Subject Name: **Basic Electrical and Electronics Engineering**

Subject Code: **BT-1004**

Semester: **1st / 2nd**

Electrical Machines: Syllabus:

Construction, Classification & Working Principle of DC machine, induction machine and synchronous machine. Working principle & Emf equation of 3-Phase induction motor, Concept of slip in 3- Phase induction motor, Explanation of Torque-slip characteristics of 3-Phase induction motor. Types of losses occurring in electrical machines. Applications of DC machine, induction machine and synchronous machine.

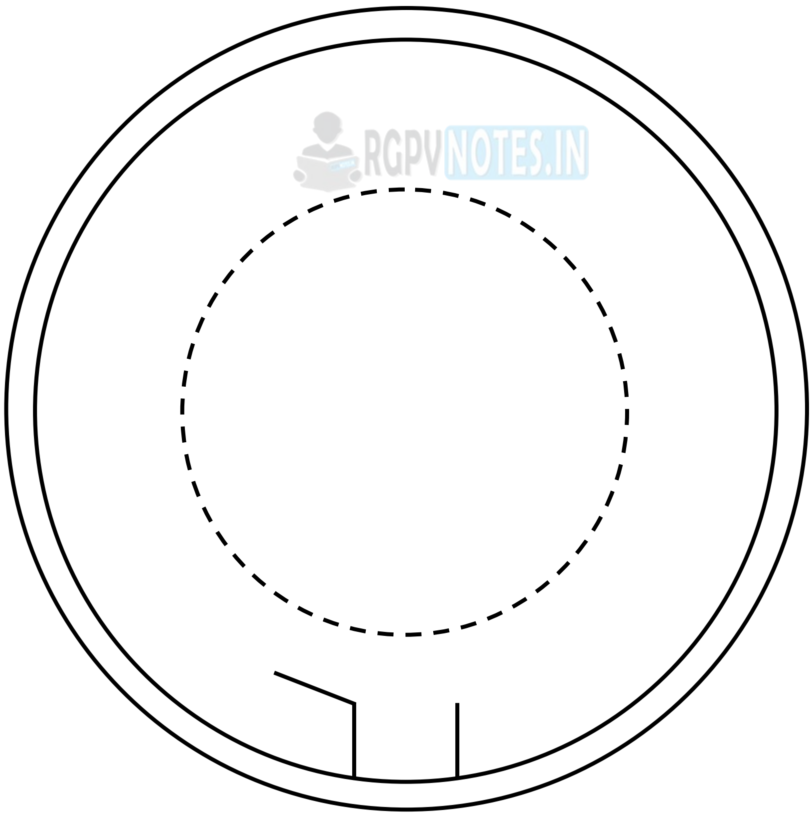
D.C. MACHINE

A DC machine can work as a motor as well as a generator. There is no constructional difference between a DC motor and a DC generator.

Constructional Features: Figure - 1 shows the constructional details of a DC Machine. Some of the essential parts of a DC machine are Yoke, Main poles, Field coil, Armature core, Armature winding, Commutator, Brushes, Bearings and End Covers.

Yoke: It is the outermost covering made of cast iron which provides support for the main poles. It also carries the magnetic flux produced by the poles.

Main poles: They are made up of laminations bunched together and fixed to the yoke. The pole core accommodates the field coils. The pole shoe helps in spreading the flux in the air gap.



Field coil: They are placed around the pole core supported by the pole shoe. The field coils after being mounted on the main poles are connected such that, when a DC exciting current flows through them, the main poles alternately become north and south poles producing the necessary flux.

Armature core: It is a laminated cylindrical core keyed to the machine shaft with slots on the outer periphery to accommodate the armature winding as shown in Fig. - 2. The important function of the core is to provide a path of very low reluctance to the flux through the armature from North pole to South pole.

Armature winding: Copper wire is used to make the armature winding in the slots of the armature core, which form the conductors. The conductors are insulated from each other as well as from the core. The armature winding of a DC machine forms a closed circuit. Depending on the manner in which the conductors are connected to the commutator segments, we have lap winding and wave winding.

Commutator: It converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit. It is a cylindrical structure mounted on the shaft of the armature core on one side. It has many segments of copper that are insulated from each other by mica sheets. The number of segments will be equal to the number of armature coils. The commutator facilitates for the collection of current from the armature conductors.

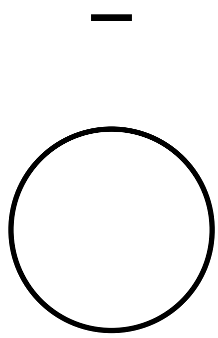


FIGURE - 2

Brushes: They are made of carbon and will be equal to the number of main poles. They rest on the commutator and help in collection of current from the commutator. The brushes are connected to brush holders that are accommodated inside the end covers.

Bearings: The bearings are fixed in the end covers. The shaft of the armature core is held on either side by the bearings. Their function is to reduce friction.

End Covers: They cover the yoke of the machine on either side. They are made of thick sheet metal. They accommodate bearings and brush holders. They also provide ventilation.

D.C. MOTOR

Working principle of DC machine as motor: A DC motor converts electrical energy into mechanical energy. Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductors experience a mechanical force, whose direction is given by Fleming's left hand rule and its magnitude is given by $F = Bil$ Newtons

Working as a motor: The field winding is excited such that the main poles become alternately north and south, the magnetic field is established in the air gap between the main poles and armature core. The DC supply is also given to the armature terminals so that current flows through the armature conductors. The current carrying conductors when placed in a magnetic field experience a mechanical force. The direction of the force developed in all the conductors will be in the same direction. These forces acting on the shaft give rise to torque.

Types of DC Motor:

- D C Motor
  - D C Shunt Motor
  - D C Series Motor
  - D C Compound Motor
    - Cumulative Compound
    - Differential Compound

Applications of DC Motors: Shunt motors are used for applications which require medium level torque such as Blowers, Fans, Centrifugal and Reciprocating pumps, Lathe machines, Machine tools.

Series motors are used for applications which require high starting torque such as in Cranes, Trolleys, Conveyers, Elevators and Electric locomotives.

Cumulative Compound motors are also used for applications which require high starting torque such as in Rolling mills, Heavy Planers and Elevators.

Differential Compound motors are not suitable for practical applications.

D.C. GENERATOR

Working principle of DC machine as generator: A DC generator is a machine that converts mechanical energy into electrical energy. The energy conversion in a DC generator is based on Faradays laws of electromagnetic induction i.e. the principle of production of dynamically induced emf. Whenever a conductor cuts magnetic flux an emf is induced, which will cause a current to flow, if the conductor circuit is closed. The direction of induced emf and hence current is given by Fleming's right hand rule. Hence the basic requirement for a generator will be a magnetic field, some number of conductors and motion of the conductors with respect to the magnetic field.

Working as a generator: When DC supply is given to the field coils, the main poles get magnetized and the pole shoes spread the magnetic flux through the air gap over the armature conductors accommodated in the armature core. If the armature core is rotated by a prime mover, armature conductors cut the magnetic flux and have induced emf in them. The armature coils connected to the commutator segments form a closed loop. The brushes moving over the commutator segments collect the current. If the brushes are externally connected to a load circuit, current flows in the external circuit.

Emf equation of DC generator:

Let Φ = Flux per pole in weber ; Z = Total number of armature conductors ; P = Number of poles

N = Speed of armature in rpm ; A = Number of parallel paths, where A = 2 for wave winding

and A = P (i.e. No. of poles) for lap winding

Eg = emf of the generator = emf per parallel path

Flux cut by one conductor in one revolution of the armature, dΦ = PΦ weber

Time taken to complete one revolution, $dt = 60/N$ **seconds**

$$emf\ generated\ per\ conductor = \frac{d\Phi}{dt} = \frac{P\Phi}{60/N} = \frac{P\Phi N}{60}\quad volts$$

$$emf\ of\ generator,\ E_g = emf\ per\ parallel\ path$$

$$= emf\ per\ conductor \times No.\ of\ conductors\ in\ series\ per\ parallel\ path$$

$$\therefore E_g = \frac{P\Phi N}{60} \times \frac{Z}{A} \quad = \quad \frac{P\Phi ZN}{60\ A}\ volts$$

Types of DC Generator:

- **D C Generator**
  - **Separately Excited**
  - **Self Excited**
    - **D C Shunt Generator**
    - **D C Series Generator**
    - **D C Compound Generator**
      - **Cumulative Compound**
      - **Differential Compound**

Applications of DC Generators: Separately excited generators are used for feeding supply to equipment used for Electro-plating and Electro-refining of materials.

Shunt generators feed supply to equipment used for Battery charging and Lighting loads.

Series generators are used as Boosters on DC feeders and for applications that need constant current.

Cumulative compound generators are usually used for Lighting purposes.

Differential compound generators are used for feeding supply to Electric arc welding equipment.

THREE PHASE INDUCTION MOTOR

An induction motor is an AC machine that converts electrical energy into mechanical energy. The rotor of the Induction motor gets its excitation through induction hence it is called Induction motor.

Production of Rotating magnetic field: Let us consider the 3 windings of the three phases of an induction motor stator with assumed positive directions of currents and the mmf space phasors as shown in Fig. -3.

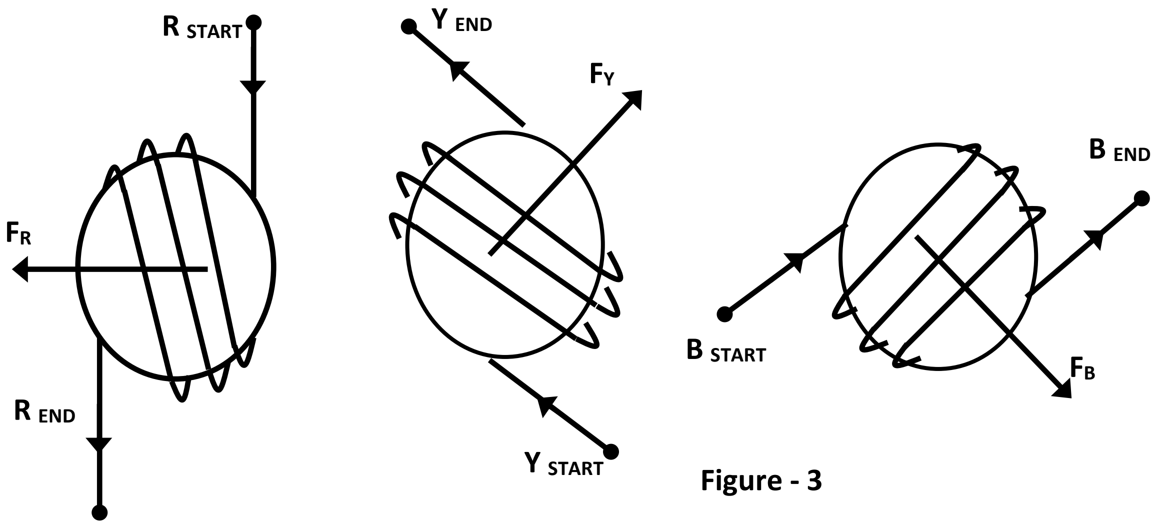


Figure - 3

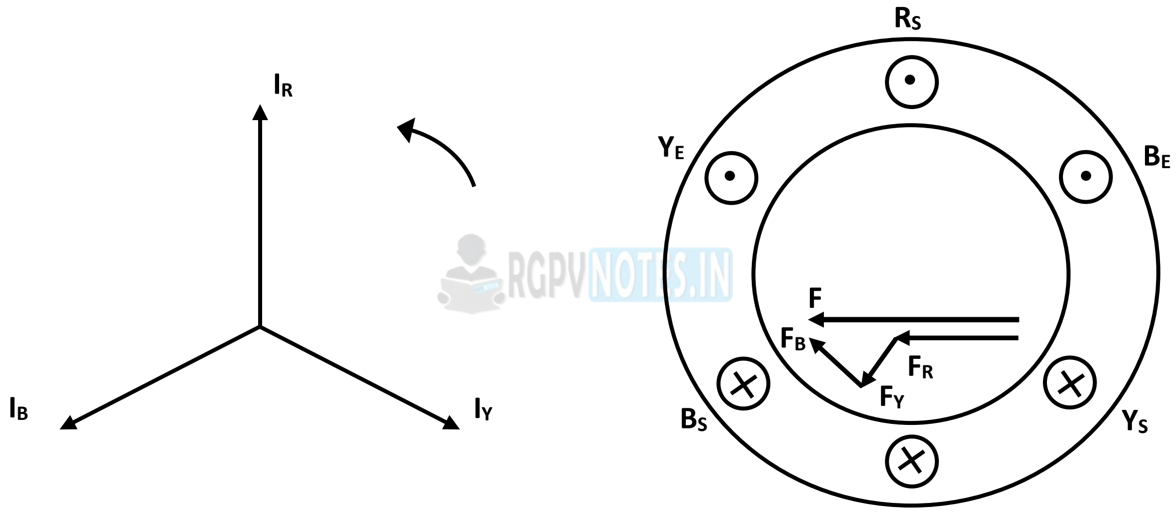


Figure – 4 (a)

The winding of phase Y is displaced from the winding of phase R by 120° and the winding of phase B is displaced from the winding of phase Y by120°. F_R, F_Y and F_B denote the mmf's of the three windings at the instant when currents in them are at their positive maximum values. As the currents alternate, the individual mmf's will vary in magnitude and change direction so as to follow the changes in the currents. Let us consider two instants as shown in Fig -4.

Figure - 4(a) corresponds to the instant when I_R is at its positive maximum value, I_Y is negative and half its maximum value, I_B is also negative and half its maximum value. So F_Y and F_B have half the magnitude of F_R since currents in phases Y and B are negative, F_Y and F_B are shown opposite to that shown in Figure - 3, F is the resultant of F_R, F_Y and F_B.

Fig 4(b) corresponds to the instant 30° later when I_R is positive and $\sqrt{3}/2$ of its maximum value, I_Y is zero, I_B is negative and $\sqrt{3}/2$ of its maximum value. So F_Y is zero, F_R and F_B are equal in magnitude. It is observed that the resultant mmf, F has the same magnitude but has advanced by 30°. So an elapse of 30 electrical

degrees in time results in a rotation of mmf by 30°. By considering more instants of time it will be seen that the movement of current phasor by a certain angle in the anticlockwise direction results in the rotation of the resultant mmf by the same angle in the clockwise direction.

Hence it is clear that when three phase voltages are applied to three phase windings, the currents flowing through the windings produce a rotating magnetic field that is of constant amplitude and constant speed.

Construction: The two main parts of an induction motor are Stator and Rotor.

Stator: It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current loss. A number of evenly spaced slots are provided on the inner periphery of the laminations. The insulated conductors are placed in the stator slots and are suitably connected to form a balanced three-phase star or delta-connected circuit. The three phase stator winding is wound for a definite number of poles as per the requirement of speed.

Rotor: The rotor is mounted on a shaft with a laminated core having slots on the outer periphery. Depending on the type of winding placed in the slots, we have two types of rotors - Squirrel cage rotor and Slip ring or wound rotor.

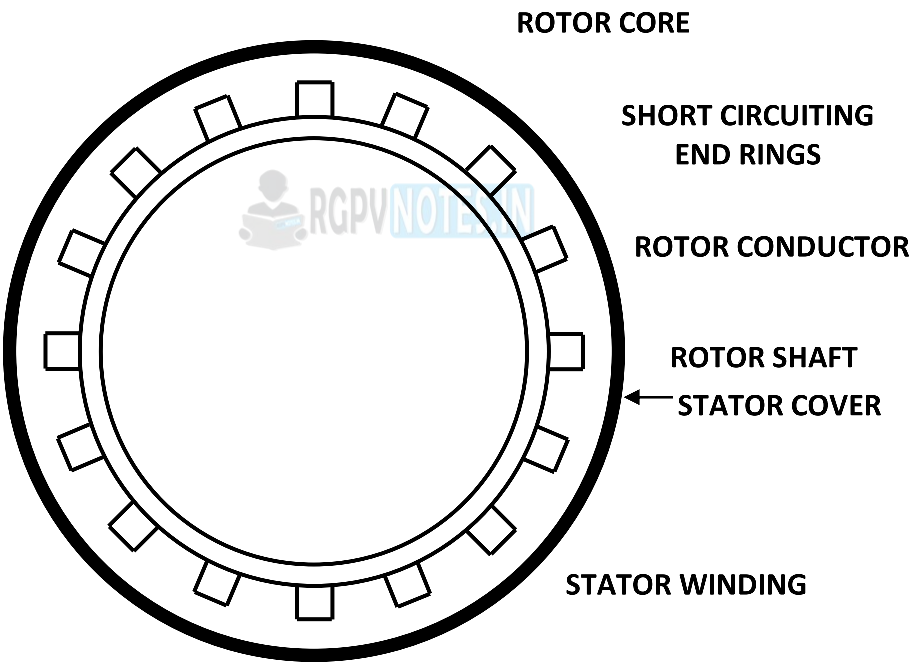


Fig. - 5 Constructional details of a squirrel cage induction motor

Squirrel cage rotor: It consists of a laminated cylindrical core having parallel slots on its outer periphery. Copper or Aluminum bars are placed in each slot. All these bars are joined at either ends by copper or aluminum rings called end rings. This forms a permanently closed circuit winding. As the placing of bars and end rings resembles a squirrel cage it is called squirrel cage rotor. As the rotor circuit is a closed one external resistance cannot be added.

Wound rotor: It consists of a laminated cylindrical core and carries a three phase winding similar to that on the stator. The rotor winding is uniformly distributed in the slots and is usually connected in star. The open ends of the rotor windings are brought out and connected to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring. The three brushes are connected to a three phase star connected rheostat to vary the resistance of the rotor circuit. At starting the resistance is included to enhance the starting torque and gradually reduced as the motor picks up speed.

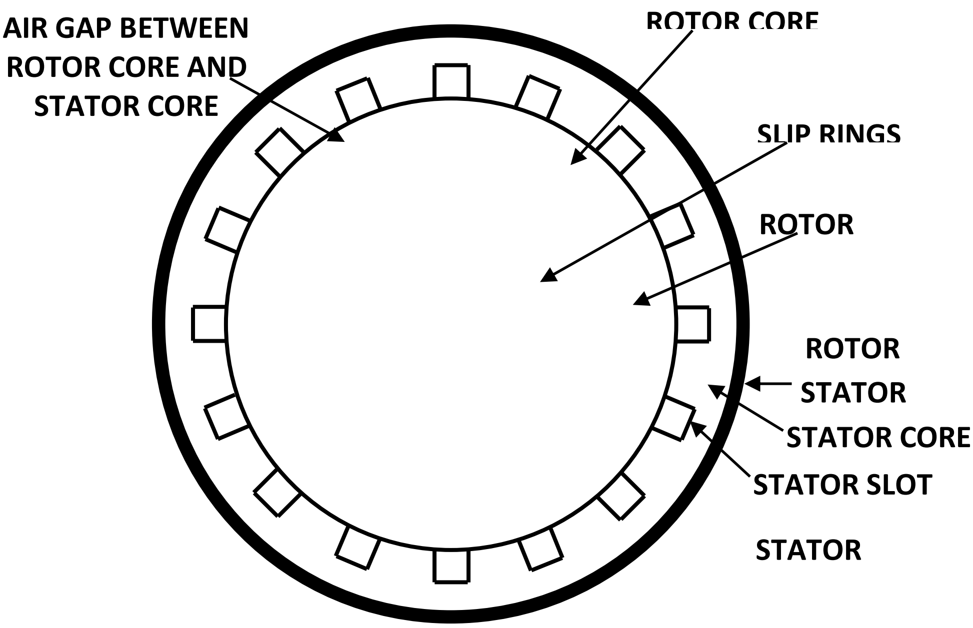


Fig. - 6 Constructional details of a slip ring induction motor

<u>Working and Principle of operation</u>: When three phase voltages are applied to the three phase stator winding, currents flow through the stator winding and a rotating magnetic field is set up. This rotating magnetic field rotates around the rotor at synchronous speed given by $N_S = 120f / P$. This rotating magnetic field passes through the air gap and cuts the rotor conductors that are initially stationary. Due to the relative speed between the rotating flux and the stationary rotor, emf's are induced in the rotor conductors. Since the rotor circuit is a closed one, currents start flowing in the rotor conductors. When current carrying conductors are placed in a magnetic field produced by the stator, the rotor conductors are acted upon by a mechanical force. The sum of the mechanical forces of all the conductors produces a torque that tends to move the rotor in the same direction as the rotating field.

<u>Applications</u>: Squirrel cage induction motors are simple and rugged in construction, cheap and require less maintenance. They are preferred for many industrial applications. They are used in – Lathes, Drilling machines, Industrial and Agricultural pumps, Compressors and Industrial drives.

Slip ring induction motors when compared to squirrel cage induction motors have high starting torque, smooth acceleration under heavy loads, adjustable speed and good running characteristics. They are used in - Lifts, Cranes and Conveyers.

<u>Emf equation of 3-Phase induction motor</u>

Let Φ = Flux per pole, in Wb

P = Number of poles

N_s = Synchronous speed in r.p.m.

f = Frequency of induced e.m.f. in Hz

Z = Total number of conductors

Z_{ph} = Conductors per phase connected in series

∴ Z_{ph} = Z/3 as number of phases = 3.

Consider a single conductor placed in a slot.

The average value of e.m.f. induced in a conductor = dΦ/dt

For one revolution of a conductor,

e_{avg} per conductor = (Flux cut in one revolution)/(time taken for one revolution)

Total flux cut in one revolution = Φ x P

Time taken for one revolution is $60/N_s$ seconds.

∴ e_{avg} per conductor = ΦP / ($60/N_s$)

= Φ ($PN_s/60$) .... (1)

But f = $PN_s/6120$

∴ $PN_s/60 = 2f$

Substution in (1),

e_{avg} per conductor = 2 f Φ volts

Assume full pitch winding for simplicity i.e. this conductor is connected to a conductor which is 180° electrical apart. So there two e.m.f.s will try to set up a current in the same direction i.e. the two e.m.f. are helping each other and hence resultant e.m.f. per turn will be twice the e.m.f. induced in a conductor.

∴ e.m.f. per turn = 2 x (e.m.f. per conductor)

= 2 x (2 f Φ)

= 4 f Φ volts

Let T_{ph} be the total number of turn per phase connected in series. Assuming concentrated winding, we can say that all are placed in single slot per pole per phase. So induced e.m.f.s in all turns will be in phase as placed in single slot. Hence net e.m.f. per phase will be algebraic sum of the e.m.f.s per turn.

∴ Average E_{ph} = T_{ph} x (Average e.m.f. per turn)

∴ Average Eph = T_{ph} x 4 f Φ

But in a.c. circuits R.M.S. value of an alternating quantity is used for the analysis. The form factor is 1.11 of sinusoidal e.m.f.

K_f = (R.M.S.)/Average = 1.11 .... for sinusoidal

∴ R.M.S. value of E_{ph} = K x Average value

E = 4.44 x f Φ T_{ph} volts .... (2)

Note : This is the basic e.m.f. equation for an induced e.m.f. per phase for full pitch, concentrated type of winding.

Where T_{ph} = Number of turns per phase

Concept of Slip in 3-Phase Induction Motor

- We know that, an induction motor consists of two assemblies i.e., rotor and stator.
- The interaction of currents that is flowing in rotor and stator bars generate a torque. In an actual operation, the rotor speed always lags the magnetic field's speed, thereby allowing the rotor bars to cut the magnetic lines of force and produce torque. This speed difference is called slip.
- Therefore, the difference between the synchronous speed Ns of the rotating stator field and the actual rotor speed N is called slip.
- The slip increase with load and is necessary for torque production. Slip speed is equal to the difference between rotor speed and synchronous speed. Percent slip is slip multiplied by 100.
- Slip is expressed as a percentage of synchronous speed i.e.,

% of slip(s) = [(Ns-N)/Ns] *100

- The quantity Ns-N is sometimes called as slip speed.
- When the rotor is stationary,slip s=1 or 100%
- In an induction motor, change in slip from no load to full load is hardly 0.1%to 3% so that it is essentially a constant speed motor.
- Three phase induction motor is a particular form of transformer which has secondary winding rotating. In transformer, the frequency of primary and secondary winding is same but in induction motor the frequency of emf induced in rotor depends on slip.

Explanation of Torque-slip characteristics of 3-Phase induction motor

As the induction motor is located from no load to full load, its speed decreases hence slip increases. Due to the increased load, motor has to produce more torque to satisfy load demand. The torque ultimately depends on slip as explained earlier. The behavior of motor can be easily judged by sketching a curve obtained by plotting torque produced against slip of induction motor. The curve obtained by plotting torque against slip from s = 1 (at start) to s = 0 (at synchronous speed) is called torque-slip characteristics of the induction motor. It is very interesting to study the nature of torque-slip characteristics.

We have seen that for a constant supply voltage, E_2 is also constant. So we can write torque equations as,

$$T \propto \frac{sR_2}{R_2^2 + (sX_2)^2}$$

Now to judge the nature of torque-slip characteristics let us divide the slip range (s = 0 to s = 1) into two parts and analyse them independently.

i) Low slip region :

In low slip region, 's' is very very small. Due to this, the term $(s X_2)^2$ is so small as compared to R_2^2 that it can be neglected.

$$T \propto \frac{sR_2}{R_2^2} \alpha\ s \qquad \text{As } R_2 \text{ is constant}$$

Hence in low slip region torque is directly proportional to slip. So as load increases, speed decreases, increasing the slip. This increases the torque which satisfies the load demand.

Hence the graph is straight line in nature.

At $N = N_s$, s = 0 hence T = 0. As no torque is generated at $N = N_s$, motor stops if it tries to achieve the synchronous speed. Torque increases linearly in this region, of low slip values.

ii) High slip region :

In this region, slip is high i.e. slip value is approaching to 1. Here it can be assumed that the term R_2^2 is very very small as compared to $(s X_2)^2$. Hence neglecting from the denominator, we get

$$T \propto \frac{sR_2}{(sX_2)^2} \alpha \frac{1}{s} \qquad \text{where } R_2 \text{ and } X_2 \text{ are constants}$$

So in high slip region torque is inversely proportional to the slip. Hence its nature is like rectangular hyperbola.

Now when load increases, load demand increases but speed decreases. As speed decreases, slip increases. In high slip region as T α1/s, torque decreases as slip increases.

But torque must increases to satisfy the load demand. As torque decreases, due to extra loading effect, speed further decreases and slip further increases. Again torque decreases as T α1/s hence same load acts as an extra load due to reduction in torque produced. Hence speed further drops. Eventually motor comes to standstill condition. The motor cannot continue to rotate at any point in this high slip region. Hence this region is called unstable region of operation.

SYNCHRONOUS MACHINES

Synchronous machines are three phase electrical machines which rotate at synchronous speed. A synchronous machine can work as a motor as well as a generator. There is not much constructional difference between a synchronous motor and a synchronous generator. The stator core will be identical but the rotors shall be different.

Construction: The main parts of a synchronous machine are - Stator frame, Stator core and Rotor. The stator frame usually holds the stampings of the stator core and windings in position. The frame is cast for small machines and for large machines the frame is fabricated from mild steel plates. Holes are provided in the stator frame for ventilation as the stator core has radial ventilating spaces provided in the stampings.

Stator core: It is made up of laminations of special magnetic iron or steel alloy. The core is laminated to minimize eddy current loss. The lamination may be a single stamping or made up of segments. The laminations are insulated from one another and have radial spaces between them for allowing the cooling air to pass through. The slots may be totally open or semi closed in which the windings of the stator are placed.

SYNCHRONOUS GENERATOR

Rotor for generator: Rotor used in synchronous machines which work as a generator are of two types - Salient pole and Non - Salient pole.

Salient pole or Projecting pole type: The rotor has laminated projecting poles shaped in a specific manner and fixed to the cast iron rotor wheel. The projecting pole makes provision for placing the field coil for DC excitation. The individual field windings are connected in series in such a way that when energized, adjacent poles become north and south. The DC supply to the field coils is fed through brushes sliding over slip rings fixed to the shaft of the rotor. These rotors have large diameters and short axial lengths. This type of rotor is employed for slow and medium speed machines mostly driven by diesel engines.

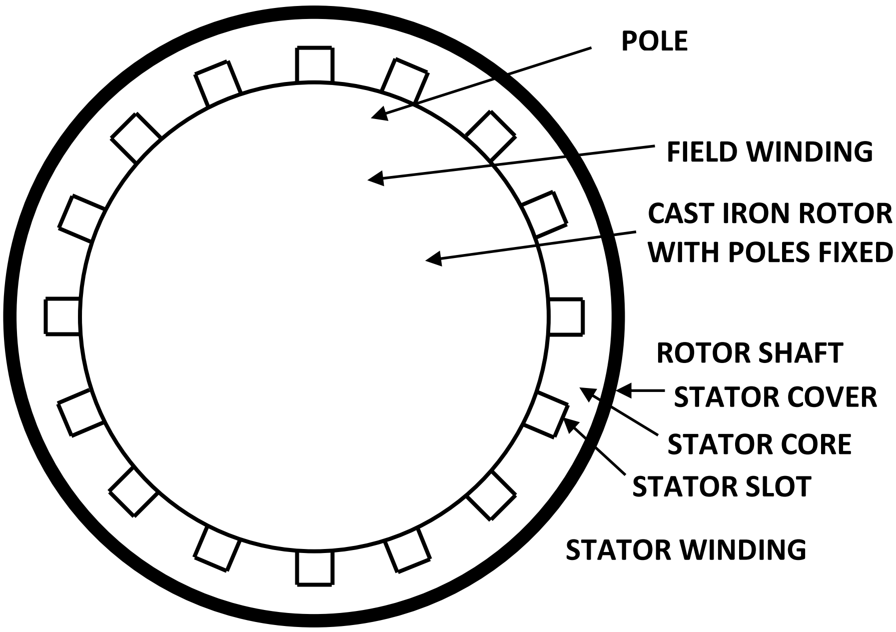


Fig. - 7 Constructional details of a salient pole synchronous machine

Non-Salient or smooth cylindrical type: The rotor is made of smooth solid forged steel radial cylinder having a number of slots along the outer periphery. The field winding is placed in these slots and connected in series. The un-slotted part of the rotor forms the pole faces. These rotors have smaller diameters and large axial length. The number of poles is restricted to 2 or 4 poles. The windings are placed in the slots around the pole faces in such a way that, the flux density is maximum on the polar central line and decreases on either side. DC supply is given to the field winding through slip rings and brushes so that alternate north and south poles are formed. These rotors are used for high-speed machines driven by turbines.

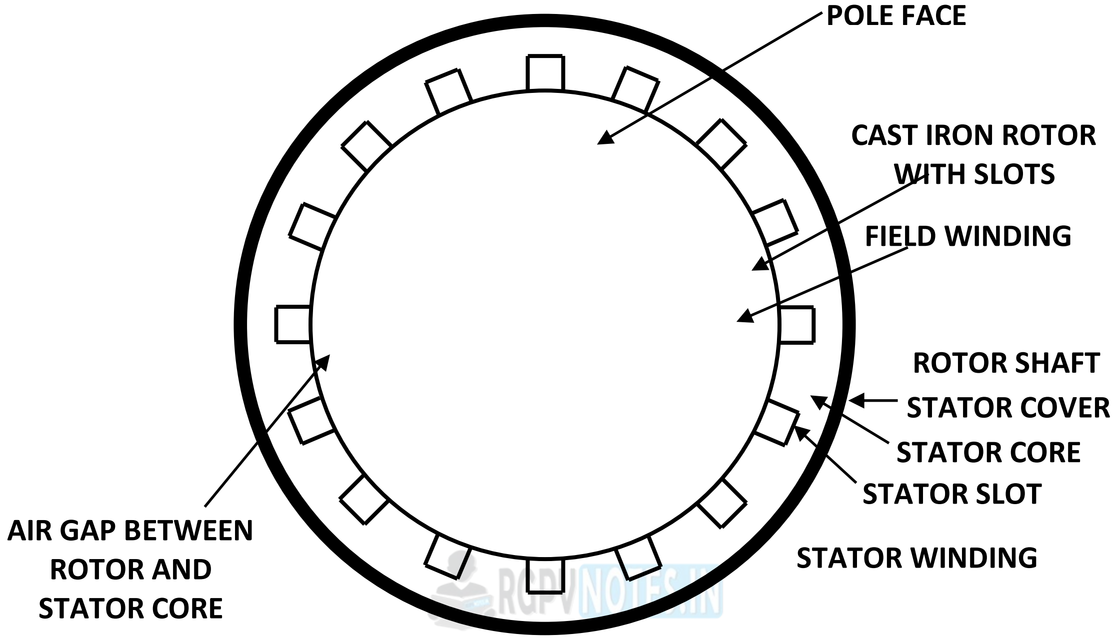


Fig. - 8 Constructional details of a non-salient pole synchronous machine

Working and Principle of operation as a generator: A synchronous generator operates on the fundamental principle of electromagnetic induction. It has a field winding on the rotating part and is fed with DC supply through two slip rings. The field windings develop alternate N and S poles on the rotor. The armature winding which is made for three phase is placed in the slots of the stator which is stationary. When the rotor is rotated by a prime mover, the magnetic flux of rotor poles cut the armature conductors placed in the slots of the stator. Consequently emf is induced in the armature conductors due to Electromagnetic Induction. The induced emf is alternating since N and S poles of rotor pass under the armature conductors. The direction of induced emf can be found by Fleming's right hand rule and the frequency is given by f = PN/120. The magnitude of the induced emf in each phase of the armature winding is the same but they differ in phase by120°.

Applications: Synchronous generators are used in all power plants for generation of Electricity.

Emf equation:

Let Z = Number of conductors in series per phase, Φ = Flux per pole in weber

P = Number of rotor poles, N = Rotor speed in rpm

In one revolution (i.e. $60/N$ sec) each stator conductor is cut by $P\Phi$ weber

$i.e. \quad d\Phi = P\Phi$ and $dt = 60/N$

$$Average\ emf\ induced\ in\ one\ stator\ conductor = \frac{d\Phi}{dt} \quad ; \qquad \therefore \frac{d\Phi}{dt} = \frac{P\Phi}{60/N} = \frac{P\Phi N}{60}$$

As there are Z conductors in series per phase

$$Average\ emf\ per\ phase = \frac{P\Phi N}{60} \times Z \quad ; \ we\ have \ \ f = \frac{PN}{120} \quad or \ \ N = \frac{120f}{P}$$

$$Average\ emf\ per\ phase = \frac{P\Phi Z}{60} \times \frac{120f}{P} \ = 2f\Phi Z \ \text{ volts}$$

$$rms\ value\ of\ emf\ per\ phase = \ Average\ emf\ per\ phase \times Form\ factor \ = 2f\Phi Z \times 1.11$$

$$E_{rms}/phase = 2.22f\Phi Z \quad \text{or} \quad E_{PH} = 2.22K_pK_df\Phi Z$$

where K_p - Pitch factor and K_d - Distribution factor.

$$Finally\ we\ have\ \ E_L = \sqrt{3}\,E_{PH} \ ; \qquad \therefore E_L = \sqrt{3} \times 2.22K_pK_df\Phi Z$$

SYNCHRONOUS MOTOR

Rotor for synchronous motor: There are two types of rotors - With amortisseur winding on rotor pole faces and without amortisseur winding.

The rotor used for the motor has laminated projecting poles shaped in a specific manner fixed to the cast iron rotor wheel. The projecting poles make provision for placing the field coil for DC excitation. The pole faces have slots for placing the amortisseur winding for starting. The amortisseur winding consist of copper or bronze bars embedded in the slots and short circuited at both ends by conducting rings, similar to the squirrel cage winding to develop starting torque by induction motor action. This winding also serves to damp out oscillations of speed during normal operation.

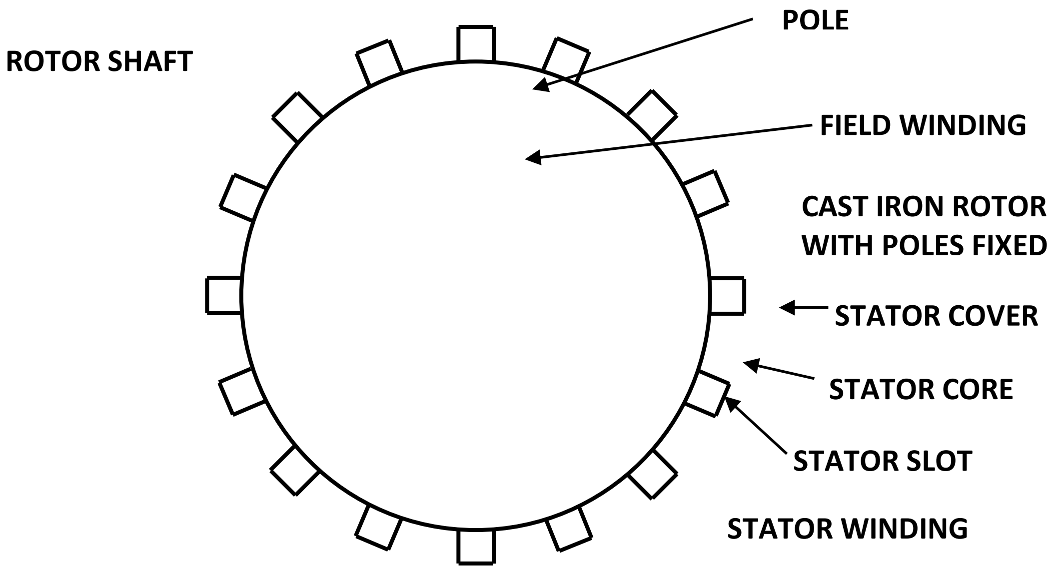


Fig. - 9 Constructional details of a synchronous machine with ammortisseur winding

<u>Working and Principle of operation as a motor</u>: The stator of a synchronous motor when fed by a three phase AC supply, produces a magnetic flux of constant magnitude but rotating at synchronous speed. The rotor pole faces have the amortisseur winding which helps in developing the starting torque by induction motor action. As the motor approaches the synchronous speed, the rotor field winding is excited by a DC source which creates alternate N and S poles on the rotor. The poles of the rotor will face the poles of opposite polarity on the stator and a strong magnetic attraction is setup between them. The rotor poles lock in with the poles of rotating flux. Consequently the rotor rotates at the same speed as the stator field ie. at synchronous speed. When the rotor rotates at synchronous speed, ie. the same speed as that of rotating magnetic field, there will be no emf induced in the amortisseur winding. Hence due to the magnetic locking the synchronous motor can only run at synchronous speed.

<u>Applications</u>: Synchronous motors with speeds below 500 rpm are used in Electroplating, Reciprocating compressors, Centrifugal pumps, Rolling mills and Paper mills.

Synchronous motors with speeds above 500 rpm are used in Fans, Blowers and Frequency changers. Over excited Synchronous motors on no load draw leading power factor current which can be used in Electrical sub-stations to improve power factor of the power system.

<u>Types of losses occurring in Electrical machines</u>:

The losses occurring in electrical machines can be listed as:

1. **Constant losses**

2. **Losses occurring in the machine which are proportional to the current drawn by the machine**
3. **Losses in machines which are proportional to the square of the current drawn by the machine**

- **Losses can be classified as Constant losses and Variable losses**
- **Constant losses comprise of Core losses and Mechanical losses**
- **Core losses are made up of Hysteresis and Eddy current loss**
- **Mechanical losses comprise of Windage and Friction loss**
- **Variable losses comprise of Copper losses and Stray load losses**
- **Copper losses comprise of Stator copper loss and Rotor copper loss**
- **Stray load losses can occur in the core as well as in the winding**

Basic Electronics: Number systems and their conversion used in digital electronics, Demorgan's theorem,Logic Gates, half and full adder circuits, R-S flip flop, J-K flip flop. Introduction to Semiconductors, Diodes, V-I characteristics, Bipolar junction transistors (BJT) and their working, introduction to CC, CB and CE transistor configurations, different configurations and modes of operation of BJT.

NUMBER SYSTEMS:

BINARY NUMBER SYSTEM : - This number system has a base or radix of 2. The symbols or digits used in this system are 0 & 1.

OCTAL NUMBER SYSTEM : - This number system has a base or radix of 8. The symbols or digits used in this system are 0 through 7 i.e.(0, 1, 2, 3, 4, 5, 6, 7)

DECIMAL NUMBER SYSTEM :- This number system has a base or radix of 10. The symbols or digits used in this system are 0 through 9 i.e. (0, 1, 2, 3, 4, 5, 6, 7, 8, 9)

HEXADECIMAL NUMBER SYSTEM :- This number system has a base or radix of 16. The symbols or digits used in this system are 0 through F i.e. (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F)

(1) BINARY TO DECIMAL CONVERSION:-

$(1111.11010)_2 = (\,?\,)_{10}$

Integeral part : $(1111)_2 = (1 \times 2^3) + (1 \times 2^2) + (1 \times 2^1) + (1 \times 2^0)$

$= 8 + 4 + 2 + 1$

$= 15$

ie. $(1111)_2 = (15)_{10}$

Fractional Part : $(0.11010)_2 = (1\times 1/2) + (1\times 1/4) + (0\times 1/8) + (1 \times 1/16) + (0\times 1/32)$

$= 0.5 + 0.25 + 0 + 0.0625 + 0$

$= 0.8125$

ie. $(0.11010)_2 = (0.8125)_{10}$

Thus $(1111.11010)_2 = (15.8125)_{10}$

2) DECIMAL TO BINARY CONVERSION :-

$(15.812)_{10} = (\,?\,)_2$

Integeral part :

2	15	1
2	7	1
2	3	1
	1	

ie. $(15)_{10} = (1111)_2$

Fractional Part :

$(0.812 \times 2) = 1.624 \rightarrow 1$

$(0.624 \times 2) = 1.248 \rightarrow 1$

$(0.248 \times 2) = 0.496 \rightarrow 0$

$(0.496 \times 2) = 0.992 \rightarrow 0$

$(0.992 \times 2) = 1.984 \rightarrow 1$

ie. $(0.812)_{10} = (0.11001$

Thus $(15.812)_{10} = (1111.11001)_2$

3) OCTAL TO DECIMAL CONVERSION:-

$(57.245)_8 = (\,?\,)_{10}$

Integeral part :

$(57)_8 = (5 \times 8^1) + (7 \times 8^0)$

= 40 + 7

= 47

ie. $(57)_8 = (47)_{10}$

Fractional Part :

$(0.245)_8 = (2\times 1/8) + (4\times 1/64) + (5\times 1/512)$

= 0.25 + 0.0625 + 0.0097

= 0. 3222

ie. $(0.245)_8 = (0.3222)_{10}$

Thus $(57.245)_8 = (47.3222)_{10}$

4) DECIMAL TO OCTAL CONVERSION :-

$(303.322)_{10} = (?)_8$

Integeral part :

8	303	7
8	37	5
	4	

ie. $(303)_{10} = (457)_8$

Fractional Part :

$(0.322\times 8) = 2.576 \rightarrow 2$

$(0.576\times 8) = 4.608 \rightarrow 4$

$(0.608\times 8) = 4.864 \rightarrow 4$

$(0.864\times 8) = 6.912 \rightarrow 6$

$(0.912\times 8) = 7.296 \rightarrow 7$

ie. $(0.322)_{10} = (0.24467)_8$

Thus $(303.322)_{10} = (457.24467)_8$

5) HEXADECIMAL TO DECIMAL CONVERSION :-

$(EA6.2FA)_{16} = (?)_{10}$

Integeral part : $(EA6)_{16} = (E\times 16^2) + (A\times 16^1) + (6\times 16^0)$

$= (14\times 16^2) + (10\times 16^1) + (6\times 1)$

= 3584 + 160 + 6

= 3750

ie. $(EA6)_{16} = (3750)_{10}$

Fractional Part : $(0.2FA)_{16} = (2\times 1/16) + (F\times 1/16^2) + (A\times 1/16^3)$

$= (2\times 1/16) + (15\times 1/256) + (10\times 1/4096)$

= 0.125 + 0.0586 + 0.00244

= 0. 18604

ie. $(0.2FA)_{16} = (0.18604)_{10}$

Thus $(EA6.2FA)_8 = (3750.18604)_{10}$

6) DECIMAL TO HEXADECIMAL CONVERSION:

$(3750.365)_{10} = (?)_{16}$

Integeral part :

16	3750	6	→ 6
16	234	10	→ A
	14		→ E

ie. $(3750)_{10} = (EA6)_{16}$

Fractional Part :

$(0.365 \times 16) = 5.84 \rightarrow 5 \rightarrow 5$
$(0.84 \times 16) = 13.44 \rightarrow 13 \rightarrow D$
$(0.44 \times 16) = 7.04 \rightarrow 7 \rightarrow 7$
$(0.04 \times 16) = 0.64 \rightarrow 0 \rightarrow 0$
$(0.64 \times 16) = 10.24 \rightarrow 10 \rightarrow A$

ie. $(0.365)_{10} = (0.5D70A)_{16}$

Thus $(3750.365)_{10} = (EA6.5D70A)_{16}$

7) BINARY TO HEXADECIMAL CONVERSION:

$(1001111010100110.001011111010)_2 = (\ ?)_{16}$

Integeral part :

$(1001111010100110)_2 = \{1001, 1110, 1010, 0110\}$
$= (\underbrace{1001}_{9}, \underbrace{1110}, \underbrace{1010}, \underbrace{0110}_{6})_2$

ie. $(1001111010100110)_2 = (9EA6)_{16}$

Fractional Part :

$(0.001011111010)_2 = \{\underbrace{0010}_{2}, \underbrace{1111}, \underbrace{1010}_{A}, \}$

ie. $(0.001011111010)_2 = (0.2FA)_{16}$

Thus $(1001111010100110.001011111010)_2 = (9EA6.2FA)_{16}$

8) HEXADECIMAL TO BINARY CONVERSION:

$(99E.2FA)_{16} = (\ ?\ )_2$

Integeral part :

$(99E)_{16} = \{\overbrace{1001}^{9}\ \overbrace{1001}^{9}\ \overbrace{1110}^{E}\} = (10011001110)_2$

ie. $(99E)_{16} = (10011001110)_2$

Fractional Part :

$(0.2FA)_{16} = \{\overbrace{0010}^{2}\ \overbrace{1111}^{F}\ \overbrace{1010}^{A}\} = (0.001011111010)_2$

Thus $(99E.2FA)_{16} = (1001111010100110.001011111010)_2$

9) OCTAL TO BINARY CONVERSION:

$(404.245)_8 = (\ ?\ )_2$

Integeral part :

$(404)_8 = \underbrace{4}\ \underbrace{0}\ \underbrace{4}$

$\{100\ 000\ 100\} = (100000100)_2$

ie. $(404)_8 = (100000100)_2$

Fractional Part :

$(0.245)_8 = \underbrace{2}\ \underbrace{4}\ \underbrace{5}$

$\{010\ 100\ 101\} = (0.010100101)_2$

Thus $(404.245)_8 = (100000100.010100101)_2$

10) BINARY TO OCTAL CONVERSION:

$(10011110.00101)_2 = (\ ?)_8$

Integeral part :

$(10011110)_2 = \{010, 011, 110\}$

$= (\underbrace{010}_{2}, \underbrace{011}, \underbrace{110})_2$

ie. $(10011110)_2 = (236)_8$

Fractional Part :

$(0.00101)_2 = \{\underbrace{001}_{1}, \underbrace{010}\}$

ie. $(0.00101)_2 = (0.12)_8$

Thus $(10011110.00101)_2 = (236.12)_8$

11) OCTAL TO HEXADECIMAL CONVERSION:

$(174654.273054)_8 = (\ ?)_{16}$

Integeral part :

$(174654)_8 = \underbrace{1}\ \underbrace{7}\ \underbrace{4}\ \underbrace{6}\ \underbrace{5}\ \underbrace{4}$

$\{001\ 111\ 100\ 110\ 101\ 100\}$

$= (\underbrace{0000}_{0}, \underbrace{1111}_{F}, \underbrace{1001}_{9}, \underbrace{1010}_{A}, \underbrace{1100}_{C})_2$

ie. $(174654)_8 = (F9AC)_{16}$

Fractional Part : $\underbrace{2}\ \underbrace{7}\ \underbrace{3}\ \underbrace{0}\ \underbrace{5}\ \underbrace{4}$

$(0.273054)_8 = 010\ 111\ 011\ 000\ 101\ 100$

$= (0.\underbrace{0101}_{5}, \underbrace{1101}_{D}, \underbrace{1000}_{8}, \underbrace{1011}_{B}, \underbrace{0000}_{0})$

ie. $(0.273054)_8 = (0.5D8B0)_{16}$

Thus $(174654.273054)_8 = (F9AC.5D8B)_{16}$

12) HEXADECIMAL TO OCTAL CONVERSION:

$(F9AC.5D8B)_{16} = (?)_8$

Integeral part :

$(F9AC)_{16} = \{\underbrace{1111}_{F}\ \underbrace{1001}_{9}\ \underbrace{1010}_{A}\ \underbrace{1100}_{C}\} = (1111100110101100)_2$

ie. $(F9AC)_{16} = (1,\ 111,\ 100,\ 110,\ 101,\ 100)_2$

$= (001,\ 111,\ 100,\ 110,\ 101,\ 100)_2 = 174654$

ie. $(F9AC)_{16} = (174654)_8$

Fractional Part :

$(0.5D8B)_{16} = \{\underbrace{0101}_{5}\ \underbrace{1101}_{D}\ \underbrace{1000}_{8}\ \underbrace{1011}_{B}\} = (0.010, 111, 011, 000, 101, 100)_2$

$= (\underbrace{010}_{2},\ \underbrace{111}_{7},\ \underbrace{011}_{3},\ \underbrace{000}_{0},\ \underbrace{101}_{5},\ \underbrace{100}_{4})_2$

$= (0.273054)_8$

ie. $(0.5D8B) = = (0.273054)_8$

Thus $(F9AC.5D8B)_{16} = (174654\ .273054)_8$

De Morgan's Theorem:

I Theorem : Complement of sum is equal to the product of complements.

$$(A+B)' = A' \bullet B'$$

II Theorem : Complement of product is equal to the sum of complements.

$$(A \bullet B)' = A' + B'$$

Note: '•' sign represent OR opration and '+' sign represent AND operation.

Proof :

Inputs		Outputs			
A	B	(A+B)'	A'.B'	(A.B)'	A'+B'
0	0	1	1	1	1
0	1	0	0	1	1
1	0	0	0	1	1
1	1	0	0	0	0

Column for (A+B)' and A'.B' are same. Column for (A.B)' and A' + B' are same. Hence proved.

LOGIC GATES:

Logic Gates: Logic circuits that perform the logical operations are called gates. Gates are blocks of hardware that produce a logic-1 or logic-0 output signal if the input logic requirement are satisfied. Some of the logic gates are-

AND gate:

It is one of the basic logic gate whose output is high when all its input are high and output is low when any one of the

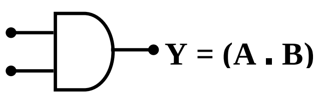


Diagram 01: AND gate

Inputs		Output
A	B	Y
0	0	0
0	1	0

input is low.

1	0	0
1	1	1

Truth Table

OR gate:

It is one of the basic logic gate whose output is high when any one of its input is high and output is low when all inputs are low.

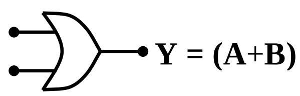


Diagram 02: OR gate

Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Truth Table

NOT gate: (Inverter)

It is one of the basic logic gate whose output is high when input is low and output is low when input is high.

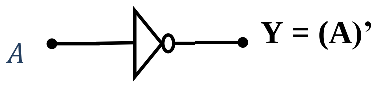


Diagram 03: NOT gate

Input	Output
A	Y
0	1
1	0

Truth Table

NAND gate:

It is made up of two types of logic gates i.e. a combination of AND and NOT gate. Its output is high when any of its input is low and output is low when all inputs are high.

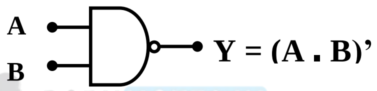


Diagram 04: NAND gate

Inputs		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

Truth Table

NOR gate:

It is made up of two types of logic gates i.e. a combination of OR and NOT gate. Its output is high when all its input are low and output is low when any one of its inputs is high.

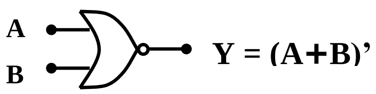


Diagram 05: NOR gate

Inputs		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

Truth Table

EX-OR gate:

It has a graphical symbol similar to that of the OR gate, except for the additional curved line on the input side. Its output is low when all its input are high and for other input cases the outputs of EX-

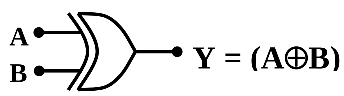


Diagram 06: EX- OR gate

Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

Truth Table

OR and OR gate are exactly same.

EX-NOR gate:

It is made up of two types of logic gates i.e. a combination of EX-OR and NOT gate. Its output is high when all its input are high and for other input cases the outputs of EX-NOR and NOR gate are exactly same.

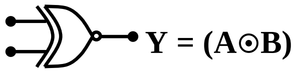


Diagram 07: EX- NOR gate

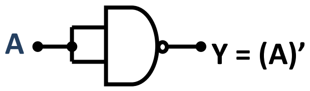
Inputs		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

Truth Table

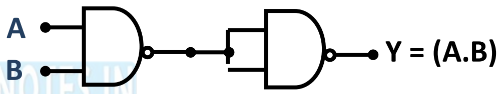
UNIVERSAL GATES:

NAND and NOR gates are called universal gates because any digital circuit, combinational and sequential circuits, can be implemented with it.

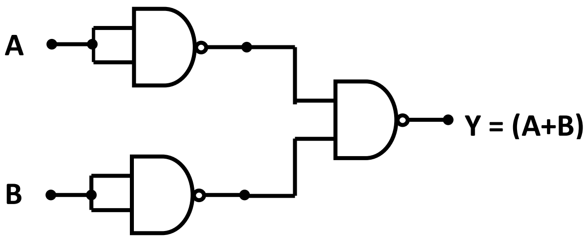
REALIZATION OF LOGIC GATES USING NAND GATES ONLY:



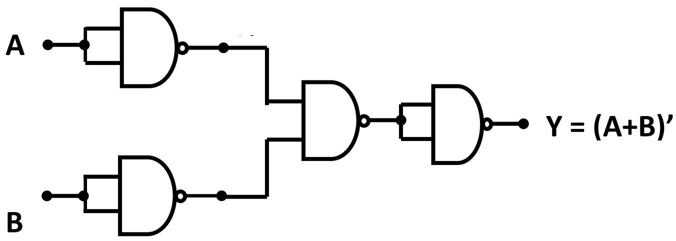
NAND gate as NOT gate



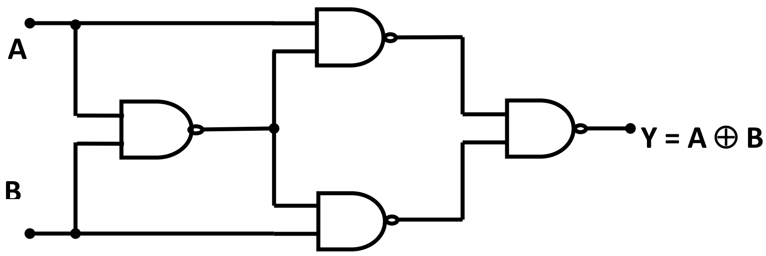
NAND gate as AND gate



NAND gate as OR gate

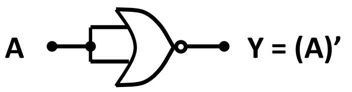


NAND gate as NOR gate

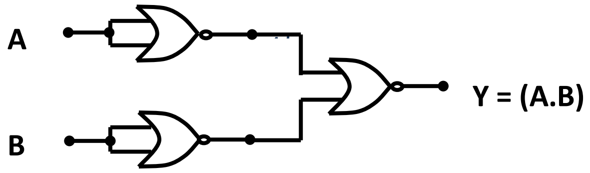


NAND gate as Ex-OR gate

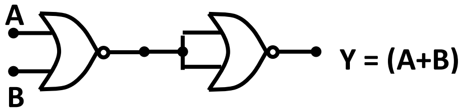
REALIZATION OF LOGIC GATES USING NAND GATES ONLY:



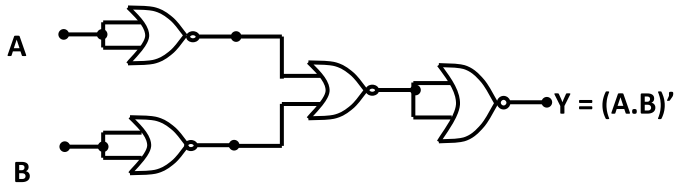
NOR gate as NOT gate



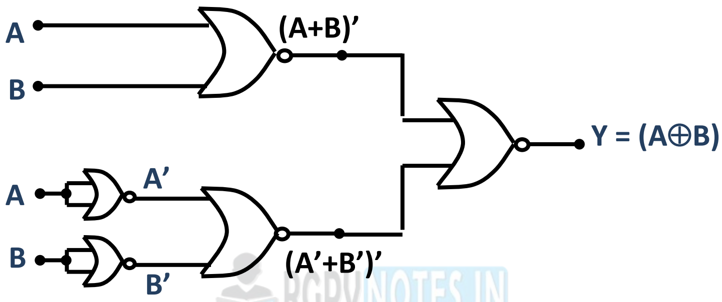
NOR gate as AND gate



NOR gate as OR gate



NOR gate as NAND gate



NOR gate as Ex-OR gate

BINARY ARITHMETIC:

BINARY ADDITION:-

1. 0 + 0 = Sum 0 with carry of 0.
2. 0 + 1 = Sum 1 with carry of 0.
3. 1 + 0 = Sum 1 with carry of 0.
4. 1 + 1 = Sum 0 with a carry of 1.
5. 1 + 1 + 1 = Sum 1 with carry of 1.

Example: Add $(111011.1101)_2$ with $(011111.0110)_2$

	1	1	1	1	1	1		1				carry
	1	1	1	0	1	1	.	1	1	0	1	Augend
+	0	1	1	1	1	1	.	0	1	1	0	Addend
1	0	1	1	0	1	1	.	0	0	1	1	sum

BINARY SUBTRACTION:

The basic principles of binary subtraction include the following:

A) 0 – 0 = 0. B) 1 – 0 = 1. C) 1 – 1 = 0. D) 0 – 1 = 1 with a borrow of 1 from the next more significant bit.

Example: Subtract $(11111.011)_2$ from $(111011.1101)_2$

	1	1	1	0	1	1	.	1	1	0	1	Minuend
–	0	1	1	1	1	1	.	0	1	1	0	Subtraend
	0	1	1	1	0	0	.	0	1	1	1	Difference

BINARY MULTIPLICATION:

The basic rules of multiplication are listed as follows:

1. $0 \times 0 = 0$.
2. $0 \times 1 = 0$.
3. $1 \times 0 = 0$.
4. $1 \times 1 = 1$.

Example: Multiply $(10.11)_2$ by $(11)_2$

		1	0	.	1	1	Multiplicand
			X		1	1	Multiplier
		1	0	.	1	1	
+	1	0	1	.	1	0	
1	0	0	0	.	0	1	Product

BINARY DIVISION:

Example: Divide $(110001)_2$ by $(111)_2$

Divisor 111	110001-Divident -0111	111 Quotient
	01010 -111	
	0111 -111	
	0000-Remainder	

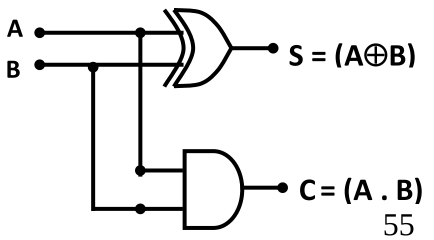
HALF ADDER: A combinational circuit that perform the addition of two bits is called half adder. This circuit needs two binary inputs and two binary outputs. The input variables, augend (X) and addend (Y) bits; the output variables SUM (S) and CARRY (C).

Truth Table:

INPUTS		OUTPUTS	
X	Y	SUM (S)	CARRY(C)
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

The simplified output Boolean function : SUM (S) = $X'.Y + X.Y'$ and CARRY (C) = $X.Y$

The logic diagram of Half Adder :



FULL ADDER: When the augend and addend numbers contain more significant digits, the carry obtained from the addition of two bits is added to the next higher order pair of significant bits. The combinational circuit that performs the addition of three bits (two significant bits and a previous carry) is a full adder. It consists of three inputs (X and Y are actual 2-inputs and third input represents the CARRY$_{IN}$ (C_{IN}) generated from the previous lower significant bit position) and two outputs, SUM (S) and CARRY$_{OUT}$ (C_{OUT}).

Truth Table:

INPUTS			OUTPUTS	
X	Y	C_{IN}	SUM (S)	CARRY(C_{OUT})
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Boolean expression shown from the truth table which is shown:

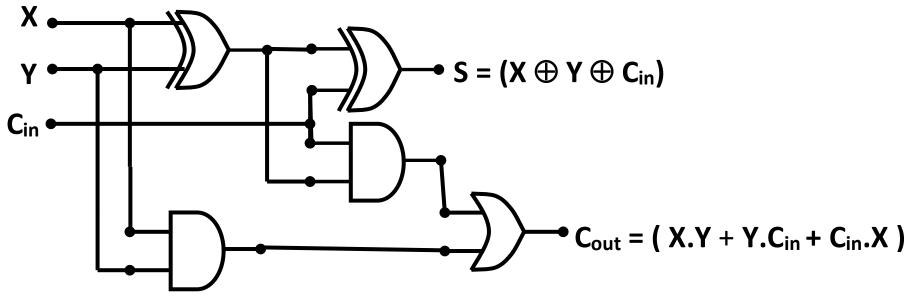
$$SUM = X'.Y'.C_{IN} + X'.Y.C_{IN}' + X.Y'.C_{IN}' + X.Y.C_{IN}$$

$$SUM = (X \oplus Y \oplus C_{in})$$

$$\begin{aligned} CARRY &= X'.Y.C_{IN} + X.Y.C_{IN}' + X.Y'.C_{IN} + X.Y.C_{IN} \\ &= Y.C_{IN}(X + X') + X.Y.C_{IN}' + X.Y'.C_{IN} \\ &= Y.C_{IN} + X.Y.C_{IN}' + X.Y'.C_{IN} \\ &= Y(C_{IN} + C_{IN}'.X) + X.Y'.C_{IN} \\ &= Y(C_{IN} + X) + X.Y'.C_{IN} \\ &= Y.C_{IN} + Y.X + X.Y'.C_{IN} \\ &= C_{IN}(Y + X.Y') + Y.X \\ &= C_{IN}(Y + X) + Y.X \end{aligned}$$

$$CARRY = C_{IN}.Y + C_{IN}.X + Y.X$$

Logic Diagram of Full Adder using 2-half adder and OR gate:



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