N G Ajjanna

Asst professor

Dept. of E&E Engineering

JNNCE,Shimoga

Electric Motors

(BEE401)

ELECTRIC MOTORS		Semester	IV
Course Code	BEE401	CIE Marks	50
Teaching Hours/Week (L:T:P: S)	3:0:0:0	SEE Marks	50
Total Hours of Pedagogy	40	Total Marks	100
Credits	03	Exam Hours	03
Examination nature (SEE)	Theory		

Course objectives:

1. To study the constructional features of Motors and select a suitable drive for specific Application.
2. To study the constructional features of Three Phase and Single phase induction Motors.
3. To study different test to be conducted for the assessment of the performance characteristics of motors.
4. To study the speed control of motor by a different methods.
5. Explain the construction and operation of Synchronous motor and special motors.

Module-1

DC Motors:

- Construction and working principle.
- Back E.M.F and its significance,
- Torque equation,
- Classification,
- Characteristics of shunt, series & compound motors,
- Speed control of shunt motor,
- Application of motors.
- Losses and Efficiency- Losses in DC motors, power flow diagram, efficiency, condition for maximum efficiency.

Module-1

Testing of DC Motors:

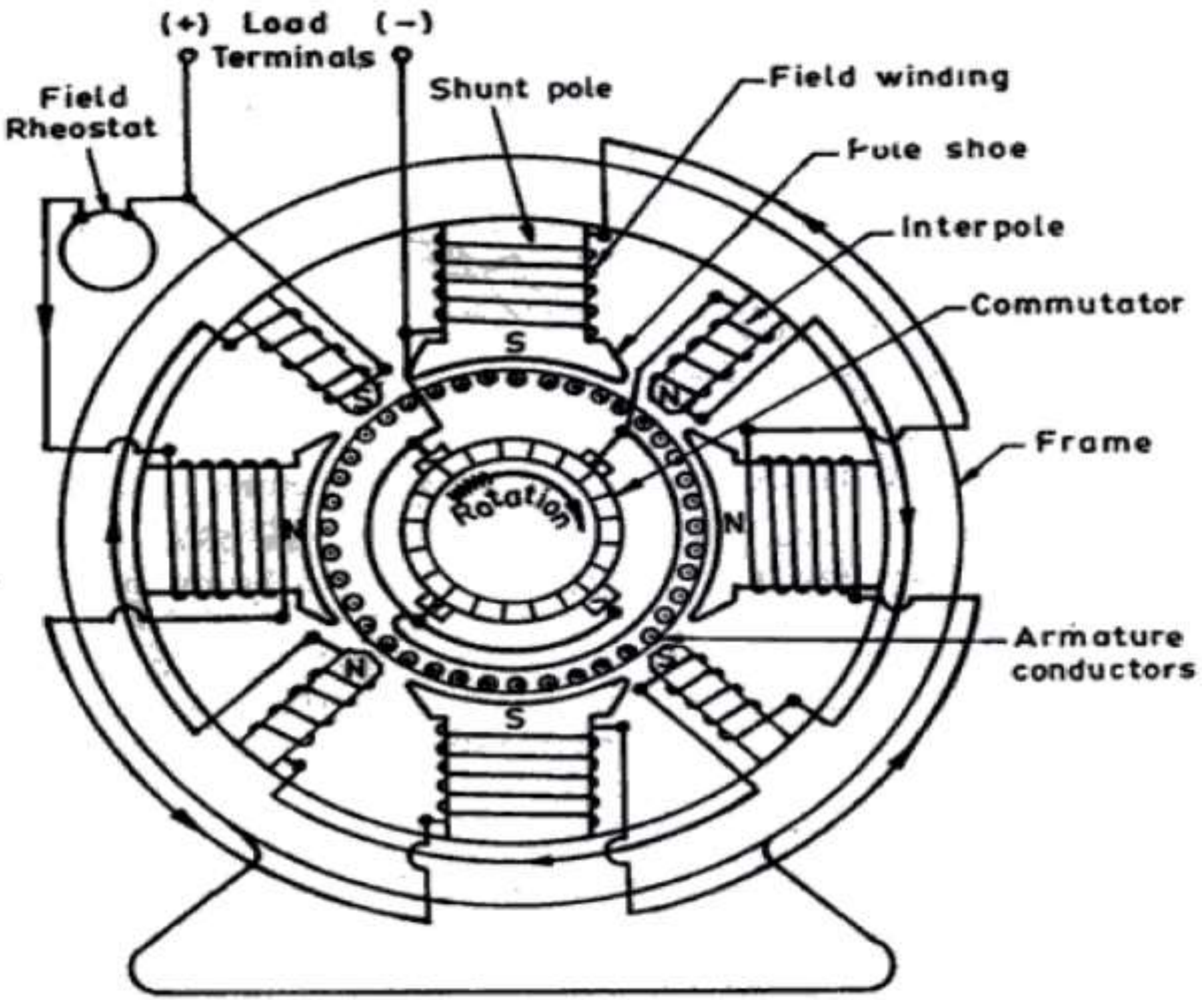
Direct & indirect methods of testing of DC motors:

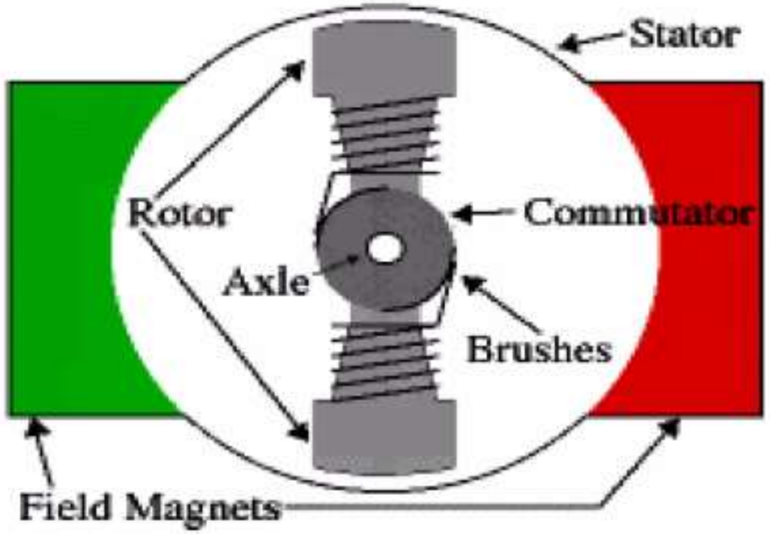
- Swinburne’s test.
- Field's test.
- Merits and demerits of tests.
- Numerical as applicable

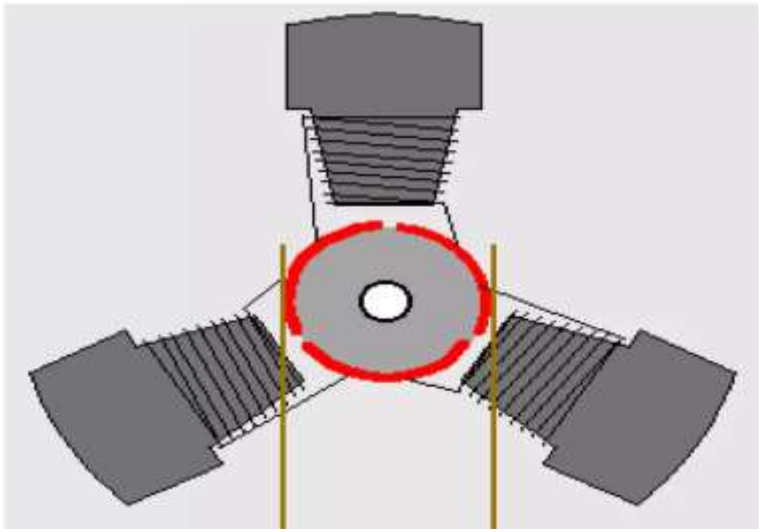
DC MOTOR

- A DC motor or Direct Current Motor converts electrical energy into mechanical energy.
- A direct current (DC) motor is a fairly simple electric motor that uses electricity and a magnetic field to produce torque, which turns the rotor and hence give mechanical work.

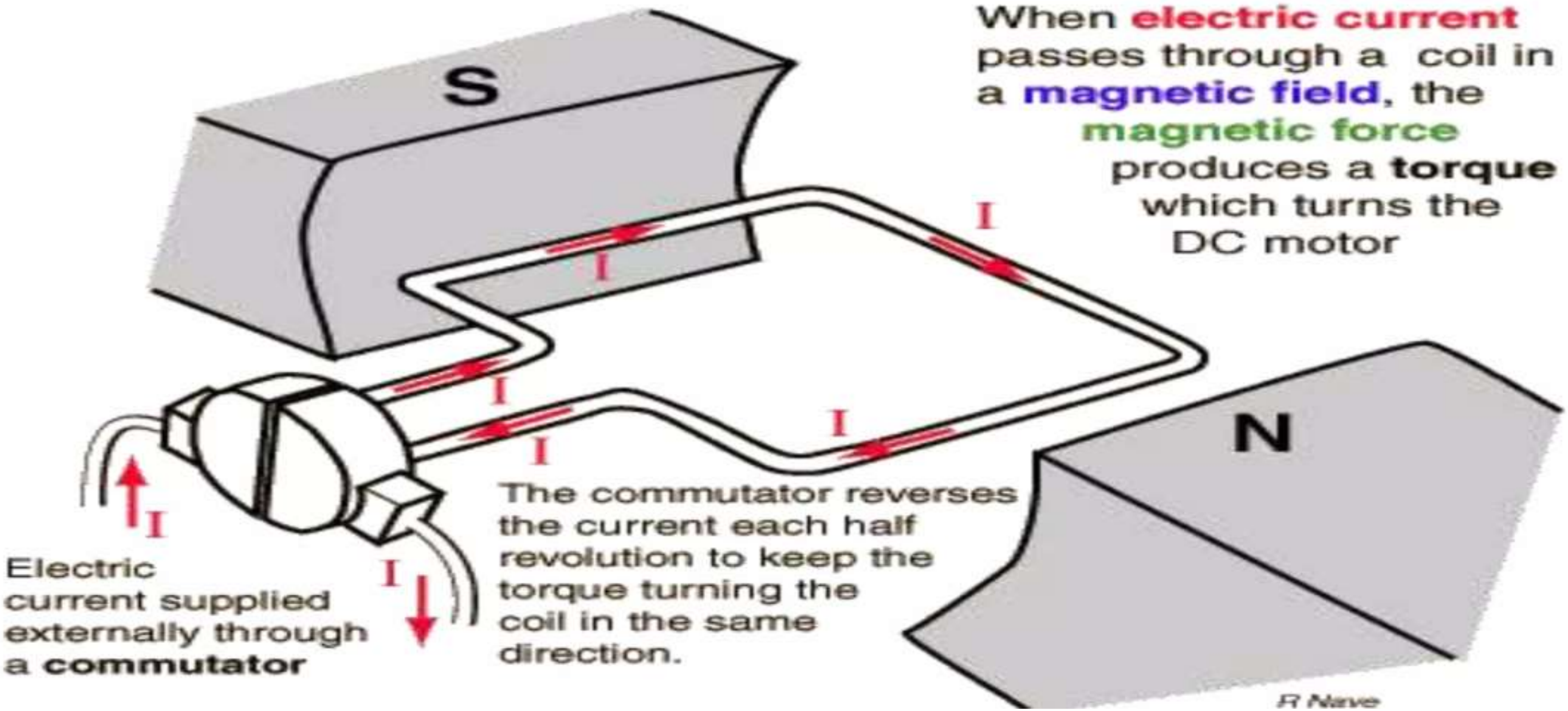
CONSTRUCTION







Working Principle of DC Motor



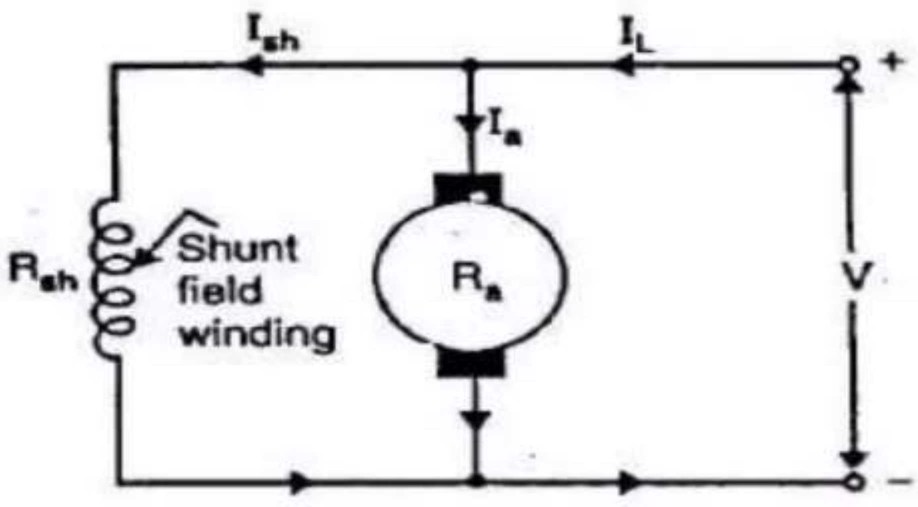
TYPES OF DC MOTORS

- **DC motor are of 3 types they are…..**

1. **DC SHUNT MOTOR**
2. **DC SERIES MOTOR**
3. **DC COMPOUND MOTOR**

1. DC SHUNT MOTOR

- The parallel combination of two windings is connected across a common dc power supply.
- The resistance of shunt field winding (R_{sh}) is always higher than that is armature winding.
- This is because the number of turns for the field winding is more than that of armature winding.
- The cross-sectional area of the wire used for field winding is smaller than that of the wire used for armature winding.



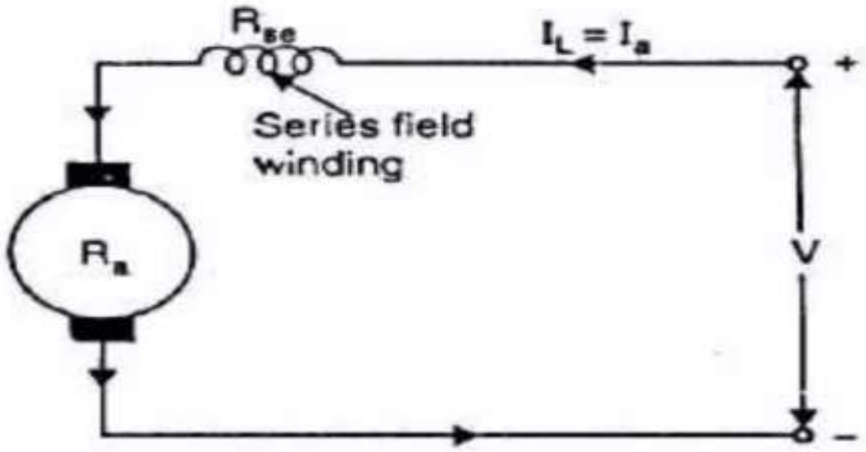
Armature

APPLICATIONS OF DC MOTORS

MOTORS..	APPLICATIONS...
D.C. SHUNT MOTOR	LATHES , FANS, PUMPS DISC AND BAND SAW DRIVE REQUIRING MODERATE TORQUES.
D.C. SERIES MOTOR	ELECTRIC TRACTION, HIGH SPEED TOOLS
D.C. COMPOUND MOTOR	ROLLING MILLS AND OTHER LOADS REQUIRING LARGE MOMENTARY TORQUES.

2. DC SERIES MOTOR

- The field winding is connected in series with the armature.
- The current passing through the series winding is same as the armature current .
- Therefore the series field winding has fewer turns of thick wire than the shunt field winding.
- Also therefore the field winding will posses a low resistance then the armature winding.



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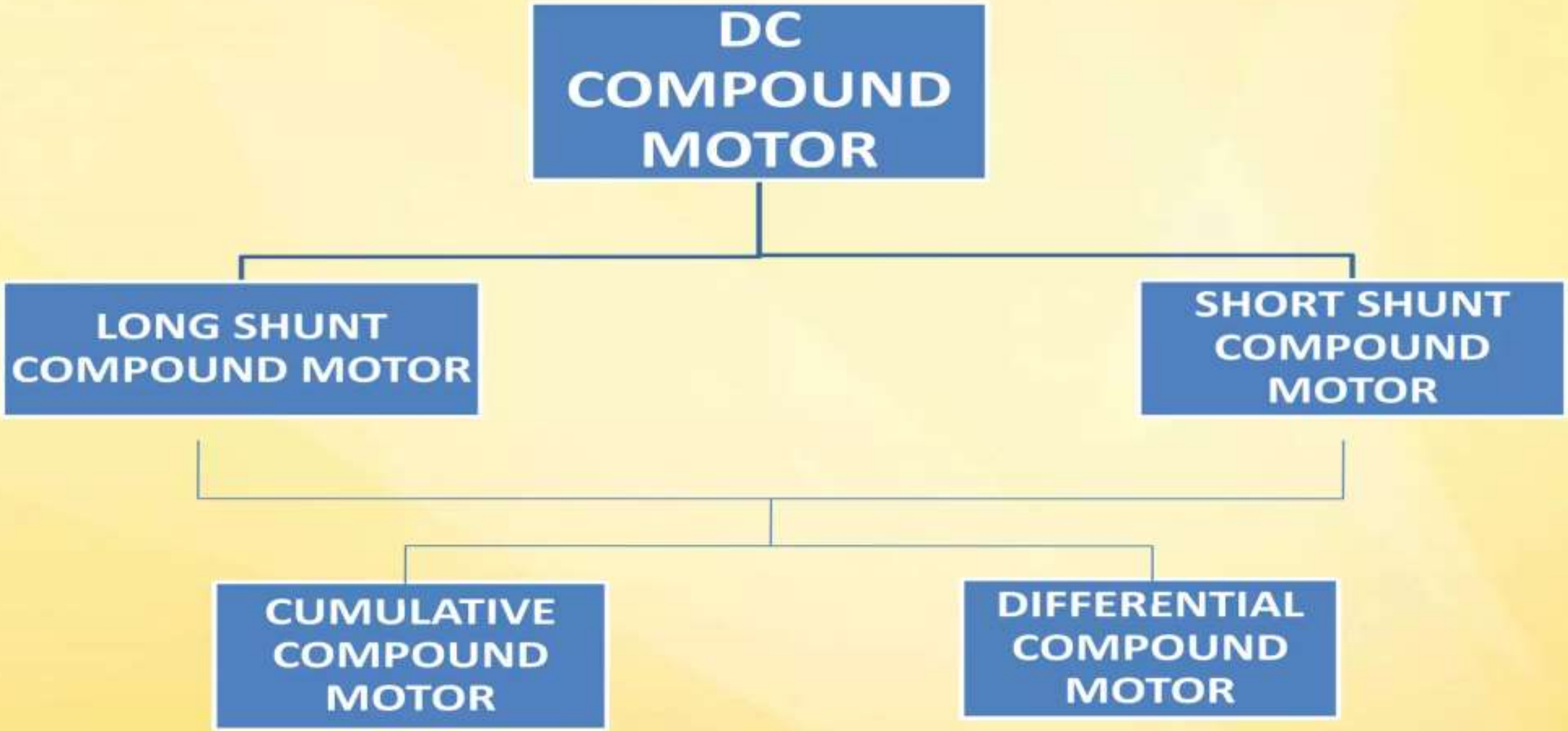
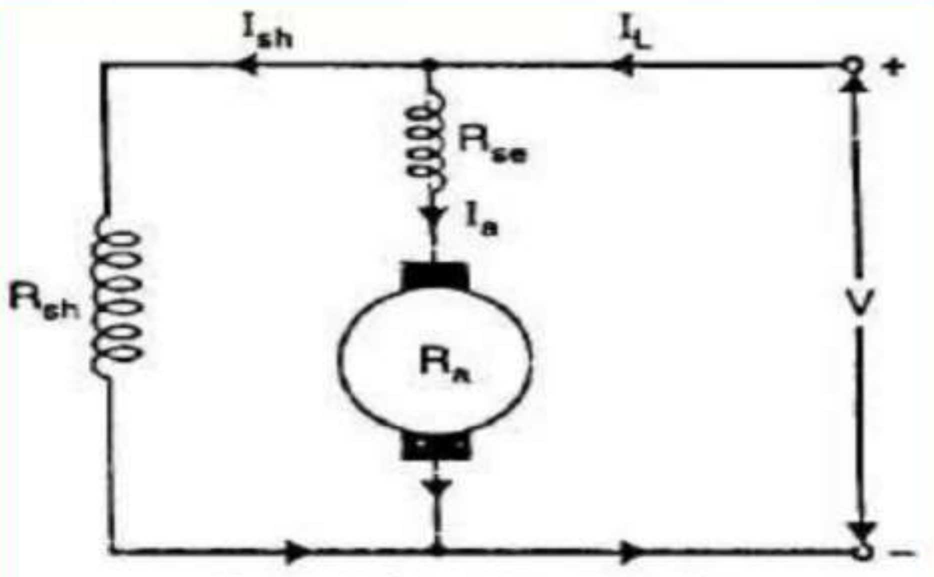
3. DC COMPOUND MOTOR



I. LONG SHUNT COMPOUND MOTOR

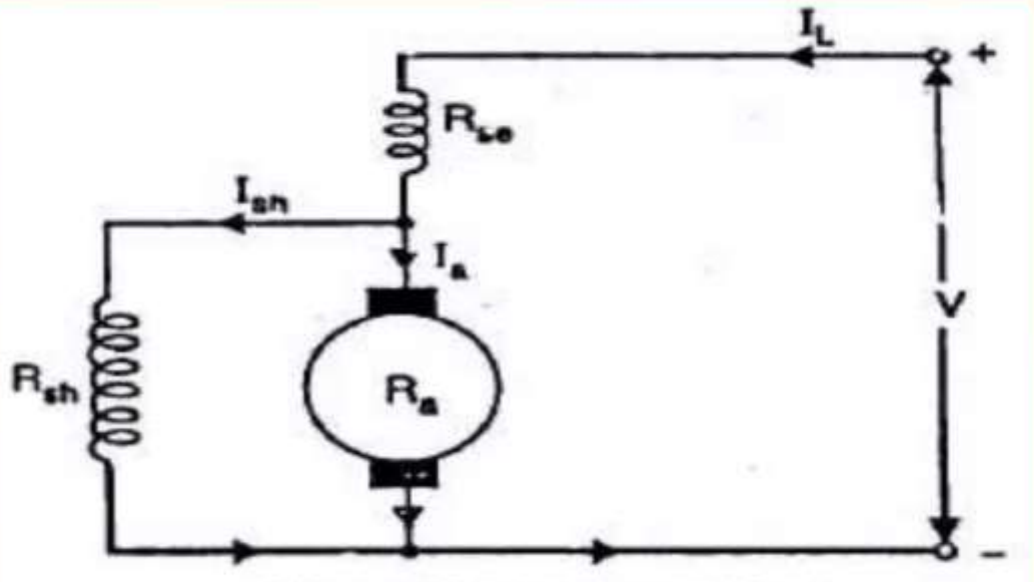
- In this the series winding is connected in series with the armature winding and the shunt winding is connected in parallel with the armature connection.



Long-shunt connection

II. SHORT SHUNT COMPUND MOTOR

- In short shunt compound motor the series winding is connected in series to the parallel combination of armature and the shunt winding
- This is done to get good starting torque and constant speed characteristics.



Short-shunt connection

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Speed Control of DC Motor

We know the Back Emf, $E_b = {}^{P\O NZ}/_{60A}$

(where, P = no. of poles, Ø = flux/pole, N = speed in rpm, Z = no. of armature conductors, A = parallel paths)

E_b can also be given as, $E_b = V - I_a R_a$

thus, from the above equations $N = E_b\ 60A/P\O Z$

but, for a DC motor A, P and Z are constants

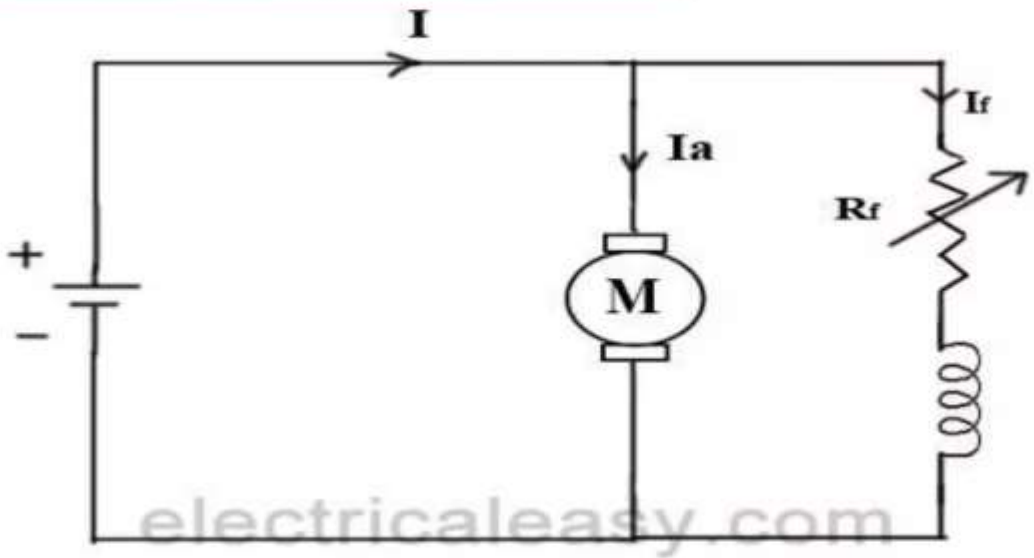
Therefore, $N \propto K\ E_b/\O$ (where, K=constant)

This shows the speed of a dc motor is directly proportional to the back emf and inversely proportional to the flux per pole.

Speed Control Of Shunt Motor

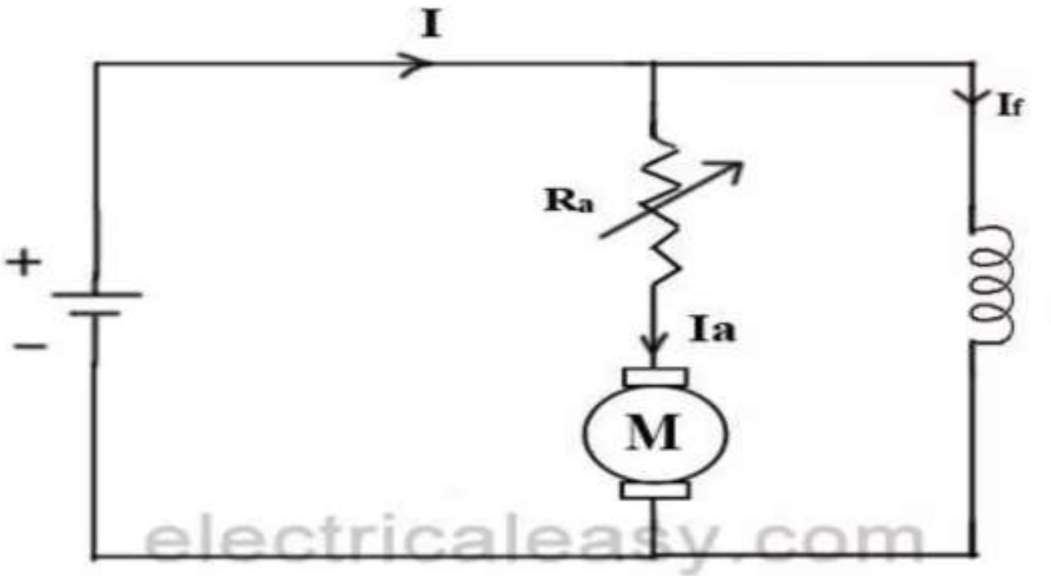
1. Flux Control Method

To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram. Adding more resistance in series with the field winding will increase the speed as it decreases the flux.



2. Armature Control Method

When the supply voltage V and the armature resistance R_a are kept constant, speed is directly proportional to the armature current I_a. Thus, if we add a resistance in series with the armature, I_a decreases and, hence, the speed also decreases.

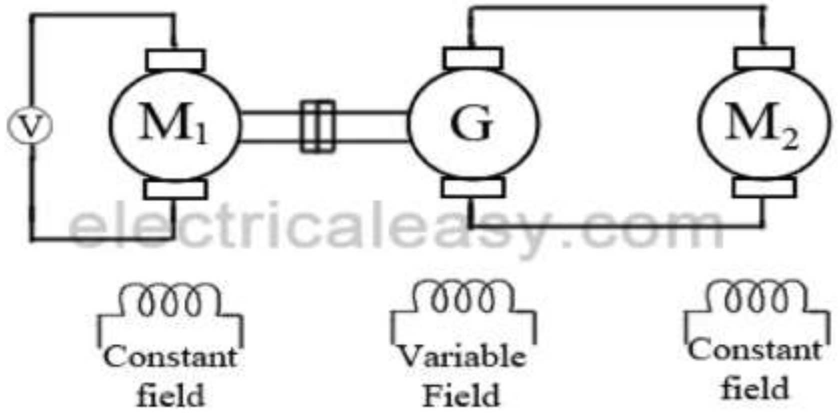


3. Voltage Control Method

a) **Multiple voltage control:**

In this method, the shunt field is connected to a fixed exciting voltage and armature is supplied with different voltages. Voltage across armature is changed with the help of a suitable switchgear.

b) **Ward-Leonard System**:



This system is used where very sensitive **speed control of motor** is required (e.g electric excavators, elevators etc.). The arrangement of this system is as shown in the figure at right.
M_2 is the motor whose speed control is required.
M_1 may be any AC motor or DC motor with constant speed.
G is a generator directly coupled to M_1.

Speed Control Of Series Motor

1. Flux Control Method

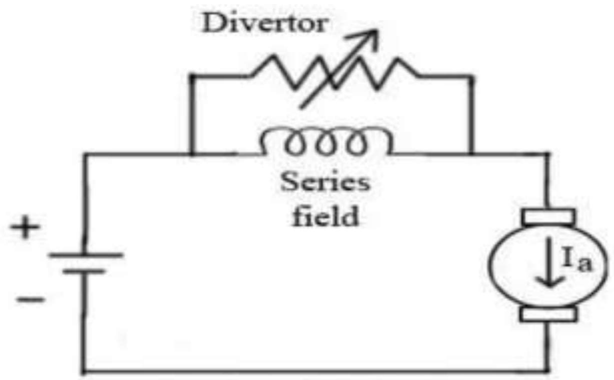


fig (a) Field Divertor

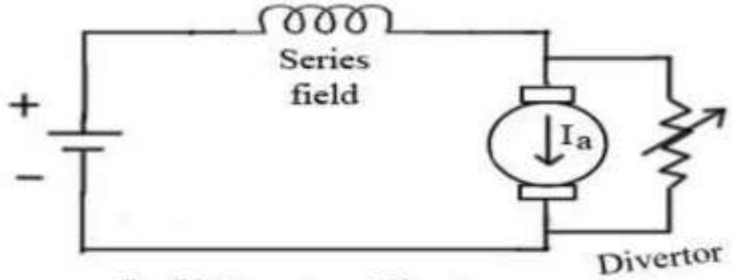


fig (b) Armature Divertor

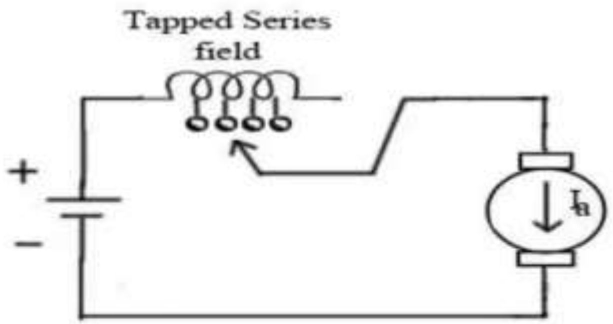


fig (c) Tapped field

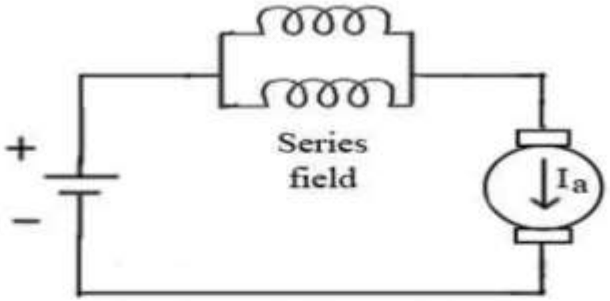


fig (d) Paralleling Field coils

2. Variable Resistance In Series With Armature

By introducing a resistance in series with the armature, voltage across the armature can be reduced. And, hence, speed reduces in proportion with it.

3. Series-Parallel Control

This system is widely used in electric traction, where two or more mechanically coupled series motors are employed. For low speeds, the motors are connected in series, and for higher speeds the motors are connected in parallel.

When in series, the motors have the same current passing through them, although voltage across each motor is divided. When in parallel, the voltage across each motor is same although the current gets divided.

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Losses in a DC Motor

In DC machines (generator or motor), the losses may be classified into three categories namely,

- Copper losses
- Iron or core losses
- Mechanical losses

All these losses appear as heat and hence raise the temperature of the machine.

They also reduce the efficiency of the machine.

Losses in a DC Motor

Constant and Variable Losses

In DC machines, we may group the above discussed losses in the following two categories

- Variable Losses
- Constant Losses

Losses in a DC Motor

Those losses in a DC machine that remain constant at all loads are called constant losses.

These losses include –

- ✓**iron losses:** eddy current and hysteresis loss
- ✓Shunt field copper loss, and
- ✓mechanical losses.

Mechanical losses: friction and windage losses

Iron Losses

- The iron losses occur in core of the armature of a DC machine due to rotation of the armature in the magnetic field.
- Because these losses occur in core of the armature, these are also called core losses.
- There are two types iron or core losses namely hysteresis loss and eddy current loss.

Hysteresis Loss

- The core loss that occurs in core of the armature of a dc machine due to magnetic field reversal in the armature core when it passes under the successive magnetic poles of different polarity is called hysteresis loss. The hysteresis loss is given by the following empirical formula,
- Hysteresisloss, **Ph=khB1.6maxfV**
- Where, kh is the Steinmetz’s hysteresis coefficient,
- Bmax the maximum flux density, f is the frequency of magnetic reversal, and V is the volume of armature core.

The hysteresis loss in dc machines can be reduced by making the armature core of such materials that have a low value of Steinmetz’s hysteresis coefficient like silicon steel.

Eddy Current Loss

- When the armature of a DC machine rotates in the magnetic field of the poles, an EMF is induced in core of the armature which circulates eddy currents in it. The power loss due to these eddy currents is known as eddy current loss. The eddy current loss is given by,
- Eddy current loss, **Pe = ke B2 max f2 t2 V**
- Where, **Ke** is a constant of proportionality, and **t** is the thickness of lamination.
- From the expression for eddy current loss it is clear that the eddy current loss depends upon the square of thickness of lamination.
- **Therefore, to reduce this loss, the armature core is built up of thin laminations that are insulated from each other by a thin layer of varnish.**

Copper Losses

In dc machines, the losses that occur due to resistance of the various windings of the machine are called **copper losses**. The copper losses are also known as **I^2R losses** because these losses occur due to current flowing through the resistance of the windings.

The major copper losses that occur in dc machines are as,

$$\text{Armature copper loss} = I_a^2 R_a$$

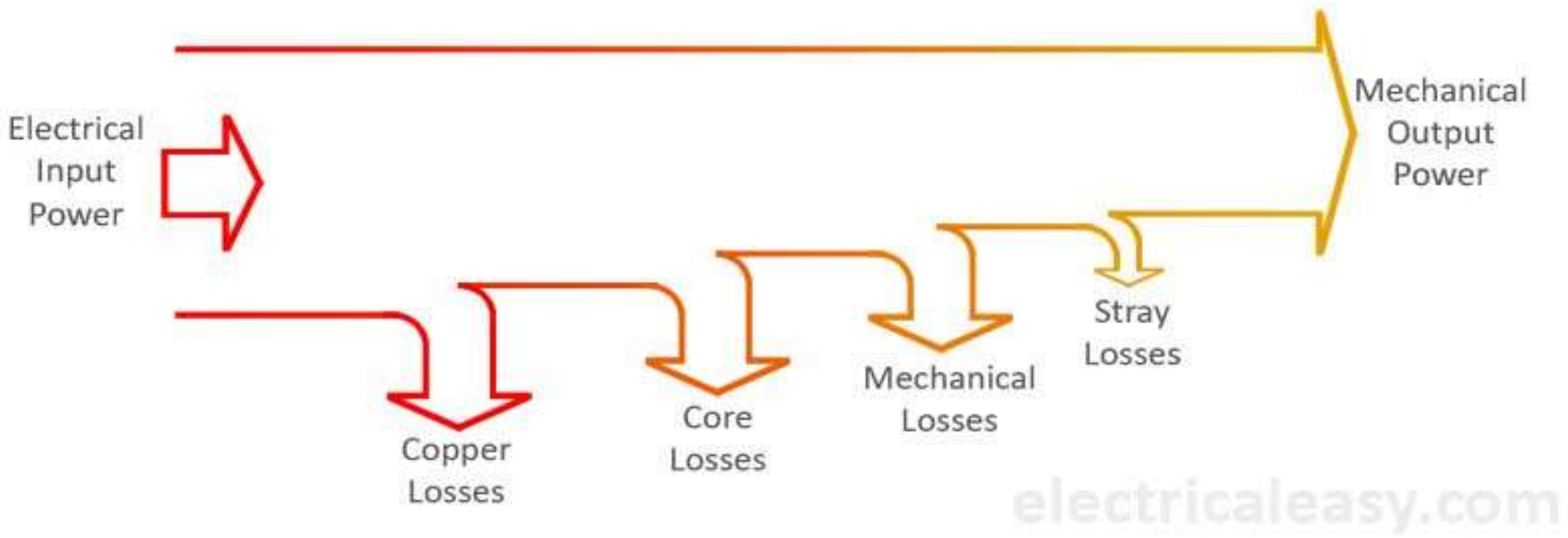
$$\text{Series field copper loss} = I_{se}^2 R_{se}$$

$$\text{Shunt field copper loss} = I_{sh}^2 R_{sh}$$

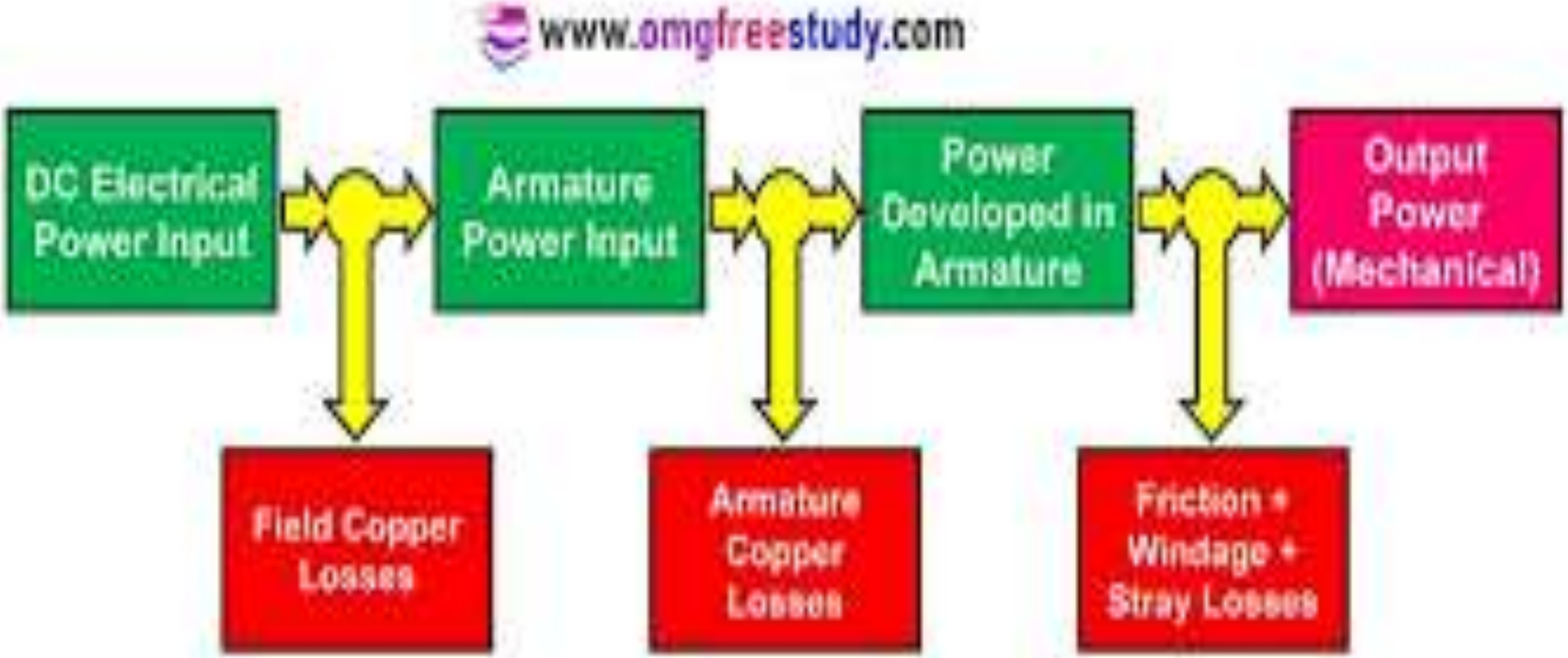
Mechanical Losses

- The power losses due to **friction and windage** in a dc machine are known as mechanical losses.
- In a dc machine, the friction loss occurs in form of bearing friction, brush friction, etc.
- while the windage loss occurs due to air friction of rotating armature.
- The mechanical losses depend upon the speed of the machine.
- But these losses are practically constant for a given speed.

Power flow diagram in a DC Motor



Power flow diagram of a DC motor



Power Flow Block Diagram of DC Motor

Maximum efficiency:

In DC machines, maximum efficiency occurs when variable losses are equal to constant losses.

Variable losses = Constant losses

Constant losses include windage losses, brush losses, hysteresis losses, and eddy current losses.

Variable losses include copper losses in the armature circuit.

Hence the efficiency is maximum when the copper loss in the armature circuit is equal to the constant loss.

Copper losses = $I_L^2 R_a$ = Constant losses

Where R_a is the armature resistance

⇒ $I_L = \sqrt{(\text{constant losses} / \text{armature resistance})}$

Testing on DC Motors

- Direct & indirect methods of testing of DC motors
- Swinburne's test.
- Field's test.
- Merits and Demerits of tests.
- Numerical as applicable

Swinburne’s test.

Circuit diagram:

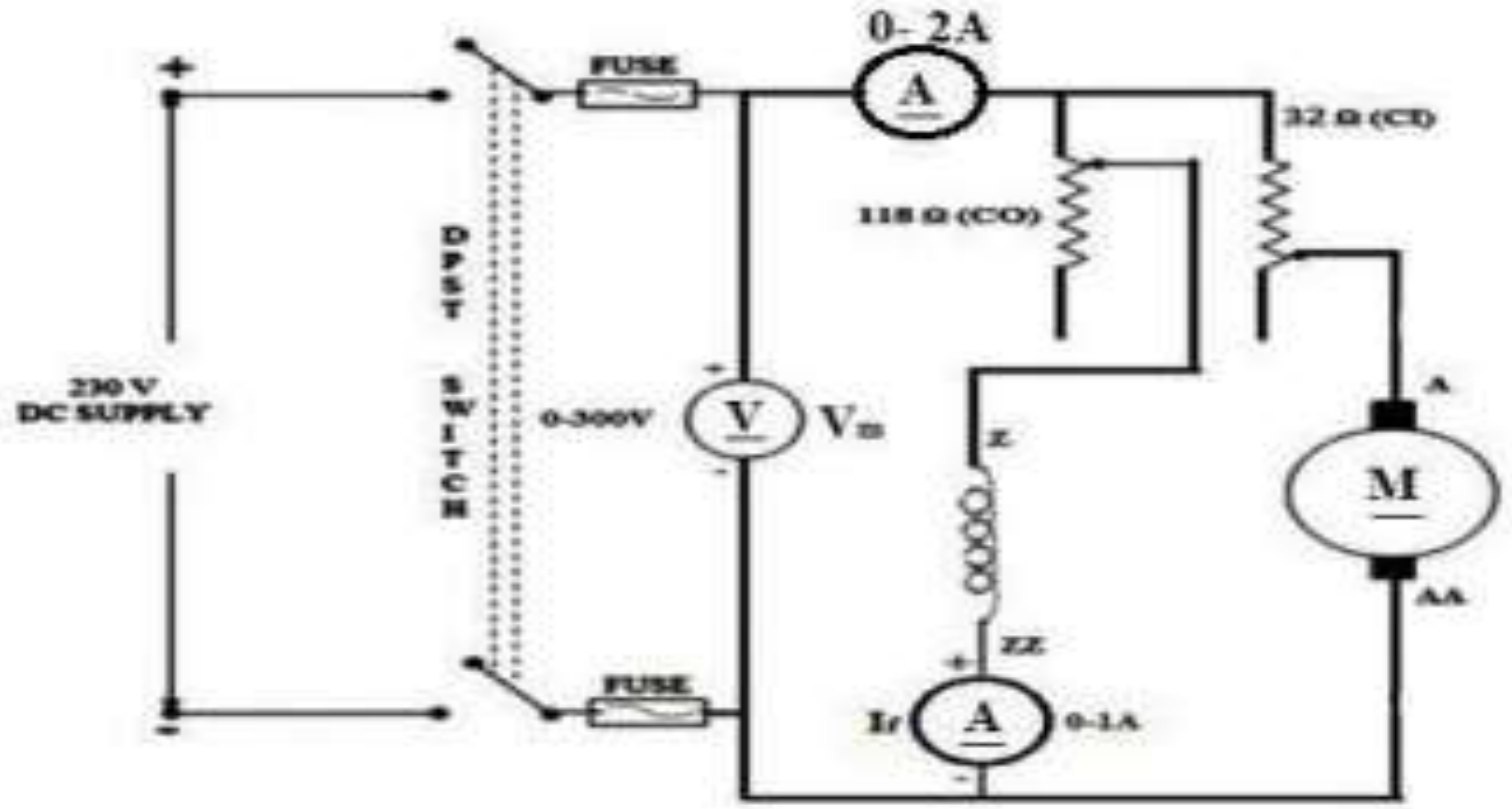


Figure 4.1 DC Shunt Motor

Procedure:

1. Circuit connections are made as per the Circuit diagram shown in figure.
2. The supply is given by closing DPST switch.
3. The Motor is started by keeping Armature Rheostat in cut in position and Field Rheostat in cut out position
4. The Motor is brought to rated speed by first cutting out (32 Ω) Armature Rheostat and then if necessary by Cutting in Field Rheostat (118 Ω)
5. The no Load readings are Tabulated.

Tabular Column:

Sl No.	Motor Voltage (V_m)	Motor current(I_{mo})	Motor field current(I_f)

Calculations: (a): When running as a Motor:

No Load input = $V_m I_{mo}$ = ------------------ =------------- Watts

No Load armature copper losses = $I_{ao}^2 R_a$= ------------------ = ------------Watts

Constant Loss (W_c) = No Load input-no Load armature copper loss

$W_c = (V_m I_{mo}) - (I_{ao}^2 R_a)$= ---------------------------------- = ------ Watts

To find efficiency of Machine when running as Motor at full Load:

Full Load input = $V_m I_{fl}$ = ------------------------------- = --------- Watts

Output = input- losses

$I_a = I_{fl} - I_f$

Output = $V_m \times I_{fl} - [W_c - I_a^2 R_a]$ = ------------------------------- =--------- Watts

$\%\eta = \frac{o/p}{i/p} \times 100$ = ------------------------- = ------- %

Repeat the procedure to Predetermine efficiency at 3/4th, 1/2th, 1/4th of full Load

To find efficiency of Machine when running as Generator at full Load:

Output = $V_L \times I_{FL}$

Full Load input = Output+Losses= $V_L \times I_{FL} + [\,W_c + (I_{FL} + I_F)^2 R_a\,]$ = ------------------------- = -------- Watts

Output = input- losses

$\%\eta = \frac{o/p}{i/p} \times 100 =$ ....%

Repeat the procedure to Predetermine efficiency at $x = 3/4^{th}, 1/2^{th}, 1/4^{th}$ of full Load

Expected Result: Predetermination of efficiency of a DC Shunt Motor is to be calculated and tabulated.

Result:

Loadings ($\%x$)	$\%\eta$ of $Motor$	$\%\eta$ of $Generator$
1		
1/2		
3/4		
1/4		

Advantages of Swinburne's Test:

- The power required for the testing of large machines is very small, therefore it is an economical and convenient method of testing DC machines.
- As the constant losses are known, thus the efficiency can be pre-determined at any load.

Disadvantages of Swinburne's Test:

- The change in iron losses is not considered from no-load to full load.
- Since Swinburne's test is performed on no-load, thus it does not indicate whether the **commutation on full load is satisfactory** and whether the temperature rise would be within specified limits.

Circuit Diagram:

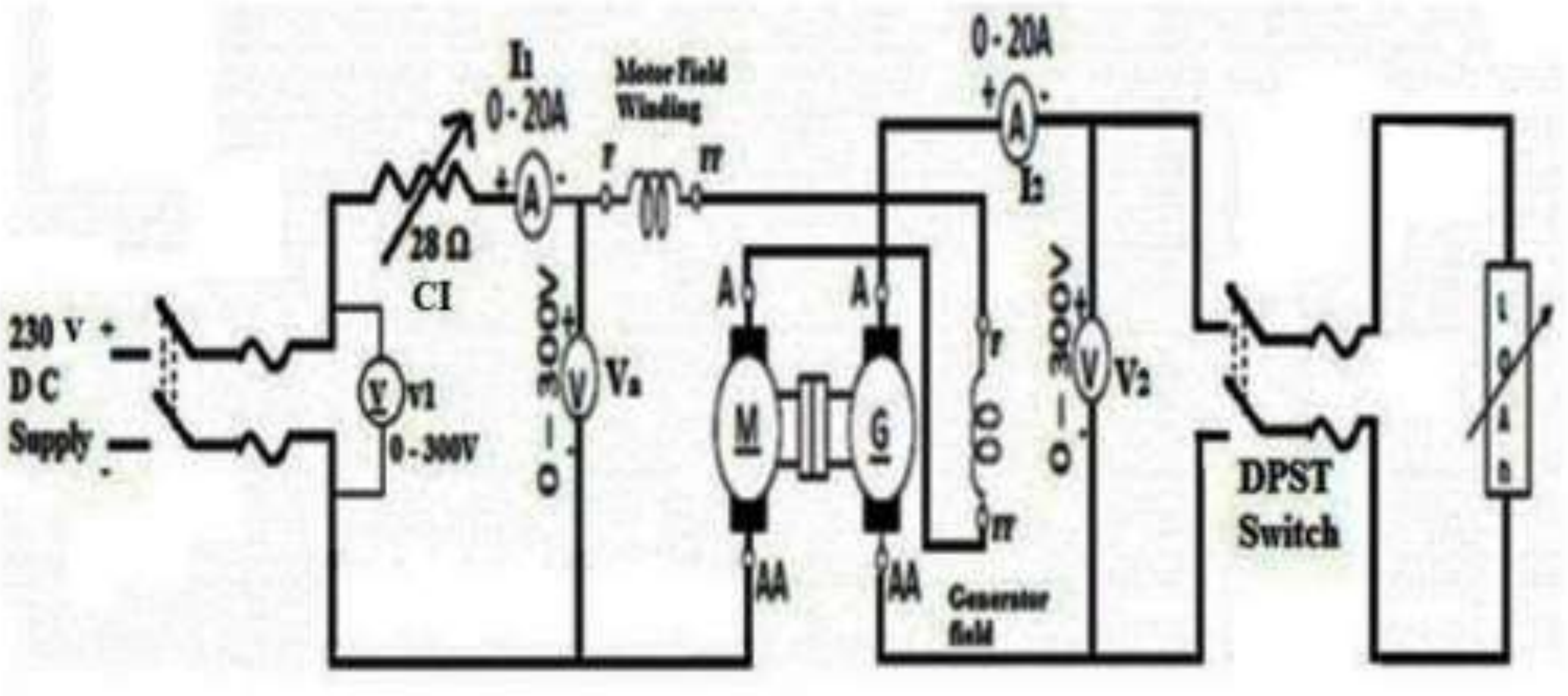


Figure 2.1 DC Series Motor and DC series Generator

PROCEDURE:

1. Circuit connections are made as per the Circuit diagram shown in figure.
2. Initially the Load switch is kept closed. There should be sufficient Load on the Generator. Rheostat connected on Motor side should be kept in cut-in position.
3. Close the supply switch and bring the Motor to its rated speed by varying the rheostat.
4. Adjust the Load such that the voltage across the armature should be of its rated value and speed of the set is within the permissible limit.
5. Note down all the meter readings along with speed.
6. Apply Load in steps and note down all meter readings. If possible maintain voltage across the Motor constant.
7. Measure the Armature and Field winding Resistances of Motor and Generator.

Sl. No	V_1 In Volts	I_1 in Amps	V_a in Volts	V_2 in Volts	I_2 In Amps	N In rpm	Input to Motor in Watts	Output of Motor In Watts	Motor %η	Torque in Nm	Generator input In Watts	Generator output in Watts	Generator Efficiency %η

Calculations:

Torque $T = \frac{output \times 60}{2\pi N} =$ .... **Nm**

Power input to whole set $= V_1 \times I_1 =$ .... **Watts**

Generator output $= V_2 \times I_2 =$ .... **Watts**

Total losses on the whole set $(W_t) = (V_1 \times I_1) - (V_2 \times I_2) =$ .... **Watts**

Armature and field copper losses $(W_c) = I_1^2(R_{am}+R_{fm}+R_{fg})+I_2^2R_{ag} =$ .... **Watts**

Rotational losses, stray losses $= W_t - W_c =$ .... **Watts**

Stray losses per Machine $(W_s) = \frac{Wt - Wc}{2} =$ .... **Watts**

Motor

Input $= V_a I_1 =$ ....**Watts**

Motor losses $=$
$I_1^2(R_{am}+R_{fm})+W_s =$ ....**Watts**

Efficiency of Motor

$(\%\eta) = \frac{o/p}{i/p} \times 100 = \frac{input - losses}{i/p} 100 =$ ....%

Generator

Output $= V_2 \times I_2 =$ .... **Watts**

Field copper losses $= I_1^2 R_{fg} =$ .... **Watts**

Armature copper losses $I_2^2 R_{ag} =$ .... **Watts**

Stray losses $(W_s)) = \frac{Wt - Wc}{2} =$ .... **Watts**

Total losses $= I_1^2 R_{fg} + I_2^2 R_{ag} + W_s =$ .... **Watts**

Efficiency of Generator

$(\%\eta) = \frac{o/p}{i/p} \times 100 =$
$\frac{output}{output+losses} \times 100 =$ ....%

Advantages:

- This is the most commonly used test of flexibility, so there is lots of data for comparison. Also, it is a cheap, easy and quick test to perform.

Disadvantages:

- Field testing can be time-consuming because it requires a large resource allocation:
- dedicated QA teams taking devices out into real-world scenarios.
- Purchasing a wide range of devices (with different models or versions) for adequate field testing will cost thousands of dollars annually.


Thank you!