LOCOPILOT

Electrical Study material

By ~ target study iq

ADVICE-CUM-STUDY MATERIAL

RAILWAY TECHNICAL EXAM.

BASIC ELECTRICAL ENGINEERING

MODEL SYLLABUS

1. Basic Electrical Definitions ✦ 2. AC Fundamentals ✦ 3. RLC Circuits ✦ 4. Batteries ✦ 5. Magnetic Circuits ✦ 6. Classification of Insulating Material ✦ 7. Electric Heating ✦ 8. Electric Welding ✦ 9. Electronic Device ✦ 10. Transformer ✦ 11. DC Machines ✦ 12. Induction Machines ✦ 13. Single Phase Motors ✦ 14. Synchronous Machines ✦ 15. Measuring Instruments.

1. BASIC DEFINITIONS

Charge : A body is said to be charged if it has either excess or deficit of electrons from normal due share.

Unit = Coulomb

Where 1 Coulomb = charge on 628×10^{16} electrons.

Free Electrons : The electrons which can be easily removed or detached from an atom are called free electrons.

Electric Potential : The capacity of a charged body to do work is called electric potential.

Unit = Volt

Potential Difference : The difference in the electric potential of two charged bodies is called Potential difference electric potential difference bewteen two points is one volt (1V). Potential is a scalar quantity if one Joule of work is done in moving 1 coulomb charge from one point to another.

Unit = Volt

Electric Current : Moving stream of electron is called electric current whenever electric charge moves, a current is said to be exist.

Unit = Ampere

Where 1 ampere of current is said to flow through a wire if through any section 628×10^{16} electrons pass in one second.

Mathematically, Current

$$= \frac{\text{Quantity of charge passing}}{\text{Time}}$$

$$i = \frac{q}{t} \text{ ampere}$$

Resistance : The property of a material by which it opposes the flow of current through it is called resistance.

Unit = Ohm (Ω)

A wire is said to have a resistance of 1Ω if it develops 0.24 calorie of heat when 1 ampere current flows through it for 1 second.

$$R = \frac{\rho . L}{a}$$

L is length of wire, a is area of cross-section of wire.

e = specific resistance of material

Resistivity : It is defined as the resistance offered by the opposite faces of 1 m cube of material. Since current is the flow of electrons, hence resistance is an opposition to the flow of electrons. So, the property of a material by virtue of which it opposes the flow of electric current is called "Resistance".

Unit = Ω-m

The factors upon which Resistance depends :

(a) Length $R \propto l$

(b) Area of corss-section $R \propto \frac{1}{a}$

(c) Nature of material

(d) Temperature

Ohm's Law : The current flowing between the ends of a conductor is directly proportional to the applied voltage, provided physical conditions, temperature do not change. $I \propto V$ or $\frac{V}{I}$ = constant

This constant is called resistance R of conductor.

Effect of Temp. on Resistance

Material	Effect
Metals	Resistance increases with rise of temperature.
Alloys	Resistance increases with rise of temp. but this increase is small and irregular.
Insulator or Electrolytes	Resistance decreases with rise of temp.

Temperature Co-efficient of Resistance

$R_t = R_o [1 + \alpha_o t]$

R_o is resistance at 0°C.

R_t is resistance at t°C.

α_o is called temp co-efficient of resistance at 0°C,

Electric Power : The rate at which work is done in electric circuit is called electric power.

P = VI, i.e.,

Product of voltage and Current

Unit ⇒ Watt Where

1 watt = 1 volt × 1 ampere.

Electric Energy : The total amount of work done in an electric circuit is called electric energy

= Total work done in electric circuit = V × I × t

Unit = Joule or watt/second.

Resistance in combination :

1. For resistances R_1, R_2........ connected is series, equivalent resistance R is : $R = R_1 + R_2$.......

2. For parallel connection equivalent resistance

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ...$$

Inductance in combination :

1. Series connection

$$L = L_1 + L_2 + ...$$

2. Parallel connection

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + ...$$

Capacitors in combination :

1. Series combination

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + ...$$

2. Parallel combination

$$C = C_1 + C_2 + ...$$

Capacitor : Two conducting elements separated by a dielectric results a component known as capacitor. $C = \frac{Q}{V}$ Farad,

Where,

Q = charge in Coulomb,

V = potential difference in volts.

The energy stored in a capacitor is given by $E = \frac{1}{2}CV^2$ Joules.

The value of capacitance of parallel plate capacitor is $C = \in \frac{A}{d}$

∈ is permittivity of dielectric

A is area of conducting plates.

d is distance between plates.

Inductance : Inductance is the property of a coil due to which it opposes the change of current in coil.

Factors affecting inductance :

1. Shape of conductor.

2. Permeability of material surrounding conductor.

Energy stored is Magnetic field : $\frac{1}{2}LI^2$ Joules

2. A C FUNDAMENTALS

Average value of sinusoidal wave form per half cycle = 0.637 × maximum value

R.M.S. value of sinusoidal wave (K_F) form = $\frac{\text{Maximum value}}{\sqrt{2}}$

= 0.707 Maximum value. The least value of K_f is 1.

$$\text{Form factor} = \frac{\text{R.M.S. Value}}{\text{Average Value}} = 1.11$$

$$\text{Peak Factor} = \frac{\text{Maximum Value}}{\text{R.M.S. Value}} = \frac{1}{0.707} = 1.4142$$

Difference between AC and DC

AC	DC
(a) Alternating Current	(a) Direct Current
(b) It changes its direction 50 times/second so, its frequency is 50 Hz.	(b) It does not changes its direction.
(c) It can be changed to D.C.	(c) It cann't be changed to AC.
(d) It is comparitively more dangeours.	(d) It is comparitively less dangerous.

3. A C CHARACTERISTIC OF ELEMENTS R, L AND C

Element	R	L	C
Unit	Ohm	Henry	Farad
Opposition to DC	Resistance R I = V/R	None (Short circuit)	Infinite (Open circuit)
Opposition to AC	Resistance R	Reactance X_L $I = E/X_L$	Reactance X_C $I = E/X_C$
Effect of Frequency	None	X_L increases with F $X_L = WL = 2\pi fL$	X_C decreases with f $X_C = \frac{1}{WC} = \frac{1}{2\pi fC}$
Series Combination	$R_T = R_1 + R_2 + ...$	$X_{LT} = X_{L1} + X_{L2} + ...$	$X_{CT} = X_{C1} + X_{C2} + ...$
Parallel Combination	$R_T = \frac{R_1 R_2}{R_1 + R_2}$	$X_{LT} = \frac{X_{L1} . X_{L2}}{X_{L1} + X_{L2}}$	$X_{CT} = \frac{X_{C1} . X_{C2}}{X_{C1} + X_{C2}}$
Phase angle Voltage and Current expression	i in phase with e $e = E_m \text{Sin} 2\pi ft$ $i = \frac{E_m}{R} \text{Sin} 2\pi ft$	i lags e by 90° $i = \frac{E_m}{X_L} = \text{Sin}\left(2\pi ft + \pi/2\right)$	i leads e by 90° $i = \frac{E_m}{X_C} \text{Sin}\left(2\pi ft - \frac{\pi}{2}\right)$
Impedance of R L C circuit	$Z = \sqrt{R^2 + (X_L - X_C)^2}$	—	—

4. CELL

The combination of two or more than two cells, suitably connected together is called a battery. This is a source of e.m.f. (D.C.) in which chemical energy converts into electrical energy.

Grouping of Cells :

1. Series : When two or more similar cells are connected such that –ve terminal of first is connected to +ve terminal of second and so on is called series grouping.

When higher voltages are required series combination is used.

2. Parallel : When two or more similar cells are connected such that all –ve or +ve terminals are connected together resulting in only one +ve terminal and one –ve terminal.

When larger currents are required parallel combination is required. Because potential is constant on each cell.

3. Series–parallel : When both higher voltage and large current are desired series - parallel connection is used.

Type of Cells :

1. Primary Cell : "Chemical action is not reversible" in them. Example : Voltaic cell, Daniell cell, dry cell. The major drawback of this cell is that e.m.f. developed and current supplied is very small.

2. Secondary Cell : "Chemical action is not reversible" in them. Example : Lead – acid, nickel iron cell. Secondary cells are also known as storage batteries or "Accumulators."

		PRIMARY CELL
Type	**Voltage**	**Remark**
Carbon - Zinc	1.5	Low cost but low current capacity used for flash light or toys
Zinc-chloride	1.5	High current capacity as compared to carbon zinc cell
Lithium	2.95	Long life, high cost, high current capacity and energy density.

SECONDARY CELL

Points of Comparison	**Lead Acid Cell**	**Alkaline**	
		Nickel - Iron	**Nickel - Cadmium**
Positive Plate	Lead peroxide PbO_2	Nickel hydro-oxide $Ni(OH)_4$	Nickel hydro-oxide $Ni(OH)_4$
Negative Plate	Spongy Lead Pb	Iron (Fe)	Cadmium (Cd)
Electrolyte	Dilute solution of sulphuric acid H_2SO_4	Caustic potash KOH	Caustic potash KOH
Average emf/cell	2 V	1.4 V	1.2 V
Efficiency 1. Ampere – hour 2. Watt-hour	 85 – 95% 70 – 80%	 75 – 80% 60 – 65%	 75 – 80% 60 – 65%
Life	1200 - 1250 charge & discharges	About 5 years	About 5 years
Cost	Greater than Primary & Less than alkaline cells	About twice of lead - acid cell	Same as Nickel-iron
Application	Heavy duty application such as power system automobile, telephone exchange etc.	because of robust construction suitable for traction work	Ni-Cd cells are most suitable for floating duties

5. MAGNETIC CIRCUITS

Magnetic Circuit : The closed path followed by magnetic flux is called magnetic circuit.

Magneto-motive force (m.m.f.) : The magnetic pressure which set up or tends to set up magnetic flux in a magnetic circuit is called m.m.f.

m.m.f. = No. of turns × current.

Unit – AT. (AT = Ampere Turns)

Reluctance : The opposition to magnetic flux in a magnetic circuit is know as reluctance.

$$\text{Reluctance} = \frac{L}{a\mu_o\mu_r},$$

Unit = AT/Wb

L is the Length of mag. path in meter a is X –sectional area in m^2

μ_0 = Permeability of air

$= 4\pi \times 10^{-7}$ H/m

μ_r = Relative permeability of material

Magnetic flux : The total magnetic lines of force passing through the material is called magnetic flux. Its symbol is "ϕ".

Unit = Weber

1Wb = 10^8 Lines. of Force.

Ohm's Law for magnetic circuit

m.m.f. = flux × reluctance

Leakage flux : The flux that does not follow the intended path in a magnetic circuit is called a leakage flux.

Magnetic Hysteresis : The phenomenon of lagging of flux density (B) behind the magnetising force (H) in a magnetic material is called magnetic Hysterisis.

Factors on which hysteresis Loss depends :

1. Area of hystersis Loop – Larger area greater Loss.

2. Frequency of reversal of magnetisation—Greater frequency Larger Loss.

3. Volume of material— Greater volume Larger Loss.

Comparison between Magnetic & Electric Circuit

	Magnetic	Electric
1	Flux = mmf/Reluctance	Current = emf/Resistance
2	mmf (ampere turn)	emf (in volts)
3	Reluctance $\frac{L}{a\mu_o\mu_r}$	Resistance = $\rho l/a$
4	Flux density B (wb/m^2)	Current density J (A/m^2)

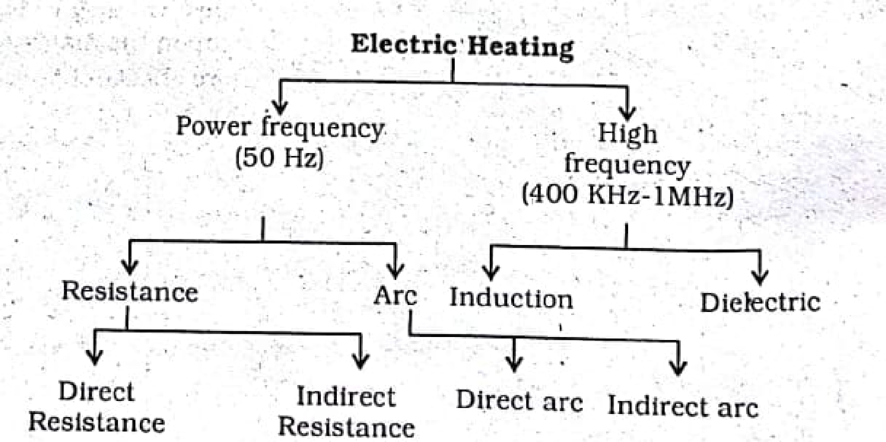
DISSIMILARITIES

1	There is no good magnetic insulator	There are a number of good electric insulators.
2	No energy is consumed in magnetic circuit.	Energy is consumed in electric circuit, $E = I^2Rt$ (Joule)

6. CLASSIFICATION OF INSULATING MATERIALS :

Class	Max Temp°C	Materials
Y	90°C	Cotton, Silk, wood, paper, fibre without impregnation
A	105°C	All materials of category Y impregnated with natural resins, cellulose, insulating oil etc.
E	120°C	Synthetic resin enamels, cotton & paper Laminates with formaldehyde bending.
B	130°C	Mica, glass, asbestos
F	155°C	All materials of class B with more thermally resistant bonding material
H	180°C	Glass fibre and asbestos material, built up mica with appropriate resins.
C	Above 180°C	Quartz mica, ceramics

7. ELECTRIC HEATING :



Electrical energy is used for heating of buildings, for melting of metals, for heat treatment of metals, cooking etc. Its main advantages are cleanliness, absence of fuel gases, ease of temperature control, uniform heating.

Resistance heating : Whenever current passes through some resistance, power loss takes place in the form of heat. An alloy of nickel-cadmium (80% ni, & 20% cd) provides a cheap material for resistance heating. Resistance ovens are used for heat treatment of metals (annealing, Hardening) etc. Resistance heating may be achieved by using (a) metal conductors (b) non-metallic conductors (c) liquid

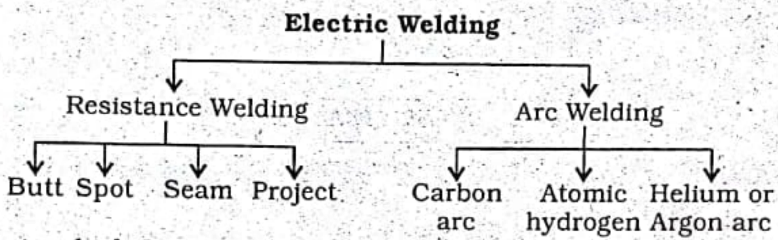
Arc heating—In this method if two electrodes are short circuicted momentarily & on withdrawing them back, an arc will occur between two electrodes even at low temp. This arc provides large quantity of power in small volume.

For high frequency heating when heating process is done on conducting and ferro magnetic material it is called induction heating while, when it is insulating material it is called Dielectric heating.

Eddy current heating—It can easily takes place in vaccum where other methods of heating can not take place.

Dielectric heating—Normally materials heated by this method are combustible which can not be heated by other methods. It is used in drying tobocco, paper, rayon wood etc. Dielectric heating is widely used in industries. It operates on the principle of converting high frequency electric energy into heat energy.

8. ELECTRIC WELDING



Welding is a process in which 2 pieces of metal is to be joined are made plastic by generating heat at the place of joining and then fused together.

In electric arc welding the heat is produced either by striking an arc between the electrode and the metallic joint or by passing heavy current through the joint. The former method is called 'arc welding' and the later 'resistance welding'.

Resistance Welding	Arc Welding
1. AC supply is usually used.	1. Both AC or DC can be used.
2. External pressure is required	2. No external pressure is required
3. No filler material is required.	3. Suitable filler metal electrodes are necessary to get proper strength.
4. It can't be used for repair work.	4. It is most suitable for repair work.
5. Most suitable for mass production	5. Not suitable for mass production.
6. Heat is developed due to flow of current through contact	6. Heat is developed due to arc formed between electrode resistance and work piece.

Resistance Welding—It is used for welding pipes, wires & rods etc. Voltage required is 2-10V & current varies from 50A to several amperes depending upon the material & area to be welded.

Spot welding— It is used for joining two or more sheets of metal. Rods, wires & small pieces can also be welded by this method.

Seam welding—It is actually a series of overlapping spot weld & is suitable for construction of tank, transformer, refrigerator, gasoline tank etc.

Projection welding—It is a modified form of spot welding & is used for certain application which can't be welded by spot welding.

Atomic hydrogen—It is used for welding stainless steel & non ferrous metals at very-very high temp. of about 4000°C.

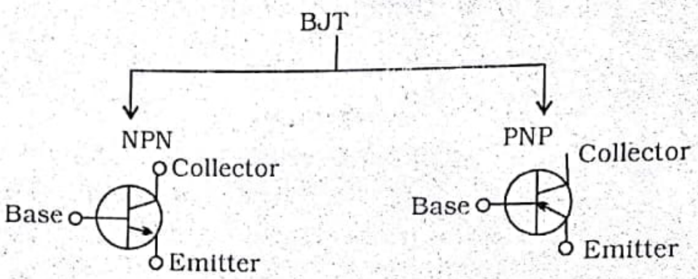
Helium arc : It is used for welding aluminium its alloys & magnesium alloys.

9. ELECTRONIC DEVICES

Diode

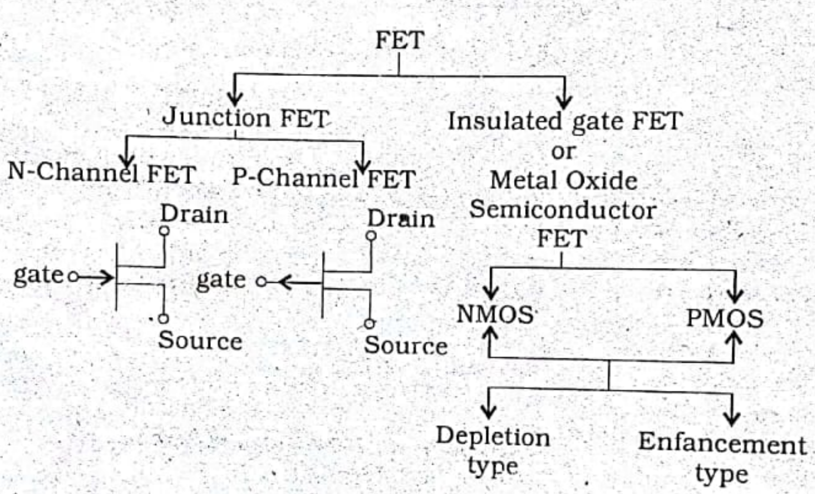
It is a unidirectional device used as electronic switch. It is used in rectifier, clipping and clamping device.

Bipolar junction Transistor

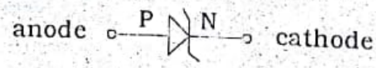


It is used in electronic amplifier, in oscillators, in regulated power supply, in multivibrators.

Field Effect transistor



Zener diode : It is similar to ordinary PN junction diode with very high doping. It is always operated in reverse bias condition. It finds its most importance application in voltage regulation.



Comparison of Transistor Connections

Characteristic	Common base	Common emitter	Common collector
Input resistance	Low about 100Ω	Low about 750Ω	Very high about 750KΩ
Output resistance	Very high about 450 kΩ	High about 45KΩ	Low about 50Ω
Voltage gain	about 150	about 500	Less than 1
Current gain	Less than 1	High 100	High 100
Application	For high frequency application	For audio frequency application	For impedance matching.

Drawback of BJT (Bi-polar junction Transistor) :

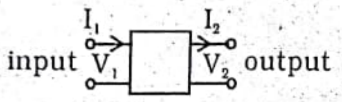
1. The input impedance is very low as compared to FET.
2. It is a bi-polar device. It's operation depends upon flow of electron and holes.
3. Effect of noise is more.

Advantages of FET (Field effect Transistor) :

1. It is a unipolar device as its operation depends upon only one type of charge carriers.
2. It is a voltage operated device.
3. Input impedance is very-very Large.
4. Effect of noise is negligible.
5. Thermal stability is higher.
6. However gain-bound-width product is smaller as compared to BJT.

10. TRANSFORMER

It is a static device which transfers a.c. electric power from one circuit to other at same frequency through magnetic flux linking both circuit, by electromagnetic induction. The voltage level is usually changed. Basic principle of transformer is electro magnetic induction.



$V_2 > V_1$ (Step up transformer)
$V_2 < V_1$ (Step down transformer)

→ At usual flux density silicon steel material has low hysteresis.

→ The core is laminated to minimise the eddy current loss. The laminations are insulated from eath other by light coat of varnish. Its thickness varies from 0.35 mm to 0.5 mm at a frequency of 50 Hz.

→ Power transformers are designed with low copper loss since these operate at high average load, which would cause more copper loss continously.

→ To obtain high efficiency distribution transformer are designed with Low iron losses.

Ideal transformer

$$\frac{E_2}{E_1} = \frac{I_1}{I_2}$$

since $E_2 \propto N_2$, $E_1 \propto N_1$

Also $E_1 \cong V_1$, $E_2 \cong V_2$

$$\frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K$$

Where K is Transformation ratio.

Transformer on DC

The DC is never applied on transformer because there will not be any back emf with DC, so primary current will be much larger than the rated full Load current.

EMF equation

$E_2 = 4.44\, N_2\, F\, \o_m$ volts
$E_1 = 4.44\, N_1\, F\, \o_m$ volts

Where E_2 & E_1 are emf in primary & secondary winding

N_1 & N_2 are no. of turns on primary & Secondary winding respectively.

F is frequency, $\o_m$ is maximum value of flux in weber.

% voltage regulation $= \dfrac{E_2 - V_2}{E_2} \times 100$

Losses in Transformer

- Iron Loss
  - Hysteresis Loss ($P_h = K_h V_f B_m^{1.6}$)
  - Eddy current Loss ($P_e = K_e V f t B_m^2$)
- Copper Loss
  - Cu-Loss in primary ($I_1^2.R_1$)
  - Cu-Loss in secondary ($I_2^2.R_2$)

Efficiency of transformer

$$\eta = \frac{\text{output power}}{\text{output power} + \text{cu Losses} + \text{Iron Losses}}$$

Constant Losses : Hystersis Loss + Eddy current Losses.
Variable Losses : Copper Losses as they depend upon Load.
→ copper Losses vary as a fraction of Load

i.e. If full Load copper Loss is 800 watt. then at 50% or $x = \frac{1}{2}$

$$\therefore \text{Cu loss} = \left(\frac{1}{2}\right)^2 . 800 = 200 \text{ watts.}$$

Condition for maximum efficiency

copper Loss = Iron Loss

All day efficiency is defined as the ratio of output in KWh to the input in KWh of a transformer for 24 hrs.

Testing of transformer :

1. **Open circuit or No load test**—It determines no load or core loss.
2. **Short circuit test :** It determines full load copper losses.

Autotransformer : It is a transformer with only one winding wound on a laminated core. A part of this winding is common to both primary and secondary winding.

11. DC MACHINES

→ It is an electro mechanical energy conversion device.

→ When a machine convert mechanical energy into electrical energy it is called generator.

→ When a machine convert electrical power into mechanical power it is called motor.

→ Although a.c. motor are commonly used in industry but when wide range of speed & good speed regulation is required dc motors are invariably applied.

EMF equation

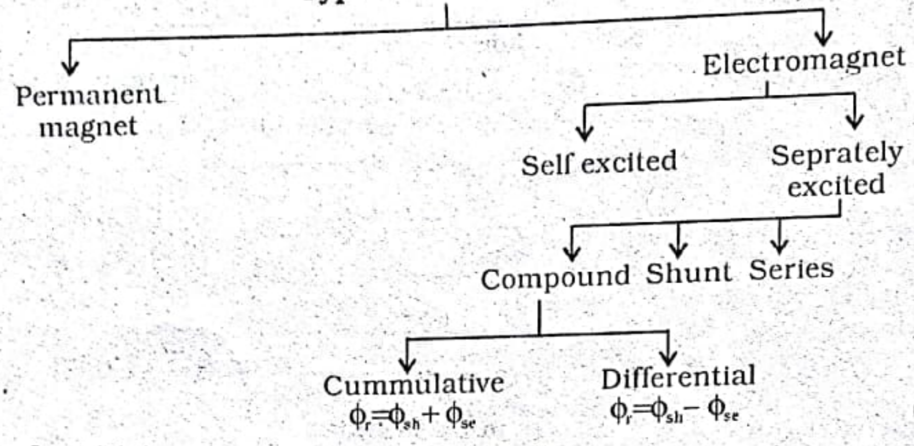
$$e = \frac{NP\phi Z}{60A}$$

N is the speed of armature in rpm, ϕ is the flux per pole in Weber.
Z is the total no. of armature conductor.
A is the no. of parallel path.

Electromagnetic torque

I_a is the armature current $\quad T = \frac{ZP\phi I_a}{2\pi A}$, $\quad T \propto \phi I_a$

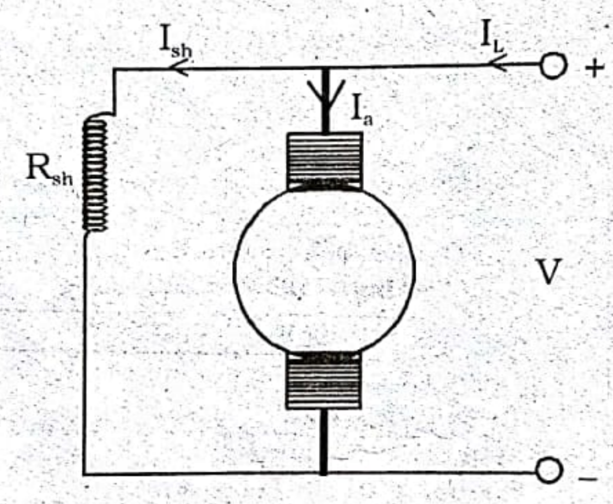
Type of DC Machine

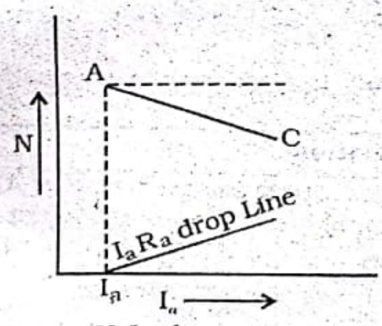


Characteristic of DC Motor

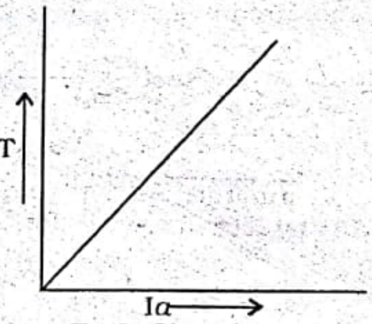
1. Shunt motor

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

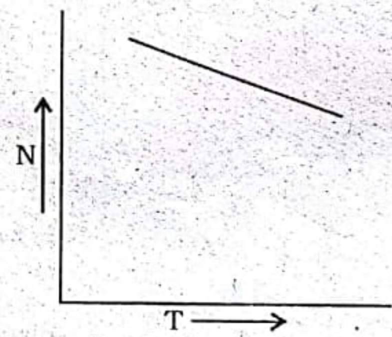




N–I_a characteristic

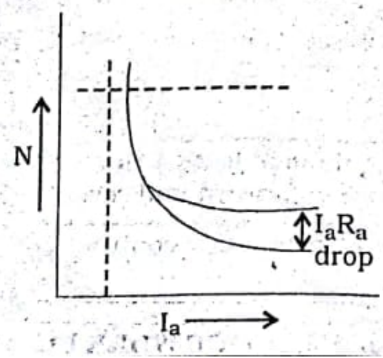


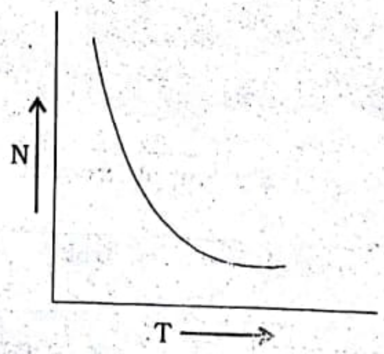
T – I_a Characteristic



N – T Characteristic

2. Series Motor





APPLICATION OF DC MOTOR

Motor	Feature	Uses or Applications
Seprately excited motor	1) Very accurate speed can be obtained. 2) Speed variation from very low value to high value.	Steel rolling mills, paper machines, disel-electric propulsion of ship etc.
Shunt motor	constant speed motor	Lathes, drills, grinders, shapers spinning & weaving machines
Series motor	Variable speed motor, Never operate at no Load as they attain dangerously high speed.	electric traction, cranes elevators
Compound motor	Combines features of both, series & shunt motor	Punching & shearing machine, rolling mills, lifts & mine-hoists etc.

$$\% \text{ speed regulation} = \frac{\text{N.L. speed} - \text{F.L. speed}}{\text{F.L. speed}} \times 100$$

Losses in DC Machine

- Constant
  - Iron Loss
  - Shunt field copper Loss
  - Mechanical Loss
- Variable
  - Armature copper Loss
  - Series Field Cu-Loss
  - Interpole winding Cu-Loss

Stray Losses = Iron Losses + Mechnical Losses

Condition for maximum efficiency : Variable Loss = constant Losses.

Testing of DC Machins

Type of Test	Category of DC M/C to which applicable	Parameter used
Hopkinson test (Back to back test)	One shunt machine run as generator and other shunt machine run as motor.	Full Load Losses.
Retardation or running down test	Shunt motor and generator	Stray Losses
Brake test	All dc motor (small)	efficiency, Losses, Net output

SUMMARY OF SPEED CONTROL METHOD

Motor	Method of speed control	Application
Shunt	1) Resistance in series with armature 2) Variation of field current by resistance in field current. 3) Resistance in armature circuit plus shunt resistance.	Torque reduces as speed reduces. Used for fan, blowers, pumps etc. Accurate control within ± 10%. Flat speed-torque characteristic many applications.
Series	1) Resistance in Shunt with field winding 2) Resistance in series with armature 3) Shunt field turns.	Suitable for higher speed than Normal. Speed control in range 2 : 1 or 3 : 1. HighLosses, suitable for higher speed?
Series–Parallel control	Used on 2 or 4 identical dc series motors.	Used in traction
Ward-Leonard	Separate excitation and dc supply from dc with field control.	Range obtainable 25:1 Speed control effective in forward and reverse direction
Seprately exited	Armature resistance plus field control	wide range of speed control

12. INDUCTION MACHINE OR ASYNCHRONOUS MACHINE

→ 3-phase induction motor are used in industry because of simple and rugged construction, low cost, high efficiency, reasonble good p.f. as well as self starting torque.

→ Induction machine consists of two main parts.

Stator is the stationary part of motor.

Rotor is the rotating part of motor. These are of two types

(1) Squirrel cage rotor

(2) Phase wound rotor

→ **Slip** the difference between rotor speed (N) and the flux speed (N_S) is called slip.

$$\% \text{ slip} = \frac{N_S - N}{N_S} \times 100$$

Rotor slip $N = N_S (1 - S)$

→ The value of slip at full Load varies from about 6% for small motor to about 2% for Large motors.

Rotor current frequency = fractional slip × supply frequency

i.e. $f_r = S \times f$

$$N_S = \frac{120f}{P}$$

EMF equation

stator induced emf

$E_1 = 4.44 \, Kw_1 \, If\phi_m$

rotor induced emf

$E_2 = 4.44 \, Kw_2 T_3 f_r \phi_m$

Where kw_1 & kw_2 = winding factors i.e. product of coil span factor K_c & distribution factor K_d.

T_1 & T_2 = No. of turns/phase for primary & secondary winding resp.

f = stator or supply frequency,

f_r = rotor frequency.

ϕ_m = Maximum value of flux

Rotor induced emf under running condition = slip × rotor induced emf at start

i.e. $E_2 = SE_2s$

Losses in Induction motor

1. Stator Losses

Stator copper Loss

$= I_1^2 R$ (Per phase)

Stator iron Losses

= Hystersis + Eddy current Losses.

Rotor Losses

Rotor copper Loss

$= I_2^2 R_2$ (Per phase)

Rotor iron Losses = usually very small and are neglected.

Mechanical Losses = Windage Losses + friction Losses

Expression for full Load torque

$$T = \frac{3}{W_S} \cdot \frac{S.E_2 S^2.R_2}{R_2^2 + (S \times 2_2 S)^2}$$

W_S = angular synchronous speed

E_2S = rotor induced emf under running condition

R_2 = rotor resistance

X_2S = rotor reactance

S = Slip

Put S=1 in above equation to get

Starting torque,

$$T = \frac{3}{Ws} \cdot \frac{E_2 S^2 R_2}{R_2^2 + X_2 S^2}$$

Maximum torque $T_m = \frac{T_s}{T_m}$

$$= \frac{3.E_2 S^2}{2Ws \, X_2^2}$$

$$\frac{\text{Starting torque}}{\text{Maximum torque}} = \frac{T_s}{T_m}$$

$$= \frac{2a}{a^2 + 1} \text{ where } a = \frac{R_2}{X_2 S}$$

$$\frac{\text{F.L. torque}}{\text{Maximum torque}} = \frac{2Sa}{a^2 + S^2}$$

Squirell Cage motor	Phase Wound motor
Simple construction	It's rotor is phase wound which needs care.
Cheap	Costly
Less maintenance cost	Because of slip ring, brushes etc. require more maintenance cost
High efficiency	Low efficiency
Poor starting torque	external resistance can be added in rotor circuit at start to improve starting torque.

Double cage induction motor

Outer cage has high resistance (brass conductor) & Low reactance while inner cage has low resistance (copper) & high reactance.

Starter

D.O.L.	Stator-Rheostat	Auto transformer	Star-Delta
Used upto 5 HP.	Reduced voltage is applied at start when motor picks up speed variable resistance connected in series with each stator phase is removed.	Expensive. But is suitable for both star connected & delta connected induction motor. It has the advantage that the reduced voltage is obtained by transformer and is not wasted in resistance.	A change-over switch is used at start to reduce currect & it is connected in star but when the motor picks up speed it is connected in delta.

Speed Control $N = \frac{120f}{P}(1-s)$

1. By changing no. of poles 2. By changing frequency 3. by change of slip.

Crawling : Sometimes an induction motor when started on load does not accelerate up to full speed but continues to run at 1/7 of the normal full load speed. This is called crawling of induction motor.

Clogging : Whenever there are equal no. of teeth on stator & rotor, the reluctance of the magnetic cirucuit would be considerably less when the teeth were opposite to one another. Particularly at low voltage, magnetic locking of the teeth on the stator & the rotor may prevent the rotation of rotor. This phenomenon is called clogging.

Induction Motor	Synchronous motor
Self starting Basic principle : mutual induction & no excitation is required. Speed is less than synchronous speed It runs at a lagging P.f. Cheap & Less maintenance	Not self starting. It requires d.c. excitator for field excitation. It only runs at synchronous speed. It runs at lagging, leading and unity P.f. Costly, requires more maintenance.

13. SINGLE PHASE MOTOR :

Summary and characteristic of Single phase motor

Motor type	Maintain Characteristic	Application
Split phase	1. Poor starting torque 2. Low p.f. & efficiency	Non-reversing drives with light load on starting.
Capacitor motor	1. Moderately good starting torque 2. Higher p.f. & efficiency than split-phase.	Suitable for reversing as well as non-reversing drive without heavy starting load, domestic refrigerator, fan etc.
Repulsion	Good starting torque	Suitable for heavy starting. Additional winding needed for reversing
Universal series	Good starting torque, high p.f.	Vacuum cleaner, motorized hand tools.
Hysteresis motor	Motor is noiseless and free from vibration	Ideal for sound equipment

14. SYNCHRONOUS MACHINE

The machine which convert mechanical power into 3-phase electrical power is called synchronous generator or alternator. When the same machine is operated as motor it is called synchronous motor.

The most important relation for these machine is

$$N_s = \frac{120f}{P}$$

N_S is the synchronous speed in rpm.
f is the supply frequency.
P is the no. of poles of machine.
Stator is the stationary part.
Rotor is the rotating part.

1. Salient pole type : Suitable for low and medium speed i.e. 200-1500 rpm. Having large no. of poles & to accomodate them large diameter and small length.

2. Non-salient pole type : Suitable for high speed i.e. 3000 rpm having small no. of poles and therefore have small diameter and large length.

EMF equation : $4.44\, K_c\, k_d\, \phi\, f\, T_m$ volts.
K_c = coil span factor
K_d = Distribution factor
ϕ = flux per pole in Weber
f = frequency in Hz.
T_m = No. of turns connected in series per phase.

15. Measuring Instruments :-