generator voltage. Armature current $I_a$ is kept equal to its rated value. So, $VI_a$ or $E_aI_a$ remains constant and the electromagnetic torque decreases as the field flux is decreased. Thus, weakening in motor field flux results in constant power and variable torque drive above base speed.

Advantages of Ward-Leonard system:—

(a) The main advantage is its simplicity, wide range and smooth speed control.

(b) Speed regulation is quite good.

(c) The direction of main motor rotation can be changed by reversing the generator field current.

(d) Speed control is carried out by the field circuits of generator and motor. Since, these field circuits are low power circuits, the control apparatus is not costly.

(e) The efficiency at low speeds is higher than that obtained by other methods of speed control.

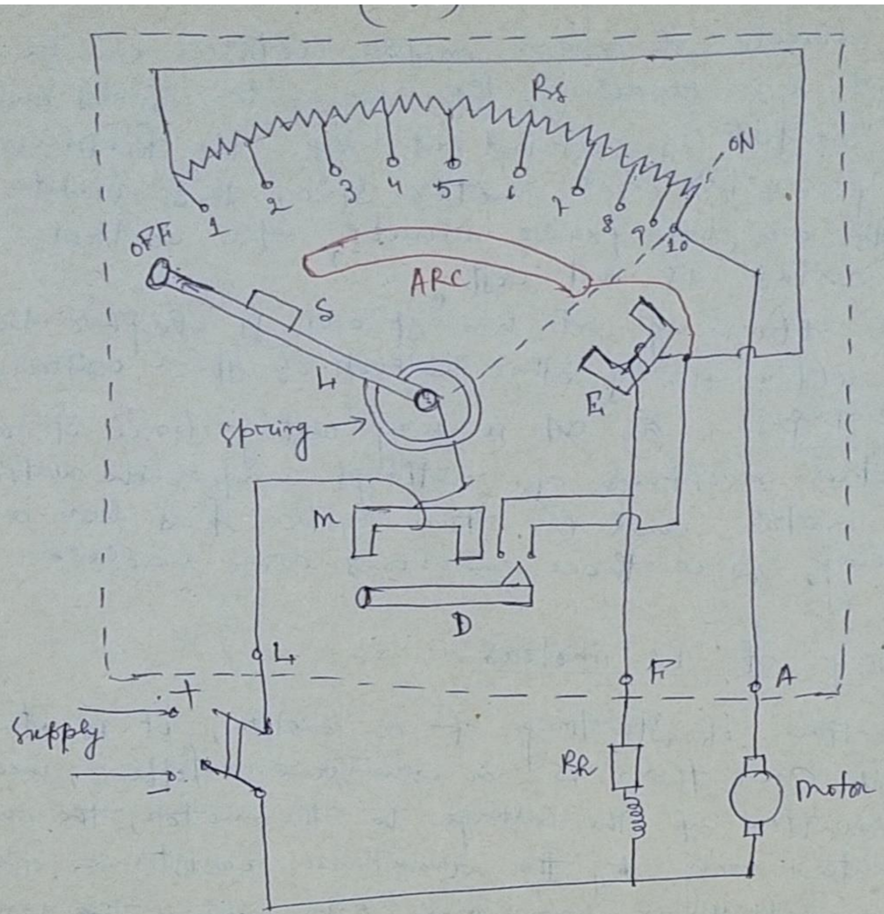
Disadvantages:- (a) It is very costly since it requires two extra machines of ratings comparable with the main motor and (b) the system has low overall efficiency, since three machines are involved.

## Starting of d.c. motors:-

At the time of starting of a motor, it is at standstill and there is no counter e.m.f. Hence, immediately on application of the voltage to the motor, the current is limited only by the armature resistance. The current will start decreasing only after the counter e.m.f. is built up i.e., only after the machine picks up speed. So, it becomes necessary to limit the current, by connecting a resistance, in series with the armature, till such time as the back e.m.f. is developed. This is done by provision of a starter, which consists, essentially, of a set of resistances connected in series with the armature, that are cut out one by one, as the motor picks up speed. Finally, all the resistances are cut out and full voltage is impressed on the motor armature.

Three point starter:- A three point starter is normally used for shunt motors. Since, it contains three terminals L, A and F, it is called a three point starter.

To start the motor, the main switch is first closed and then the starting arm is slowly moved to the right. When the arm makes contact with stud No-1, the field




circuit is directly connected across the line and at the same time full starting resistance Rs is placed in series with the armature. The starting current drawn by the armature $= \frac{V}{(R_a + R_s)}$, where Rs is the starting resistance. As the arm is further moved, the starting resistance is gradually cut out and when the arm reaches the running position, the resistance is fully cut-out. The arm moves over the various studs against a strong spring, which tends to restore it to OFF position. There is a soft iron ~~piece~~ piece S attached to the arm which in the full 'ON' position is attracted and held by an electromagnet E energised by the shunt current. It is known as 'HOLD ON' coil, or LOW VOLTAGE or NO VOLTAGE release.

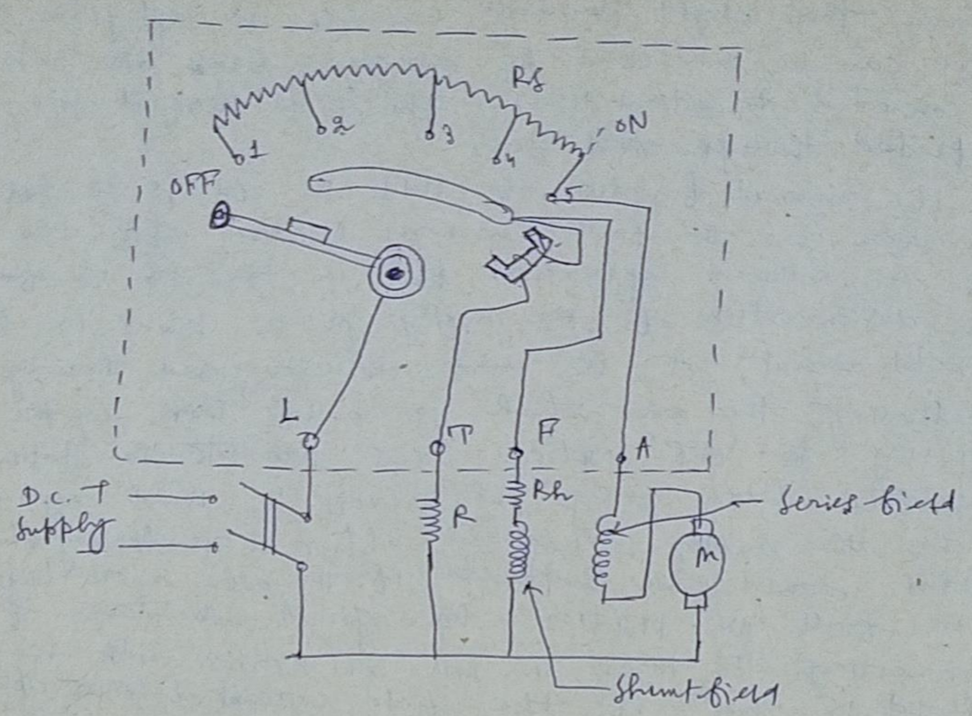
When the arm is moved from stud No-1 to the last stud, the field current has to travel back through that portion of the starting resistance that has been cut out of the armature circuit. This results in slight decrease of shunt current. But as the value of starting resistance is very small compared to shunt field resistance, this slight decrease in $I_{sh}$. is negligible. This defect can be over come by using a brass arc which is connected to stud No.-1. The field circuit is completed through this arc.

The normal function of 'HOLD ON' coil is to hold on the arm in the full running position, when the motor is in normal operation. But in the case of failure or disconnection of the supply or a break in the field circuit, it is ~~dee~~ de-energised thereby releasing the arm which is pulled back by the spring to 'OFF' position. This prevents the stationary armature from being put across the lines again when the supply is restored after a temporary shutdown. This would have happened if the arm were left in full 'ON' position. One great advantage of connecting the 'HOLD ON' coil in series with the shunt field is that if the field circuit becomes open the starting arm immediately springs back to 'OFF' position, thereby preventing the motor from running away.

The over current release consists of an electromagnet connected in the supply line. If the motor becomes over loaded beyond a certain predetermined value, then D is lifted and short circuits the electromagnet E. Hence, the arm is released and returns to OFF position.

If it is desired to control the speed of the motor in addition, then a field rheostat is connected in the field circuit. But there is one difficulty with such an arrangement for speed control. If too much resistance is 'cut in' by the field rheostat, then field current is reduced very much so that it is unable to create enough electromagnetic pull to over come the spring tension. Hence, the arm is pulled back to 'OFF' position. It is this undesirable feature of a three point starter which makes it unsuitable for use with variable speed motors.

<u>Four Point Starter:—</u> In this starter, the 'HOLD ON' coil is connected in series with a high resistance to the supply voltage and hence, there is a fixed current flowing through the 'HOLD ON' coil, which produces sufficient magnetism to ~~attar~~ attract the handle.

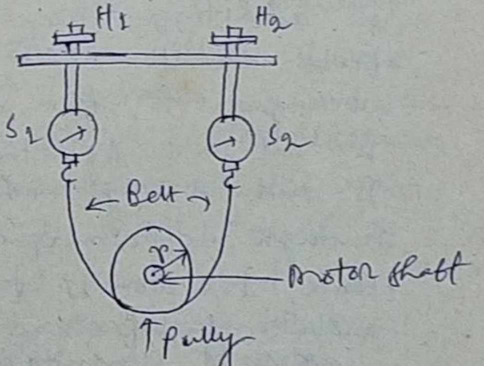



## Testing of D.C. machines:-

D.C. machines can be tested by three different methods — (i) direct method (ii) indirect method (iii) regenerative-method.

### (i) Direct method:-

#### Brake test:—




A belt around the air or water cooled pulley has its ends attached to spring balances $S_1$ and $S_2$.
The belt tightening hand wheels $H_1$ and $H_2$, help in adjusting the load on the pulley and therefore, on the motor.

If spring balances are calibrated in kg., the motor output is given by,

$$\text{Motor output} = (S_1 - S_2) \times 9.81 \times r \times \omega \text{ watts.}$$

where $S_1$ and $S_2$ are the tensions on the tight and slack sides of the belt.

$r$ = effective radius of the brake in metre,
$= \frac{1}{2}$ outside pulley diameter $+ \frac{1}{2}$ belt thickness.

$\omega$ = motor speed in rad./sec.

If $V_t$ = motor terminal voltage

$I_L$ = line current

∴ power input to motor = $V_t \cdot I_L$ watts.

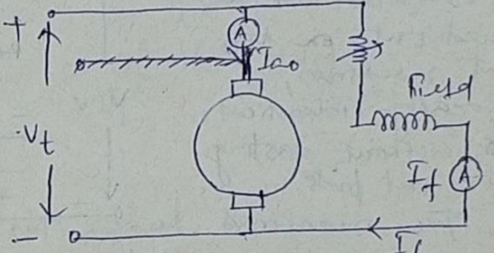
∴ efficiency, $\eta = \dfrac{\omega(S_1 - S_2) r \times 9.81}{V_t I_L} \times 100\%$

The simple brake test can be used for small motors only, because in the case of large motors, it is difficult to dissipate the large amount of heat generated at the brake.

(ii) <u>Indirect method</u> :- In this method, the no-load machine losses are first measured by a suitable test and then the additional losses on load are determined from the machine data, in order to calculate the machine efficiency.

The simplest method in measuring the no-load machine losses is by Swinburne's method.

<u>Swinburne's test</u> :-




As this is a no-load test, it can not be performed on a d.c. series motor.

In this method, the machine is run as a no-load shunt motor at rated speed and with rated terminal voltage $V_t$.

Let, $I_{a0}$ = No-load armature current

$I_f$ = No-load field current.

∴ Power absorbed by the armature = $V_t I_{a0}$.

= No-load rotational loss $W_0$ + small amount of armature circuit loss $I_{a0}^2 r_a$.

∴ No load rotational loss, $W_0 = V_t I_{a0} - I_{a0}^2 r_a$.

Shunt field loss = $V_t I_f$.

Let, $I_L$ = load current at which the machine efficie[ncy] is required.

<u>Generator efficiency</u> :- Generator out put = $V_t I_L$.

Armature current, $I_a = I_L + I_f$.

Armature circuit loss = $I_a^2 r_a$.

Shunt field loss = $V_t I_f$.

Total loss $= W_0 + I_a^2 r_a + V_t I_f$

$$\therefore \eta_g = 1 - \frac{W_0 + I_a^2 r_a + V_t I_f}{V_t I_L + W_0 + I_a^2 r_a + V_t I_f}$$

Motor efficiency:- $I_a = I_L - I_f$

motor input $= V_t I_L$.

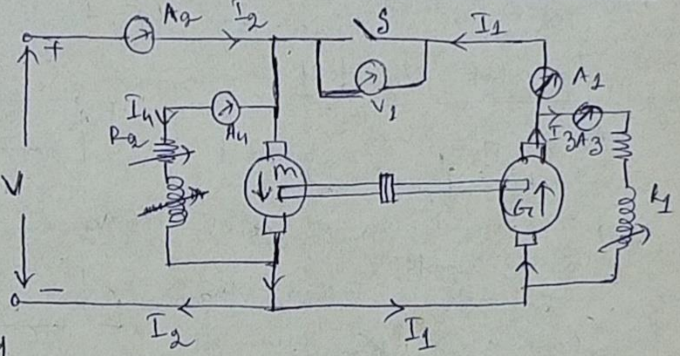
$$\therefore \eta_m = 1 - \frac{W_0 + I_a^2 r_a + V_t I_f}{V_t I_L}$$

Advantages:-

(i) Low power required for testing even large machines, since only no-load losses are to be supplied from the mains.

(ii) Efficiency of the machine can be calculated at any desired load.

(iii) Regenerative or Hopkinson's test:- (Back to Back test):-



By this method, full load test can be carried out on two shunt machines, preferably identical ones, without wasting their output.

The two machines are mechanically coupled and are so adjusted electrically that one of them runs as a motor and the other as a generator. The mechanical output of motor drives the generator and the electrical output of generator is used in supplying the greater part of input to the motor. If there were no losses in the machines, they would have run without any external power supply. But due to these losses, generator output is not sufficient to drive the motor and vice versa. The losses are supplied either by an extra motor which is belt connected to the motor generator set or electrically from the supply mains.

Machine M is started up from the supply mains with the help of a starter. Main switch S is kept open. Its speed is adjusted to normal value by means of its field regulator. Machine M drives machine G as a generator and its voltage is read on voltmeter $V_1$. When the generator voltage will be same as that of main supply both in polarity and magnitude, Switch S- is closed, to parallel the machines. generator current $I_1$ can be adjusted to any desired value by increasing the excitation of G or by reducing the excitation of M and the corresponding values of different ammeters are read.

The electrical out put of the generator plus the small power taken from the supply, is taken in by the motor and is given out as a mechanical power after supplying the motor losses.

Let, V = Supply voltage

$\therefore$ motor input $= V(I_1+I_2)$

where, $I_2$ = current taken from the supply.

generator out put $= VI_1$

Assuming that both machines have same efficiency $\eta$,

out put of motor $= \eta V(I_1+I_2)$

$=$ generator input.

$\therefore$ out put of generator $= \eta \times \eta V(I_1+I_2)$

$= \eta^2 V(I_1+I_2)$

$$\therefore \quad \eta^2 V(I_1+I_2) = VI_1$$

$$\Rightarrow \quad \eta = \sqrt{\frac{I_1}{I_1+I_2}}$$

When efficiencies are not equal,

Let, $R_a$ = armature resistance of each machine

$I_3$ = exciting current of the generator

$I_4$ = exciting current of the motor

Armature Cu-loss in generator $= (I_1+I_3)^2 R_a$

Armature Cu-loss in motor $= (I_1+I_2-I_4)^2 R_a$

Shunt Cu loss in generator $= VI_3$

Shunt Cu-loss in motor $= VI_4$.

But total motor and generator losses are equal to the power supplied by the mains.

Power drawn from supply $= VI_2$.

$\therefore$ Total stray losses for the set

$$= VI_2 - \left[(I_1+I_3)^2 R_a + (I_1+I_2-I_4)^2 R_a + VI_3 + VI_4\right]$$

$= W$ (say).

Let stray losses are equally divided between the machines, then stray loss per machine $= \frac{W}{2}$.

For generator:-

Total losses $= (I_1+I_3)^2 R_a + V I_3 + \frac{W}{2} = W_g$ (say)

out put $= V I_1$

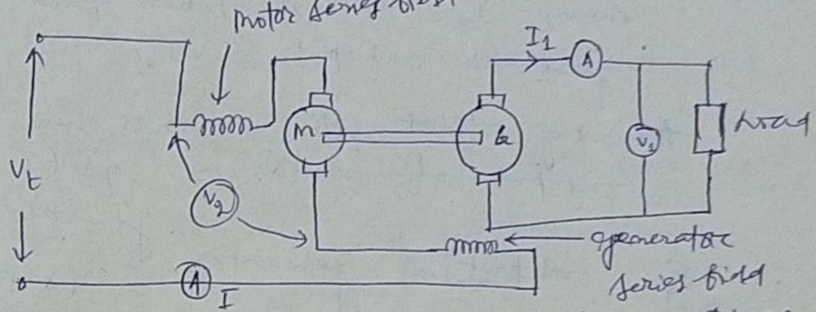
$$\therefore \eta_g = \frac{V I_1}{V I_1 + W_g}.$$

For motor:- Total losses $= (I_1+I_2-I_4)^2 R_a + V I_4 + \frac{W}{2} = W_m$ (say)

Input $= V(I_1+I_2)$.

$$\therefore \eta_m = \frac{V(I_1+I_2) - W_m}{V(I_1+I_2)}.$$

Field's test for series machines:-




In this method, two identical d.c. series machines, mechanically and electrically coupled are required. machine M acting as a motor drives machine G as a generator. The series fields of both M and G are connected in series with the motor armature. The motor M is started in usual manner and the generator out put is wasted in the variable resistive load. Voltage $V_2$ across the motor terminals should be equal to its rated value.

Since, the motor and generator fields are in series, the iron losses in both machines are the same.

Let, $V_t$ = supply voltage

$I$ = motor input current

$V_1$ = generator terminal voltage

$I_1$ = generator out put current.

Power input to whole set $= V_t I$.

Power out put of the generator $= V_1 I_1$.

$\therefore$ Total losses in the whole set,

$$W = V_t I - V_1 I_1.$$

Total ohmic losses, $W_c = I^2 (r_{am} + r_{sm} + r_{s(g)}) + I_1^2 r_{ag}$.

$\therefore$ No-load rotational loss of both the machines,

$$W_0 = W - W_c.$$

∴ No-load rotational loss of each machine $= \frac{W_0}{2}$.

Motor power input $= V_2 I$.

∴ Motor efficiency, $\eta_m = 1 - \frac{\frac{W_0}{2} + I^2(r_{am} + r_{sm})}{V_2 I}$

generator input $= V_1 I_1 + \frac{W_0}{2} + I^2 r_{sg} + I_1^2 r_{ag}$.

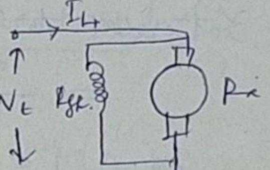
∴ generator efficiency, $\eta_g = 1 - \frac{\frac{W_0}{2} + I^2 r_{sg} + I_1^2 r_{ag}}{V_1 I_1 + \frac{W_0}{2} + I^2 r_{sg} + I_1^2 r_{ag}}$.

Problems:-

① A 230 V. d.c. shunt motor takes an armature current of 3.33 A. at rated voltage and at a no-load speed of 1000 r.p.m. The resistance of the armature circuit and field circuit are respectively 0.3 Ω and 160 Ω. The line current at full load and at rated voltage is 40 A. Calculate the full load speed if the armature reaction weakens the no-load flux by 4%.

Soln:- At no-load,

the counter e.m.f.,




$E_{a1} = V_t - I_{a1} R_a$

$= 230 - 3.33 \times 0.3$

$= 229$ V.

Field current, $I_f = \frac{230}{160} = 1.44$ A.

At full load, $I_{a2} = I_L - I_f = 40 - 1.44 = 38.56$ A.

∴ Counter e.m.f. at full-load,

$E_{a2} = 230 - 38.56 \times 0.3 = 218.43$ V.

At full load, the field flux $\phi_2 = 0.96\,\phi_1$.

$$\frac{E_{a1}}{E_{a2}} = \frac{\phi_1 N_1}{\phi_2 N_2}$$

$$N_2 = N_1 \times \frac{E_{a2}}{E_{a1}} \times \frac{\phi_1}{\phi_2}$$

$$= 1000 \times \frac{218.43}{229} \times \frac{\phi_1}{0.96\,\phi_1}$$

$$= 994 \text{ r.p.m.}$$

*② A 250 V., 4-pole shunt motor has two circuit armature winding with 500-conductors. The armature circuit resistance is 0.25 Ω, field resistance is 125 Ω and the flux per pole 0.02 Wb. Armature reaction is neglected. If the motor draws 14 A. from the mains, then compute,

(i) Speed and the internal (total or gross) torque developed
(ii) the shaft power, shaft torque and efficiency with rotational losses equal to 300 watts.

Soln.:- $P = 4$, $z = 500$, $r_a = 0.25\Omega$, $r_f = 125\Omega$,
$\phi = 0.02$ wb.

(i) Constant field current $= \frac{250}{125} = 2A$.

Armature current, $I_a = 14 - 2 = 12A$.

Counter e.m.f., $E_a = V_t - I_a r_a$

$= 250 - 12 \times 0.25 = 247 V$,

$$E_a = \frac{\phi z N P}{60 \times A}$$

$$\Rightarrow N = \frac{247 \times 2 \times 60}{500 \times 4 \times 0.02} = 741 \text{ r.p.m}$$

Electromagnetic power, $P_e = E_a I_a = 247 \times 12$
$= 2964$ W.

$\therefore$ Internal torque developed $= \frac{P_e}{\omega}$

$$= \frac{2964}{2\pi \times 741/60} = 38.197 \text{ N-m.}$$

(ii) Shaft power, $P_{sh.} = P_e -$ rotational losses

$= 2964 - 300 = 2664$ W.

$$\text{Shaft torque} = \frac{2664 \times 60}{2\pi \times 741} = 34.33 \text{ N-m.}$$

$$\text{Efficiency} = \frac{\text{Output at the shaft}}{\text{Power input}}$$

$$= \frac{2664}{250 \times 14} = 76.1\%$$

(3) A 200V, d.c. shunt motor takes 22A at rated voltage and runs at 1000 r.p.m. Its field resistance is 100 Ω and armature circuit resistance (including brushes) is 0.1 Ω. Compute the value of additional resistance required in the armature circuit to reduce the speed at 800 r.p.m., when,

(i) the load torque is independent of speed
(ii) the load torque is proportional to speed
(iii) the load torque varies as square of the speed (as in a fan motor)
(iv) the load torque increases as the cube of speed.

Soln. :— Constant field current, $I_f = \frac{200}{100} = 2A$.

$\therefore$ Armature current, $I_a = 22 - 2 = 20A$.

The speed is to be controlled from 1000 to 800 r.p.m by armature resistance controlled method.

If $I_f$ is constant, field flux $\phi$ remains constant.

(i) Since, load torque is independent of speed, the torque is constant at both speeds.

$$T \propto \phi_1 I_{a1} \propto \phi_2 I_{a2}$$

$$\therefore \phi_1 I_{a1} = \phi_2 I_{a2}$$

$$\Rightarrow I_{a1} = I_{a2} = 20\ A. \quad [\because \phi_1 = \phi_2]$$

At 1000 r.p.m., the counter e.m.f., $E_{a1} = V_t - I_{a1} r_a$

$$= 200 - 20 \times 0.1 = 198\ V.$$

At 800 r.p.m., the counter e.m.f. $E_{a2} = V_t - 20(0.1 + R_{ext.})$

$$\frac{E_{a2}}{E_{a1}} = \frac{\phi_2 N_2}{\phi_1 N_1} = \frac{N_2}{N_1}$$

$$\Rightarrow \frac{800}{1000} = \frac{200 - 20(0.1 + R_{ext.})}{198}$$

$$\Rightarrow R_{ext.} = 1.98\ \Omega.$$

Loss in $R_{ext.} = (20)^2 \times 1.98 = 792\ W.$

(ii) Here, load torque $T_L \propto N$.

$$\therefore T_e = K\phi I_a$$

$$\therefore K\phi_1 I_{a1} \propto N_1$$

$$K\phi_2 I_{a2} \propto N_2$$

$$\Rightarrow \frac{I_{a2}}{I_{a1}} = \frac{N_2}{N_1}$$

$$\Rightarrow I_{a2} = 20 \times \frac{800}{1000} = 16A.$$

$$\therefore E_{a2} = 200 - 16(0.1 + R_{ext.})$$

$$E_{a1} = 198\ V.$$

$$\therefore \frac{E_{a2}}{E_{a1}} = \frac{200 - 16(0.1 + R_{ext.})}{198} = \frac{800}{1000}$$

$$\Rightarrow R_{ext.} = 2.5\ \Omega.$$

Loss in $R_{ext.} = (16)^2 \times 2.5\ W = 640\ W.$

(iii) Load torque, $T_L \propto N^2 \propto \phi I_a$ /
using similar approach, $R_{ext.} = 3.25\ \Omega$.

(iv). $T_L \propto N^3 \propto \phi I_a$

$R_{ext.} = 3.96\ \Omega$.

(4) It is desired to reduce the speed of a 460V., 10HP., shunt motor by 25% by the insertion of a resistance in the armature circuit. The torque is to remain unchanged; If the full load efficiency is 84%, calculate the necessary resistance, given the field current of constant at 1.1 A. and the armature resistance 0.2 Ω.

Soln.:— Full load out put = ~~10×746 = 7460 W.~~ 10×746 = 7460W.

Full load efficiency = 84%.

$\therefore$ full load input $= \dfrac{10\times 746}{0.84} = \cancel{8762\ W.}$ 8880.95 W.

Full load line current, $I_L = \dfrac{\cancel{8762}\ 8880.95}{460} = \cancel{19.05}\ A.$ 19.31 A.

Shunt field current, $I_f = 1.1\ A.$

Full load armature current, $I_a = \cancel{19.05}\ 19.31 - 1.1 = \cancel{17.95}\ A.$ 18.21 A.

Back e.m.f. at normal speed, $E_1 = 460 - 0.2\times \cancel{17.95}\ 18.21$

$= \cancel{456.4\ V.}$ 456.36 V.

$$\frac{E_2}{E_1} = \frac{\phi_2 N_2}{\phi_1 N_1} = \frac{N_2}{N_1} = 0.75$$

$\therefore E_2 = 0.75 E_1 = 0.75 \times \cancel{456.4}\ 456.36$

$= \cancel{342\ V.}$ 342.27 V.

Voltage to be dropped across the armature and series resistance $(R_a + R_s)$ $= 460 - \cancel{342}\ 342.27$

$= \cancel{118\ V.}$ 117.73V.

Since, the torque is kept constant,

$\phi_1 I_{a1} = \phi_2 I_{a2}$

$\therefore I_{a1} = I_{a2} = \cancel{17.95 A.}$ 18.21 A.

$\therefore (R_a + R_s) = \dfrac{118}{\cancel{17.95}\ 18.21} = \cancel{6.57\ \Omega}$ 6.48 Ω

$\therefore R_s = \cancel{6.57}\ 6.48 - 0.2 = \cancel{6.37}\ \cancel{6.37\ \Omega}$ 6.28 Ω

= series resistance required.

(5) A 240V., unsaturated shunt motor has an armature resistance (including brushes and interpoles) of 0.04 Ω and a field resistance of 100 Ω.

(i) Find what resistance should be added to the field circuit to increase the speed from 1200 to 1500 r.p.m., when the supply current is 200 A.

(ii) With the field as in (i), find the speed when the supply current is 100A.

Soln.:— (i). Supply current to the motor, $I_{L1} = 200A$.

field current, $I_{f1} = \frac{240}{100} = 2.4$ A.

Armature current $I_{a1} = 200 - 2.4 = 197.6$ A.

$\therefore$ counter e.m.f. $E_{a1} = 240 - 197.6 \times 0.04$

$= 232.1$ V.

$\phi_1 \propto I_{f1} \propto 2.4$

$N_1 = 1200$ r.p.m., $N_2 = 1500$ r.p.m.

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \times \frac{\phi_2}{\phi_1}$$

It can be assumed that $E_2 \approx E_1$.

$\therefore I_{f2} = \frac{N_1}{N_2} \times I_{f1} = \frac{1200}{1500} \times 2.4 = 1.92$ A.

$\therefore$ Total field resistance $= \frac{240}{1.92} = 125\ \Omega$.

$\therefore$ Extra resistance required $= 125 - 100 = 25\ \Omega$.

(ii) $I_{L1} = 200$ A, $I_{f1} = 1.92$ A.

$\therefore I_{a1} = 200 - 1.92 = 198.08$ A.

$E_{a1} = 240 - 198.08 \times 0.04 = 232.08$ V.

$I_{L2} = 100$ A.

$\therefore I_{a2} = 100 - 1.92 = 98.08$.

$\therefore E_{a2} = 240 - 98.08 \times 0.04 = 236.08$ V.

$N_2 = \frac{E_2}{E_1} \times \frac{\phi_1}{\phi_2} \times N_1$ [given, $\phi_1 = \phi_2$, $N_1 = 1500$ r.p.m.]

$\therefore N_2 = \frac{236.08}{232.08} \times 1500 = 1526$ r.p.m.

(6) A 240V. series motor takes 40A. when giving its rated output at 1500 r.p.m.. Its resistance is 0.3 Ω. Find what resistance must be added to obtain rated torque —

(i) at starting and (ii) at 1000 r.p.m..

Soln.:— $V = 240$V., $R_t = 0.3\ \Omega$.

$N_1 = 1500$ r.p.m, $I_{a1} = 40$A

$T \propto I_a^2$

$\therefore I_{a1}^2 = I_{a2}^2 \Rightarrow I_{a1} = I_{a2} = 40$A.

During starting induced e.m.f. is zero, hence current is limited only by the resistance in the armature circuit.