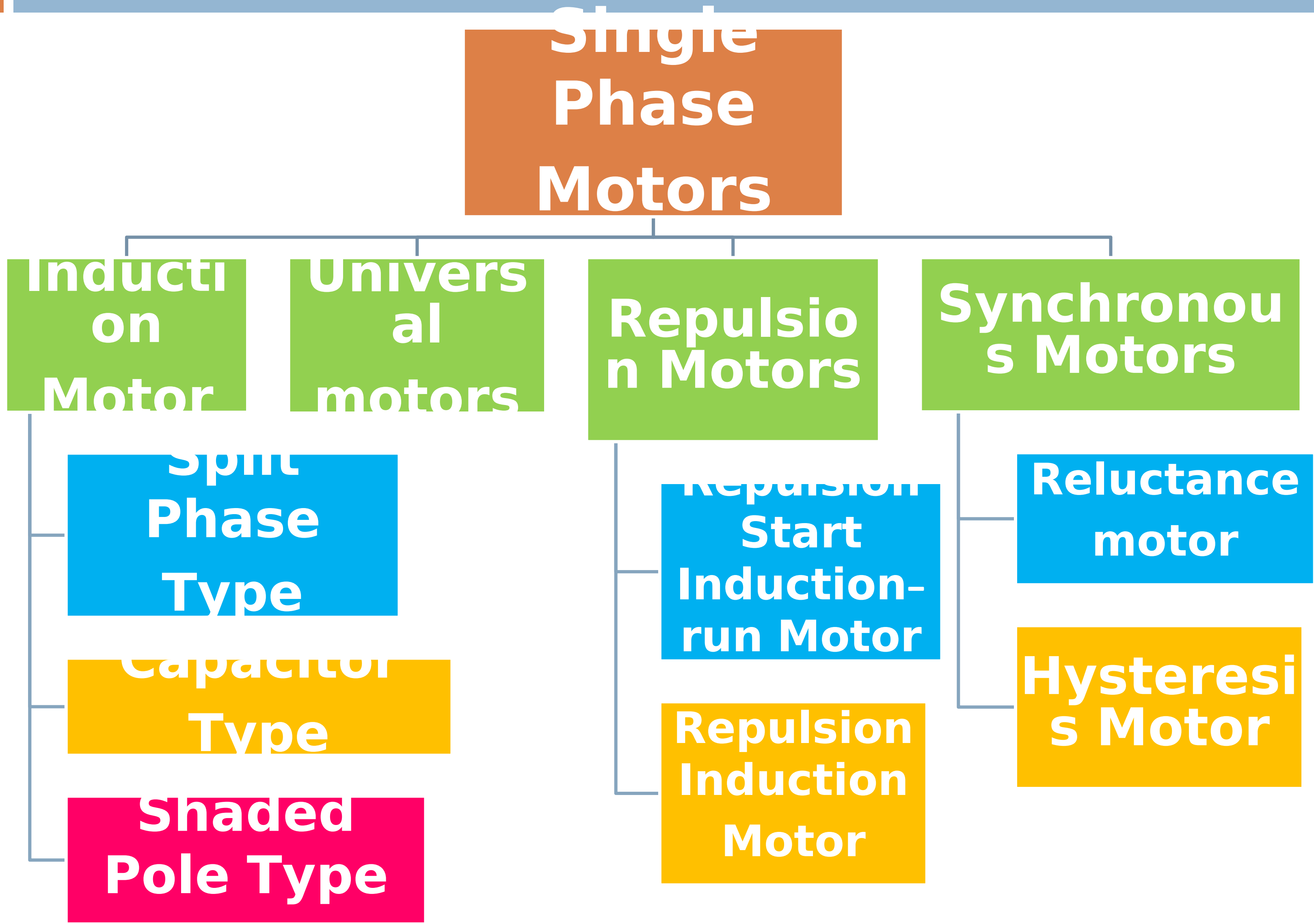
SINGLE PHASE INDUCTION MOTORS

Introduction

- The motors which work on single phase ac supply are called **single phase induction motors**.

- The power rating of these motors are very small. Some of them are of fractional horse power.
- Are used in applications like small toys, small fans, hair driers etc.

Types of Single Phase Motors



Construction

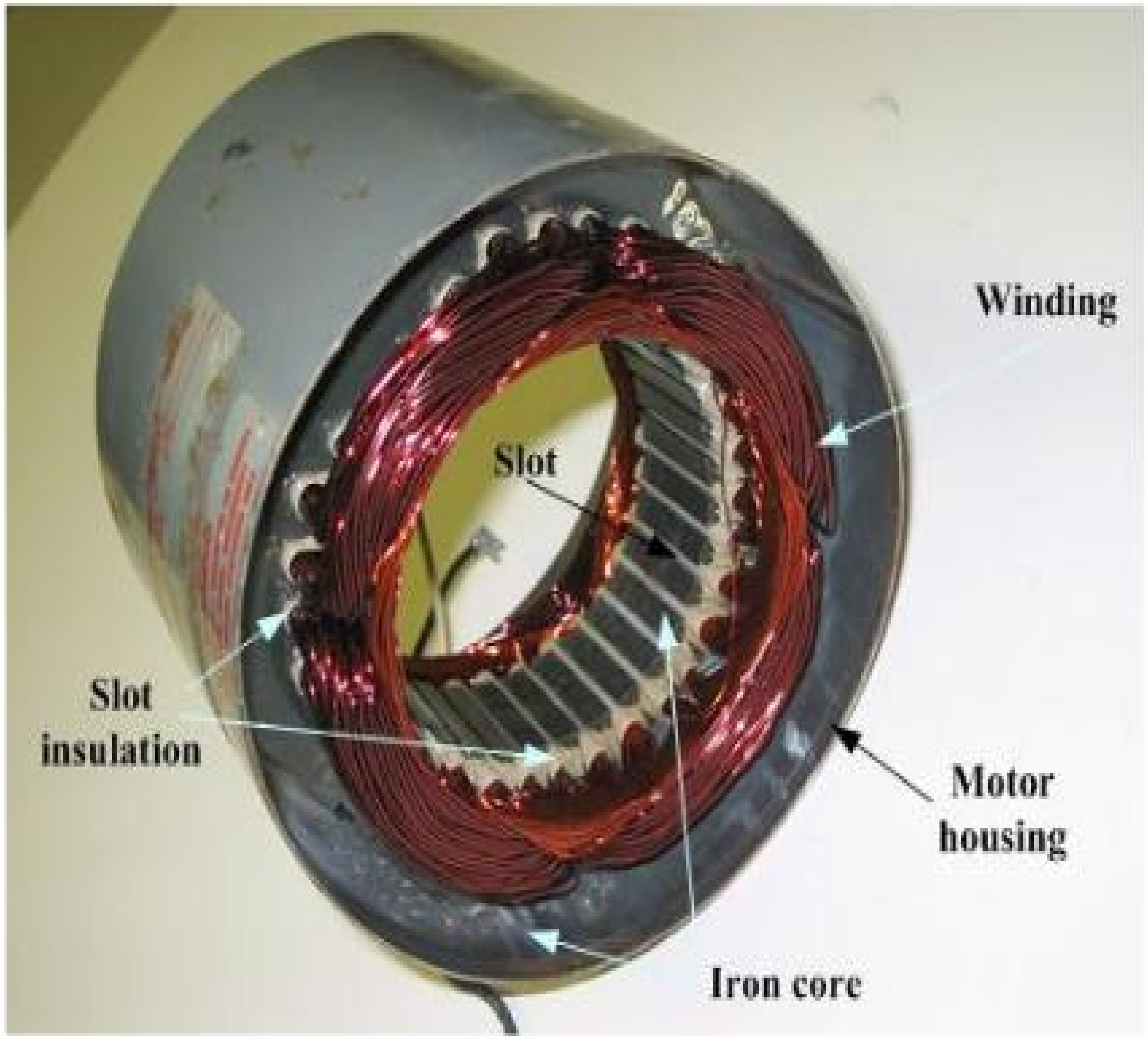
- Single phase induction motors are has
  - One rotating (rotor) and
  - Other stationary (stator)

.

Stator

- Stator has laminated construction, made up of stampings.
- The stampings are slotted on the periphery to carry the winding called the stator winding or main winding.
- This is excited by single phase ac supply.
- The stator winding is wound for certain definite no of poles.
- The no of poles which stator windings are wound decides the synchronous speed of the motor

Single Phase Induction Motor



Construction

- The synchronous speed is denoted by Ns and relation is given as

$$Ns = \frac{120f}{p} rpm$$

- IM never rotates at synchronous speed but rotates at speed slightly less than the synchronous speed .

Construction

Rotor

- The rotor construction is of squirrel cage type .
- In this type rotor consist of uninsulated copper or aluminum bars, placed in the slots.
- The bars are permanently shorted at both the ends with the help of conducting rings called end rings.
- The entire structure look like a cage hence called **squirrel cage rotor**.
- As bars are permanently shorted to each other the resistance of the entire rotor is very small.
- **The main feature of this rotor is that is automatically adjust itself for same no of poles as that of stator winding**

Single Phase Induction Motor

- As the name suggests, this type of motor **has only one stator winding** (**main winding**) and **operates with a single-phase power supply**.
- In all single-phase induction motors**, the rotor is the squirrel cage type**.
- The single-phase induction motor is **not self-starting**.
- When the motor is connected to a single-phase power supply, **the main winding carries an alternating current**. This current produces a pulsating magnetic field. **Due to induction, the rotor is energized**.
- As the main magnetic field is pulsating, the torque necessary for the motor rotation is not generated. This will cause the rotor to vibrate, but not to rotate. **Hence, the single phase induction motor is required to**

Single Phase Induction Motor

- The single-phase induction motor operation can be described by two methods:
  - Double revolving field theory; and
  - Cross-field theory.

Double field revolving theory

- A single-phase ac current supplies the main winding that produces a pulsating magnetic field.

- Mathematically, the pulsating field could be divided into two fields, which are rotating in opposite directions.

- The interaction between the fields and the current induced in the rotor bars generates opposing torque.

- According to this theory any alternating quantity can be resolved into two rotating components which rotate in opposite direction and each having magnitude as half of the maximum

Double field revolving theory

- Under conditions, with only the main field energized the motor will not start.
- However, if an external torque moves the motor in any direction, the motor will begin to rotate.
- The pulsating filed is divided a forward and reverse rotating field
- Motor is started in the direction of forward rotating field this generates small (5%) positive slip

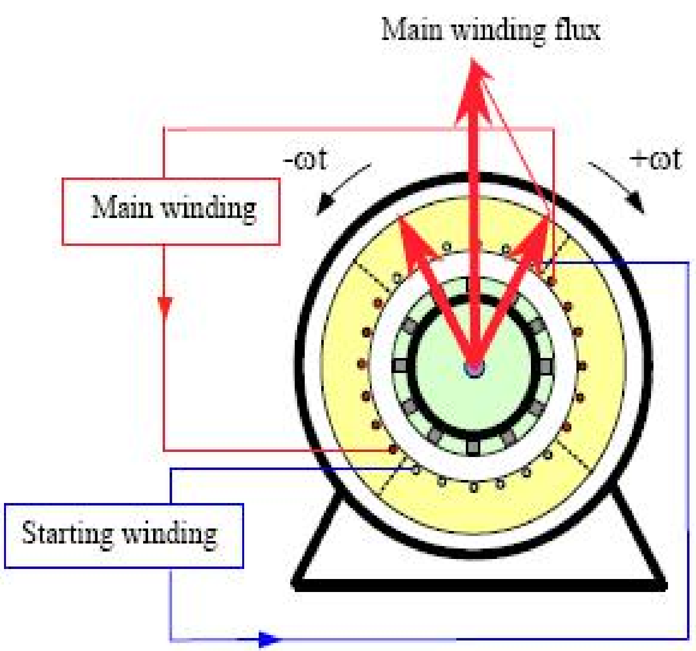


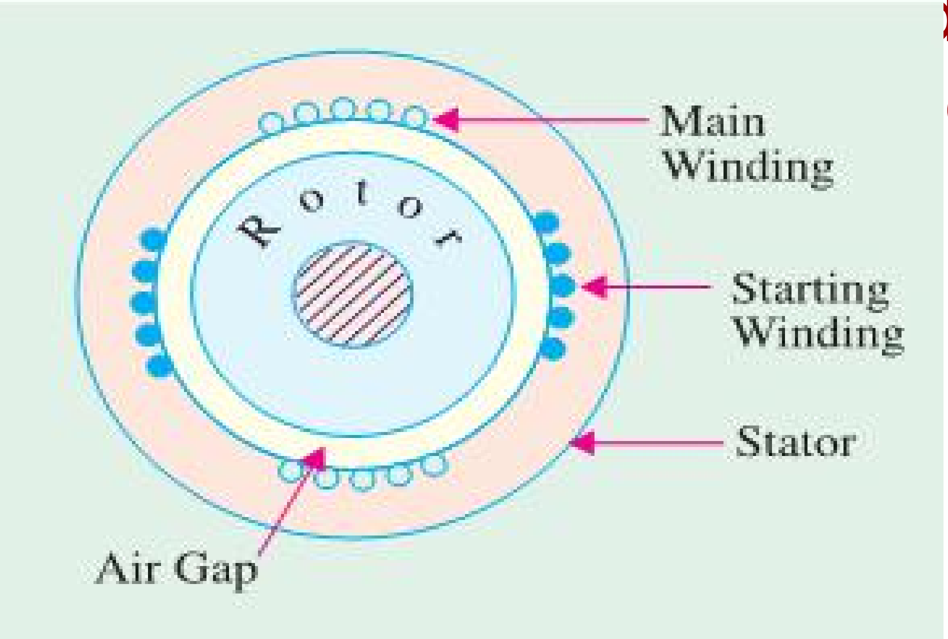
Figure 43 Single-phase motor main winding generates two rotating fields, which oppose and counter-balance one another.

Double field revolving theory

- The three-phase induction motor starting torque inversely depends on the slip.
- This implies that a small positive slip generates larger torque than a larger negative slip.
- This torque difference drives the motor continues to rotate in a forward direction without any external torque.
- Each of the rotating fields induces a voltage in the rotor, which drives current and produces torque.

Making Single Phase Motor Self Starting

- To make the motor self-starting, it is temporarily converted into a two-phase motor during starting period.
- For this purpose, **the stator of a single-phase motor is provided with an extra winding, known as star... ding, in addition to th... ding**.



- The two windings are spaced 90º electrically apart and are connected in parallel across the single–phase supply.
- It is so arranged that the phase–difference between the currents in the two stator windings is very large (ideal value being 90º).
- Hence, the motor behaves like a two– phase motor. These two currents produce a revolving flux

Starting torque

- The single-phase motor starting **torque is zero** because of the pulsating single-phase magnetic flux.
- The starting of the motor requires the generation of a rotating magnetic flux similar to the rotating flux in a three-phase motor.
- Two perpendicular coils that have currents 90° out of- phase can generate the necessary rotating magnetic fields which start the motor.
- Therefore, single-phase motors are built

- The phase shift is achieved by connecting

– a resistance,

– an inductance, or

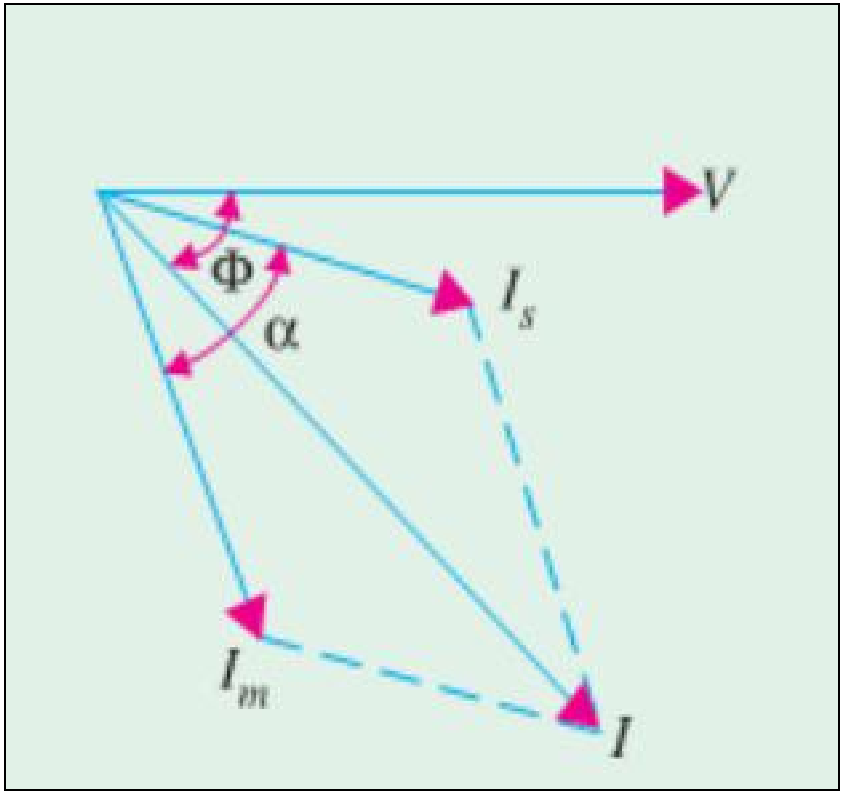
– a capacitance in series with the starting winding.

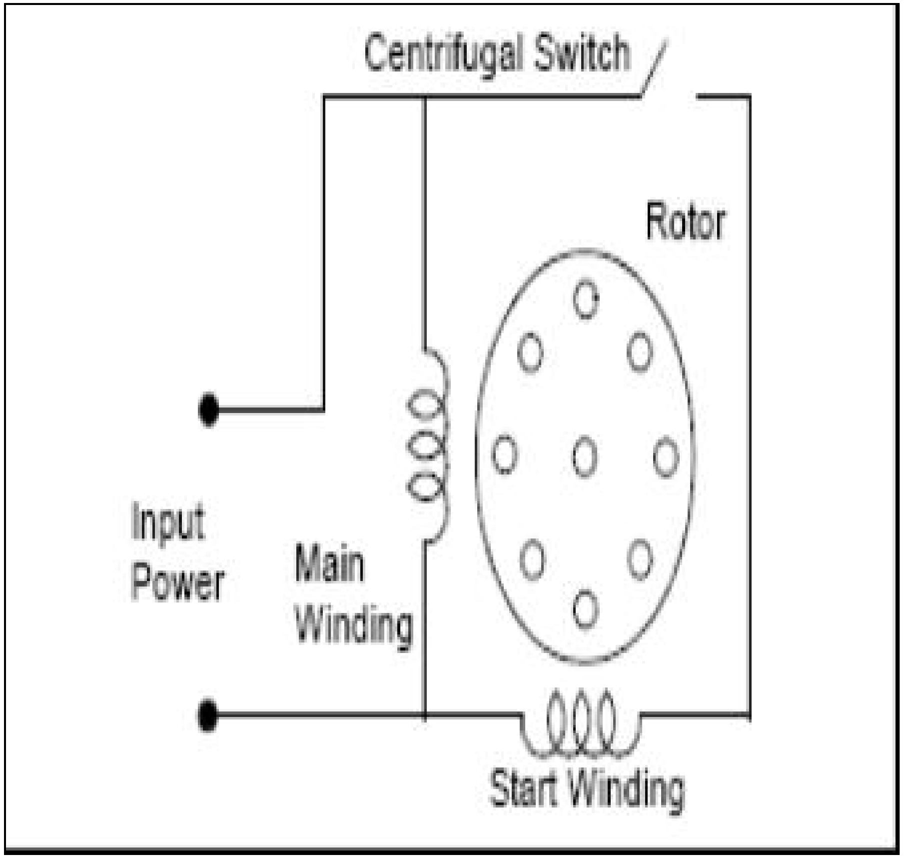
- Most frequently used is a capacitor to generate the starting torque.

Split-Phase AC Induction Motor

- **The split-phase motor is also known as an induction start/induction run motor.**
- It has two windings: **a start and a main winding**.
- The start winding is made **with smaller gauge wire and fewer turns**, relative to the main winding to create more resistance, thus putting the start winding's field at a different angle than that of the main winding which causes the motor to start rotating.
- The main winding, which is of a **heavier wire**, keeps the motor running the rest of the time.

Split-Phase AC Induction Motor





Split-Phase AC Induction Motor

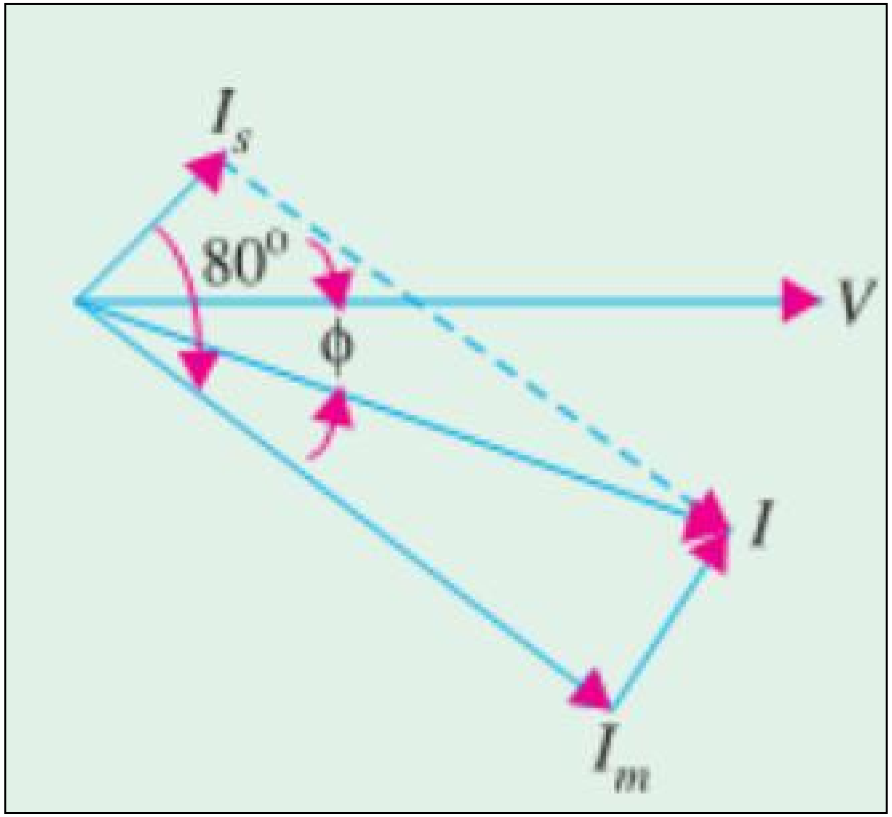
- The **starting torque** is 1.5 to 2 times of the full load torque with a starting current of 6 to 8 times the full load current.

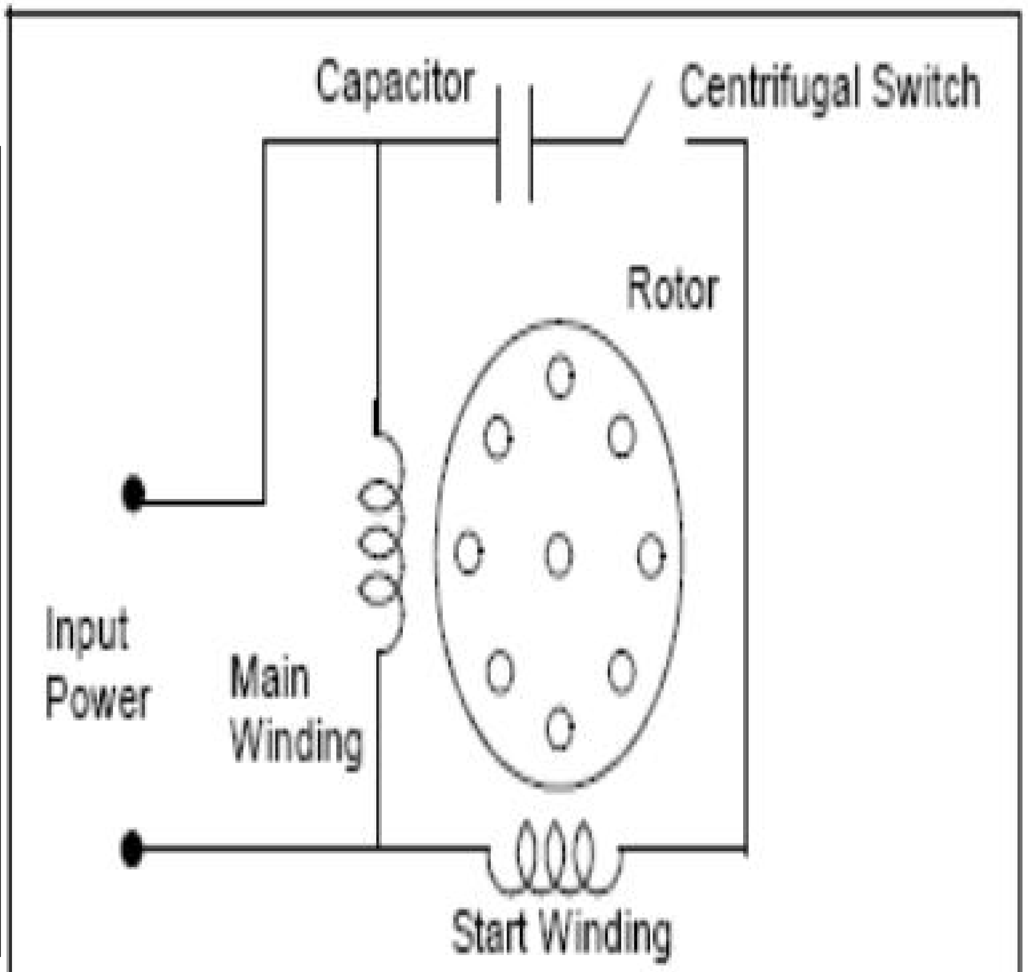
- Since the starting winding is made up of fine wires, the current density is high and the winding heats up quickly. If the starting period exceeds 5 sec. , the winding may burn out unless the motor is protected by built-in thermal relay.
- These are constant speed motors, speed variation is 2-5% from no load to full load.
- Applications for split-phase motors include small grinders, small fans and blowers and other low starting torque applications.

Capacitor Start AC Induction Motor

- This is a modified split-phase motor with a **capacitor in series** with the start winding to provide a start "boost."
- Like the split-phase motor, the capacitor start motor also has a **centrifugal switch which disconnects the start winding and the capacitor when the motor reaches about 75% of the rated speed**.
- Since the capacitor is in series with the start circuit, it creates more starting torque, typically **200% to 400% of the rated torque**.

Capacitor Start AC Induction Motor





Capacitor Start AC IM

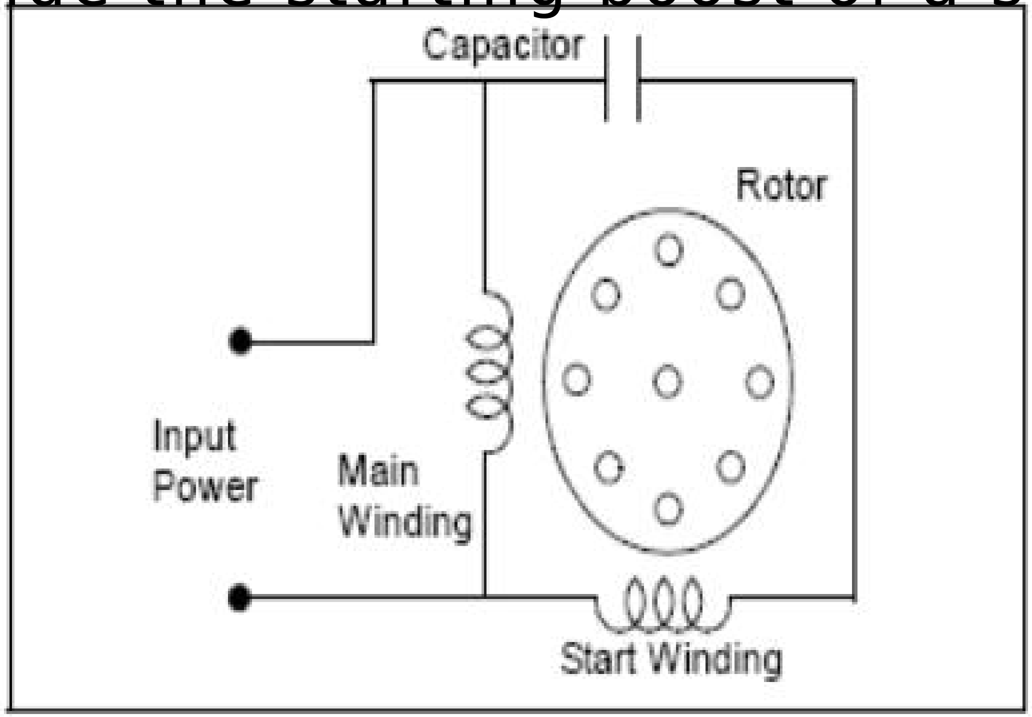
- And the starting current, is much lower than the split-phase due to the larger wire in the start circuit.

- They are used in a wide range of belt-drive applications like **small conveyors, large blowers and pumps, as well as many direct-drive or geared applications.**

Permanent Split Capacitor (Capacitor Run) AC IM

A permanent split capacitor (PSC) motor has a run type capacitor permanently connected in series with the start winding.

- The run capacitor must be designed for continuous use, it cannot provide the starting boost of a starting capacitor.



Permanent Split Capacitor (Capacitor Run) AC IM

- The typical starting torque of the PSC motor is low, from 30% to 150% of the rated torque.
- PSC motors have **low starting current**, usually **less than 200%** of the rated current, making them excellent for **applications with high on/off cycle rates**

Permanent Split Capacitor (Capacitor Run) AC IM

The PSC motors have several advantages:

- The motor design can easily be altered for use with speed controllers.
- They can also be designed for optimum efficiency and High-Power Factor (PF) at the rated load.
- They're considered to be the most reliable of the single-phase motors, mainly because no centrifugal starting switch is required.

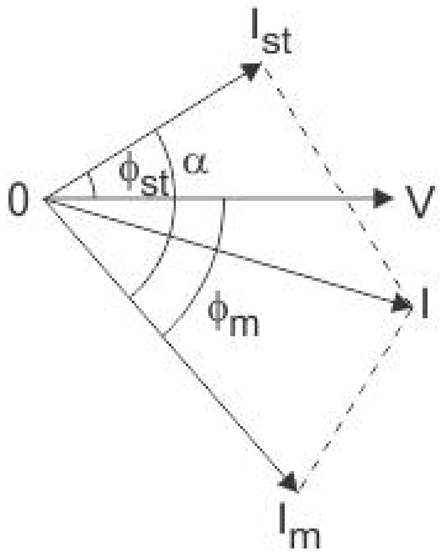
Applications of permanent split capacitor (PSC)

- Permanent split-capacitor motors have a wide variety of applications depending on the design.
- These include **fans, blowers with low starting torque, washing machines, oil burners, small machine tools etc**.
- **Power rating of these motors lies between 60W and 250W**

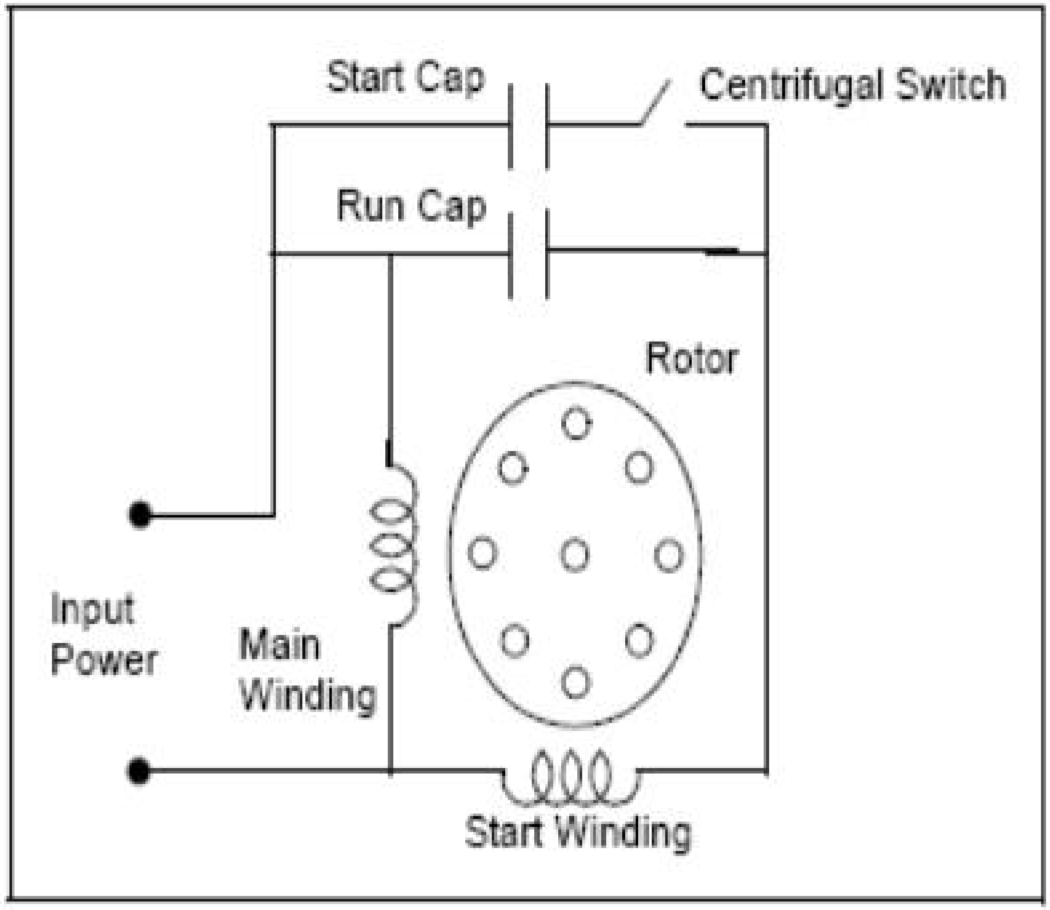
Capacitor Start/Capacitor Run AC Induction Motor

- This motor has a **start type capacitor in series** with the auxiliary winding like the capacitor start motor for high starting torque.
- Like a PSC motor, it also has a run type capacitor that is in series with the auxiliary winding after the start capacitor is switched out of the circuit. This allows high overload torque.
- This type of motor can be designed for lower full-load currents and higher efficiency.
- This motor is costly due to start and run capacitors and centrifugal switch.

Capacitor Start/Capacitor Run AC Induction Motor



Phasor diagram



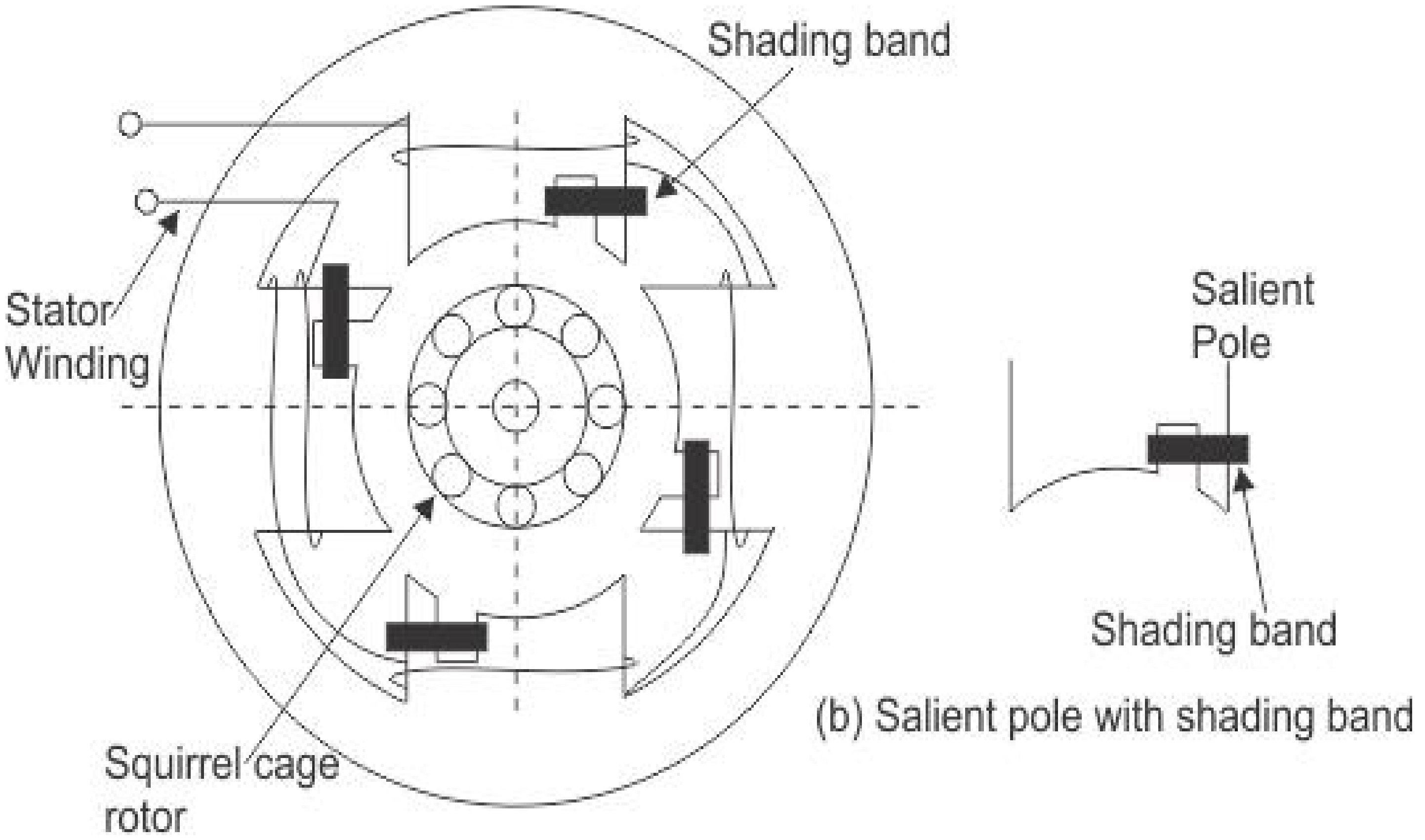
Capacitor Start/Capacitor Run AC Induction Motor

- It is able to handle applications demanding for any other kind of single-phase motor.
- These include **woodworking machinery, air compressors, high-pressure water pumps, vacuum pumps and other high torque applications requiring 1 to 10 hp.**

Shaded-Pole AC Induction Motor

- Shaded-pole motors have only one main winding and no start winding.
- Starting is by means of a design that rings a continuous copper loop around a small portion of each of the motor poles.
- This “shades” that portion of the pole, causing the magnetic field in the shaded area to lag behind the field in the unshaded area.
- The reaction of the two fields gets the shaft rotating.

Shaded-Pole AC Induction Motor



(b) Salient pole with shading band

(a) 4-pole shaded pole construction

Advantages

- Because the shaded-pole motor lacks a start winding, starting switch or capacitor, it **is electrically simple and inexpensive**.

- Also, the speed can be controlled merely by varying voltage, or through a multi-tap winding. Mechanically, the shaded-pole motor construction allows high-volume production.

- In fact, these are usually considered as "**disposable" motors**, meaning they are much cheaper to replace than to repair.

Disadvantages

- It's low starting torque is typically **25% to 75% of the rated torque.**
- It is a high slip motor with a running speed **7% to 10% below the synchronous speed.**
- Generally, efficiency of this motor type is very low **(below 20%).**

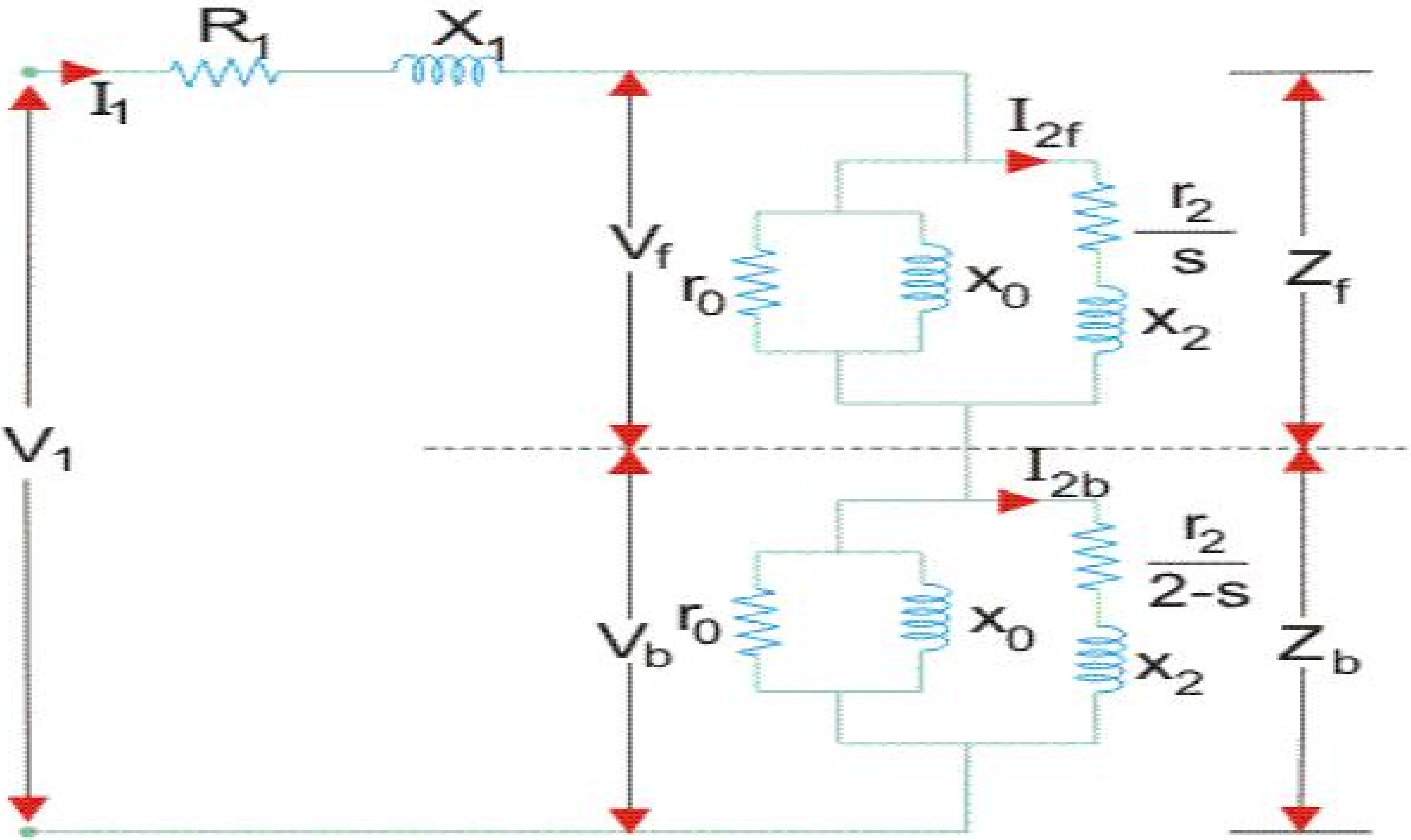
Applications

- The low initial cost suits the shaded-pole motors to low horsepower or light duty applications.

- Its Largest use is in multi-speed fans for household use.

- But **the low torque, low efficiency and less sturdy mechanical features** make shaded-pole motors impractical for most industrial or commercial use, where higher cycle rates or continuous duty are the norm.

Equivalent Circuit of a Single Phase Induction Motor



Induction motor (single phase) equivalent circuit referred to the stator

Universal motor

- The motors which can be used with a single phase AC source as well as a DC source of supply and voltages are called as **Universal Motor**. It is also known as **Single Phase Series Motor**.
- A universal motor is a commutation type motor.

Construction of the universal motor

- The construction of the universal motor is same as that of the series motor.
- In order to minimize the problem of commutation, high resistance brushes with increased brush area are used.
- To reduce Eddy current losses the stator core and yoke are laminated.
- The Universal motor is simple and less costly.
- It is used usually for rating not greater than 750 W.

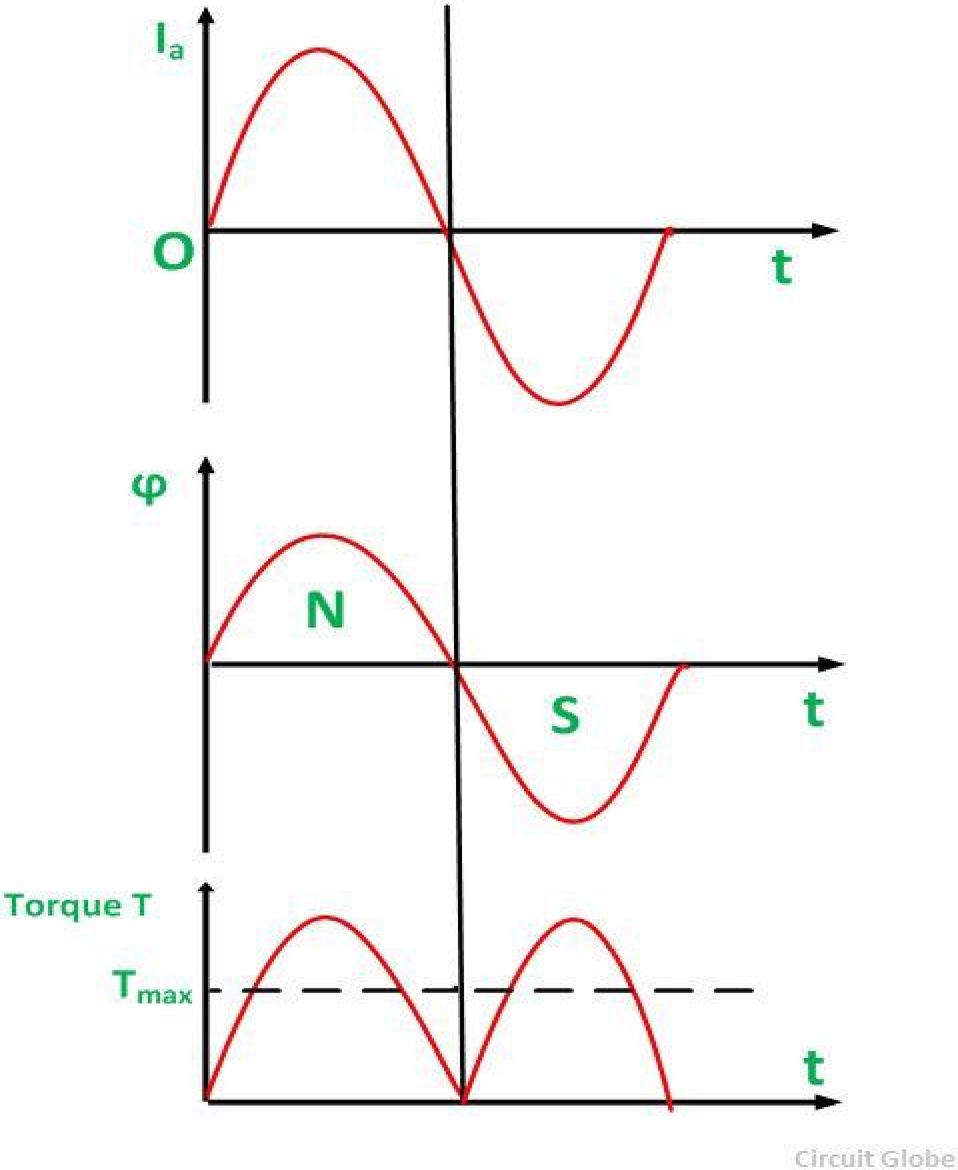
Characteristic of Universal motor

- The characteristic of Universal motor is similar to that of the DC series motor.
- When operating from an AC supply, the series motor develops less torque.
- By interchanging connections of the fields with respect to the armature, the direction of rotation can be altered.

Universal motor

- The direction of the developed torque will remain positive, and direction of the rotation will be as it was before.

- The nature of the torque will be pulsating, and the frequency will be twice that of line frequency as shown in the waveform.



Universal motor

Thus, a Universal motor can work on both AC and DC. However, a series motor which is mainly designed for DC operation if works on single phase AC supply suffers from the following drawbacks.

- The efficiency becomes low because of hysteresis and eddy current losses.
- The power factor is low due to the large reactance of the field and the armature windings.
- The sparking at the brushes is in excess.

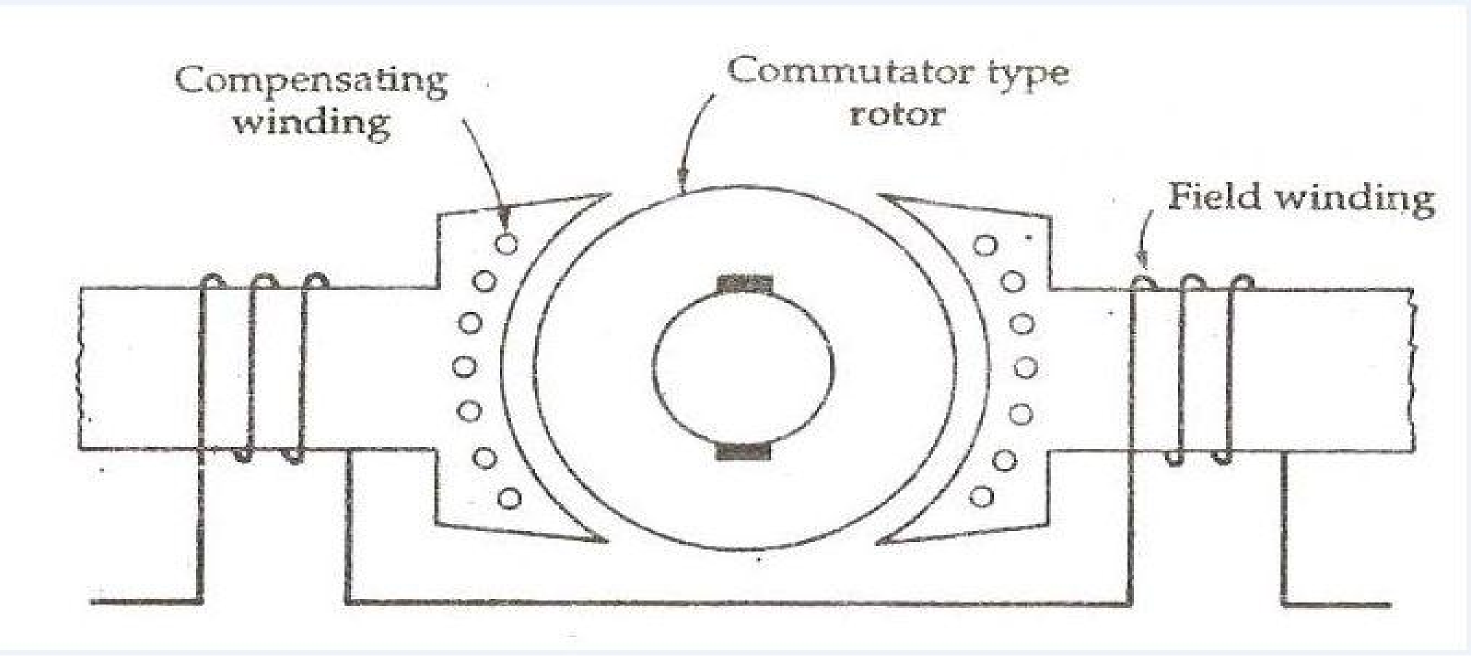
Universal motor

In order to overcome the following drawbacks, certain modifications are made in a DC series motor so that it can work even on the AC current. They are as follows:–

- The field core is made up of the material having a low hysteresis loss. It is laminated to reduce the eddy current loss.
- The area of the field poles is increased to reduce the flux density. As a result, the iron loss and the reactive voltage drop are reduced.
- To get the required torque the number of conductors in the armature is increased.

Universal motor

- A compensating winding is used for reducing the effect of the armature reaction and improving the commutation process.
- The winding is placed in the stator slots as shown in the figure below.

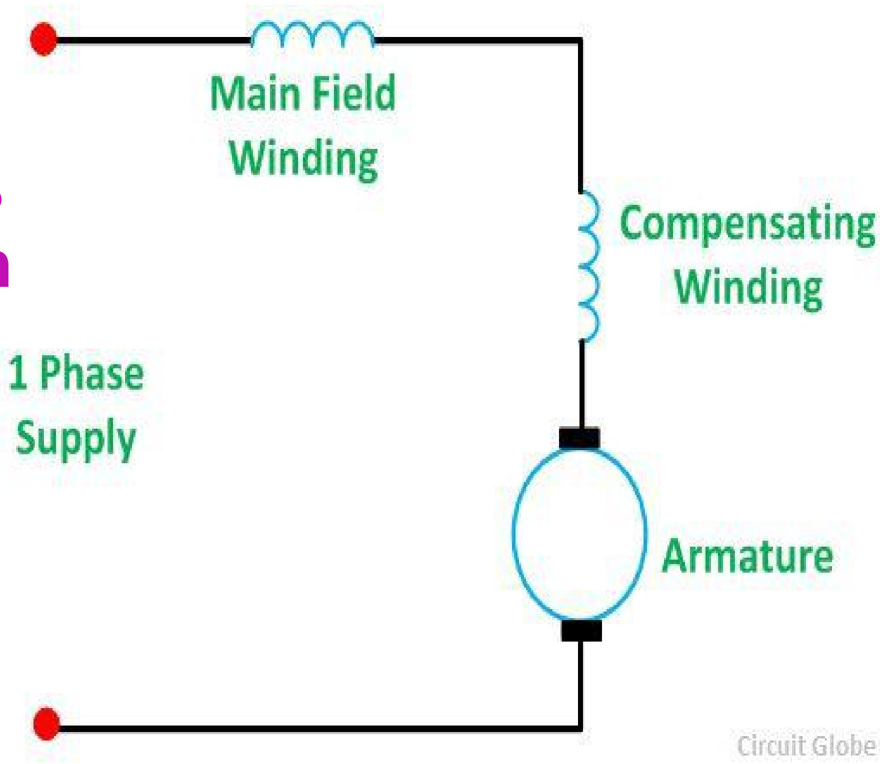


Universal motor

- The series motor with the compensated winding is shown in the figure below.

The winding is put in the stator slot. **The axis of compensating winding is 90 degrees with the main field axis.**

The compensating winding is connected in series with both the armature and the field, hence, it is called Conductively compensated.



Advantages &Disadvantage

Advantages

- High starting torque
- Very compact design if high running speeds are used.

Disadvantage

- Requires maintenance
- and short life problems caused by the commutator.

As a result, such motors are usually used in AC devices such as **food mixers and power tools which are used only intermittently, and often**

Reluctance motor

The three phase synchronous motors are usually large machines of the order of several hundred kilowatts or megawatts.

- Single phase synchronous motor are constant speed machines of small ratings.
- Two widely used synchronous motors are
  - Reluctance motor
  - Hysteresis motors

These motors are simple in construction.

They do not require dc field excitation nor do they use permanent magnet.

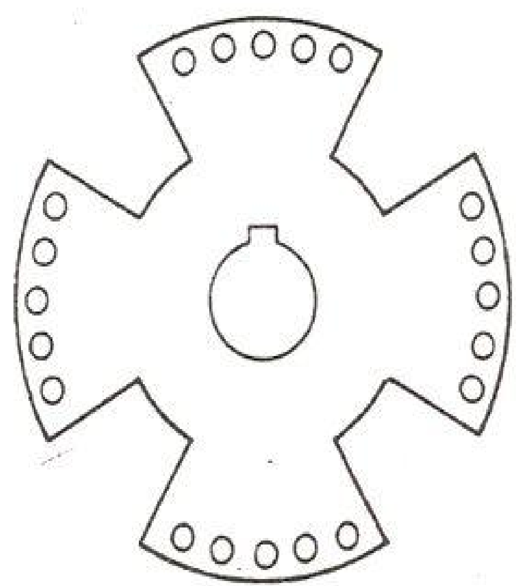
Reluctance motor Construction

- **It is a single phase synchronous motor which does not require dc excitation to the rotor.**

It consists of

- A Stator :
  - Carrying a single phase winding along with an auxiliary winding to produce a synchronous-revolving magnetic field.
- A squirrel-cage rotor:
  - Has unsymmetrical magnetic construction . This is achieved by symmetrically removing some of the teeth from squirrel cage rotor to produce salient poles on the rotor.

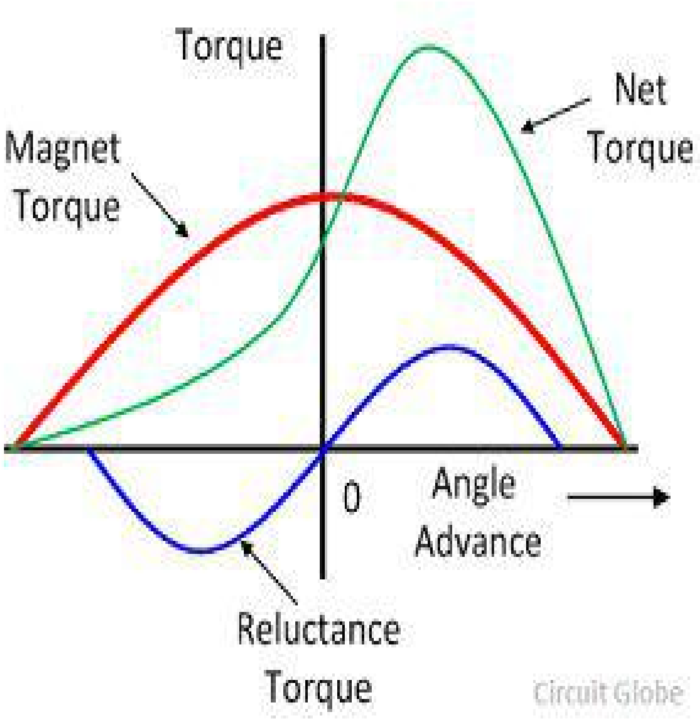
- In the figure the teeth have been removed in four locations to produce a 4 pole structure.
- The two end rings are short circuited.
- When the stator is connected to a single phase supply, the motor starts as a single phase induction motor.
- A centrifugal switch disconnects the auxiliary winding as soon as the speed of the motor reaches about 75% of the synchronous speed.



- The motor continues to speed up as

Reluctance Torque

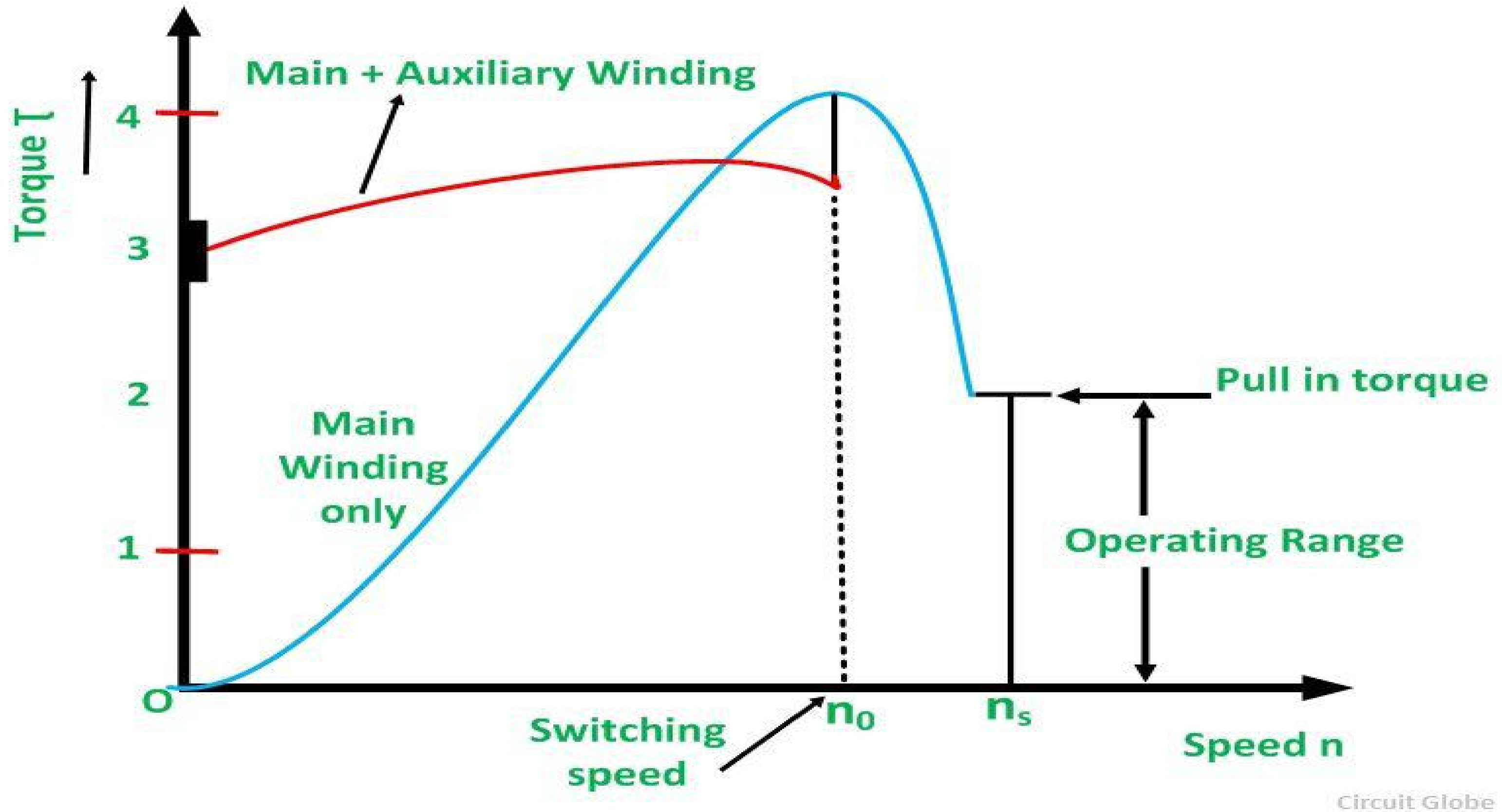
- **Reluctance torque or alignment torque is experienced by a ferromagnetic object placed in an external magnetic field, which causes the object to line up with the external magnetic field.**
- **An external magnetic field induces an internal magnetic field in the object and**



Working Operation of Reluctance Motor

- When 1-phase stator having auxiliary winding is energized, **a synchronous- revolving field is produced**. The motor starts as a standard -cage IM and will accelerate to near its synchronous speed.
- As the rotor approaches synchronous speed, the rotating **stator flux will exert reluctance torque on the rotor poles tending to align the salient-pole axis with the axis of rotating field.**
- The rotor assumes the position where its salient poles lock with the poles of the revolving field.
- Consequently, the motor will continue to run at the speed of the revolving flux i.e at the

Torque Speed Characteristic



- The starting torque depends upon the rotor position. The value of the starting torque varies between 300 to 400 % of its full load torque.
- The motor operates at a constant speed up to a little over than 200% of its full load torque.
- If the loading of the motor is increased above the value of the pull out torque, the motor loose synchronism but continues to run as a single phase induction motor up to over 500% of its rated torque.
- At the starting the motor is subjected to Cogging. This can be reduced by skewing the rotor bars and by having the rotor slots not exact multiples of the number of poles.

Applications of a Reluctance Motor

- Simple construction as there is no slip rings, no brushes and no DC field windings).
- Low cost
- Maintenance is easy.
- It is used for many constant speed applications such as **electric clock timer, signaling devices, recording instruments etc.**

Hysteresis Motor

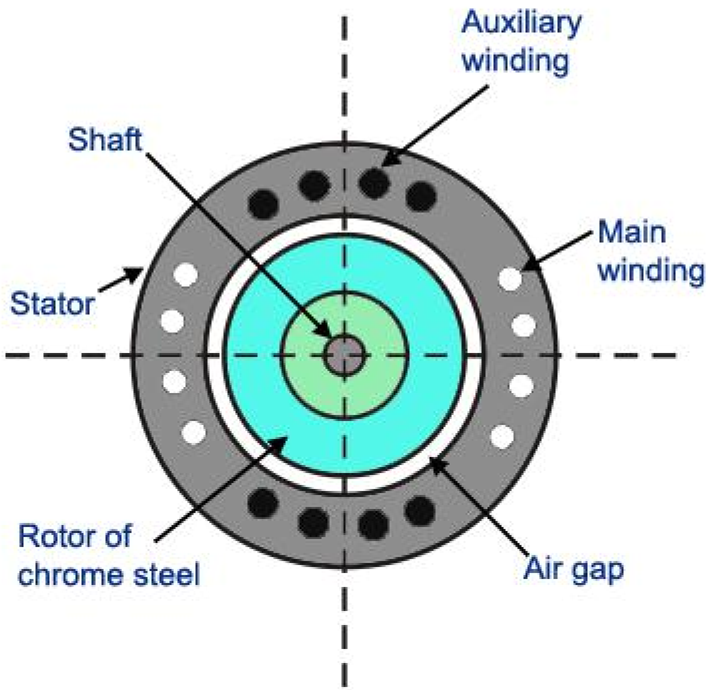
- A **Hysteresis Motor** is a synchronous motor with a uniform air gap and without DC excitation.
- It operates both in single and three phase supply.
- **The Torque in a Hysteresis Motor is produced due to hysteresis and eddy current induced in the rotor by the action of the rotating flux of the stator windings.**

Construction of Stator of Hysteresis Motor

- The stator of the hysteresis motor produces a rotating magnetic field and is almost similar to the stator of the induction motor.
- Thus, the stator of the motor is connected either to single supply or to the three phase supply.
- The three phase motor produces more uniform rotating field as compared to that of the single phase supply.
- **The stator winding of the single–phase hysteresis motor is made of permanent split capacitor type or shaded pole type**.
- **The capacitor is used with an auxiliary winding in order to produce a uniform field.**

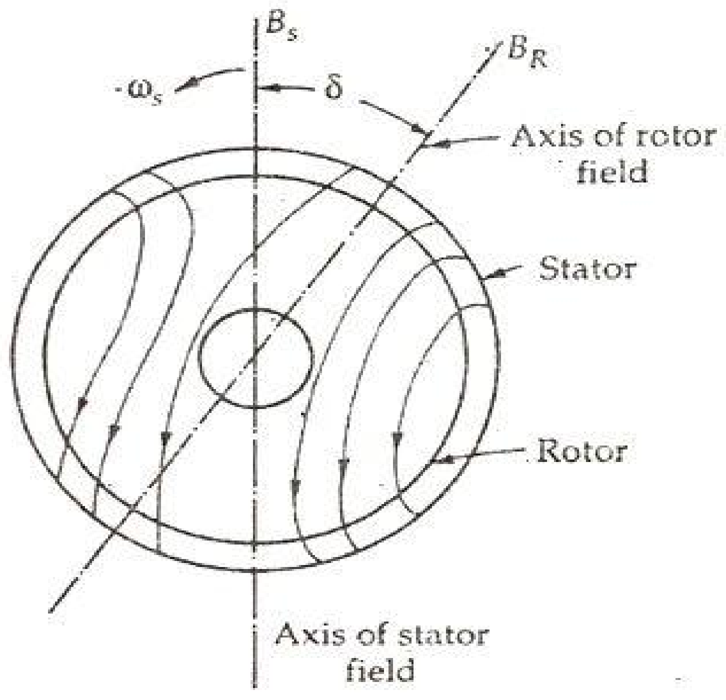
Construction of Rotor of Hysteresis Motor

- The rotor of the hysteresis motor consists of the core of aluminium or some other non-magnetic material which carries a layer of special magnetic material.
- The figure below shows h y s t e r e s i s
  - The outer layer has a number of thin rings forming a laminated rotor.
  - The rotor of the motor is a smooth cylinder, and it does not carry any windings.
  - **The ring is made of hard chrome or cobalt steel having a large**



Operation of a Hysteresis Motor

- When supply is given applied to the stator, a rotating magnetic field is produced.
- This magnetic field magnetizes the rotor ring and induces pole within it. Due to the hysteresis loss in the rotor, **the induced rotor flux lags behind the rotating stator flux**.



- The angle δ between the stator magnetic field B_S and the rotor magnetic field B_R is responsible for the production of the torque.
- The angle δ depends on the shape of the hysteresis loop and not on the frequency.

- The ideal material would have **a rectangular hysteresis loop**.
- The stator magnetic field produces Eddy currents in the rotor.
- As a result, they produce their own magnetic field.
- The electromagnet torque is developed by the motor is uniform because of the hysteresis loss remains constant at all rotor speed until the breakdown torque.
- At the synchronous speed, the eddy current torque is zero and only torque due to hysteresis loss is present.
- Applications are record players, tape recorders,

ALTERNATOR

Elementary Concepts of Rotating Machines

- Voltages can be induced by time–varying magnetic fields.

- In rotating machines, voltages are generated in windings or groups of coils by rotating these windings mechanically through a magnetic field, by mechanically rotating a magnetic field past the winding, or by designing the magnetic circuit so that the reluctance varies with rotation of the rotor.
- The flux linking a specific coil is changed cyclically, and a time–varying voltage is generated.

Elementary Concepts of Rotating Machines

- Electromagnetic energy conversion occurs when changes in the flux linkage result from mechanical motion.
- A set of such coils connected together is typically referred to as an armature winding, a winding or a set of windings carrying ac currents.
  - In ac machines such as synchronous or induction machines, the armature winding is typically on the stator. (the stator winding)
  - In dc machines, the armature winding is found on the rotor. (the rotor winding)

Elementary Concepts of Rotating Machines

- Synchronous and dc machines typically include a second winding (or set of windings), referred to as the field winding, which carries dc current and which are used to produce the main operating flux in the machine.
- In dc machines, the field winding is found on the stator.
- In synchronous machines, the field winding is found on the rotor.
- In most rotating machines, the stator and rotor are made of electrical steel, and the windings are installed in slots on these structures.The stator and rotor structures are typically built from thin laminations of electrical steel, insulated from each other, to reduce eddy-current losses.

Synchronous Generators

- Are the primary source of all electrical energy
- Commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines, hydro turbines into electrical power for the grid
- Can be extremely large — power ratings up to 1500MW
- Are known as synchronous machines because they operate at synchronous speed (speed of rotor always matches

Stationary Field Synchronous Generator

- Poles on the stator (field winding) are supplied with DC to create a stationary magnetic field.
- Armature winding on rotor consists of a 3-phase winding whose terminals connect to 3 slip-rings on the shaft.
- Brushes connect the armature to the external 3-phase load
- This arrangement works for low power machines (<5kVA). For higher powers (& voltages), issues with brushes and

Revolving Field Synchronous Generator

- Most common — also known as alternator
- Stationary armature with 3-phase winding on stator
- 3-phases directly connected to load
- Rotating magnetic field created by DC field winding on rotor, powered by slip-rings & brushes

Number of Poles

- The number of poles on a synchronous generator depends upon the speed of rotation and desired frequency

$$f = pn/120$$

- Where f = frequency of the induced voltage (Hz)
- p = number of poles on the rotor n = speed of the rotor (rpm)

Producing the DC field

- For both stationary and revolving fields, DC supply is normally produced by DC generator mounted on same shaft as rotor.
- Permanent magnets can also produce DC field

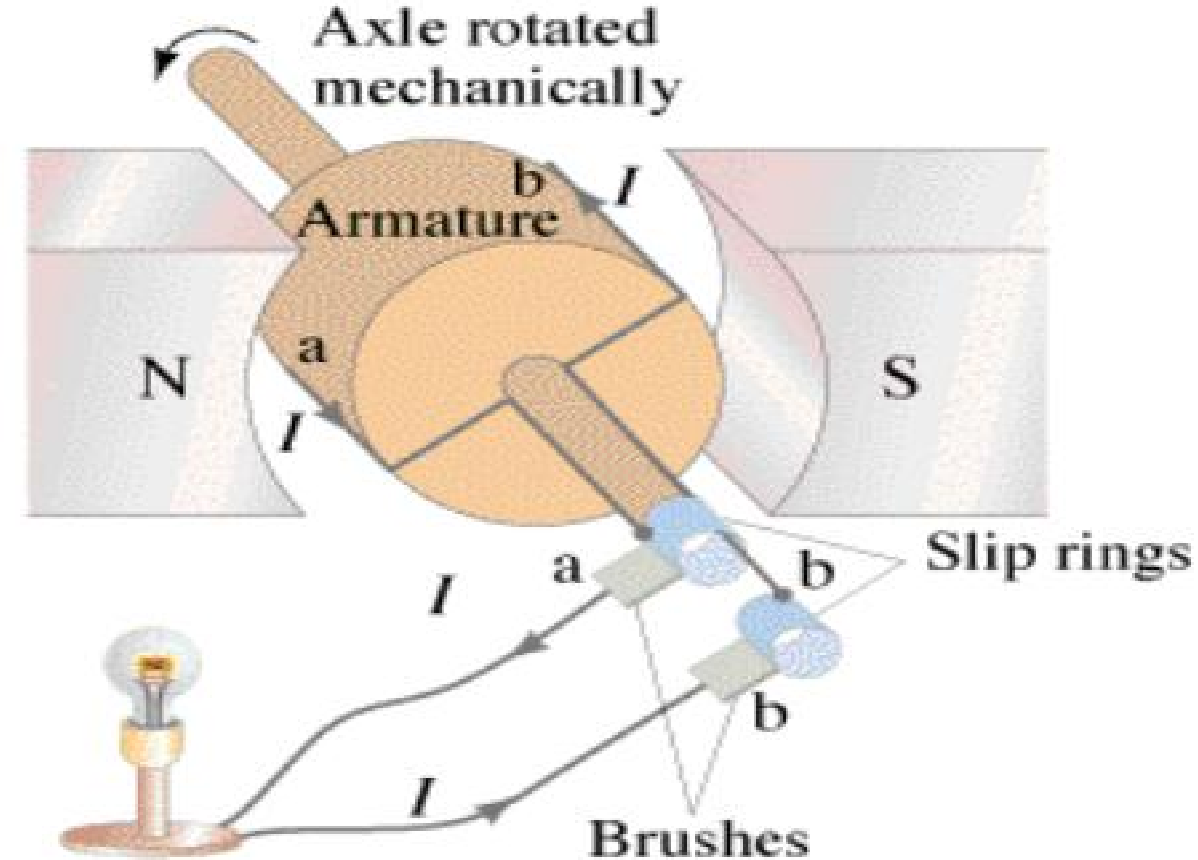
  — used increasingly in smaller machines as magnets get cheaper.

Difference between A.C. & D.C. Generator

- In D.C. Generator

  Armature-- Rotating

  Field -- Stationary

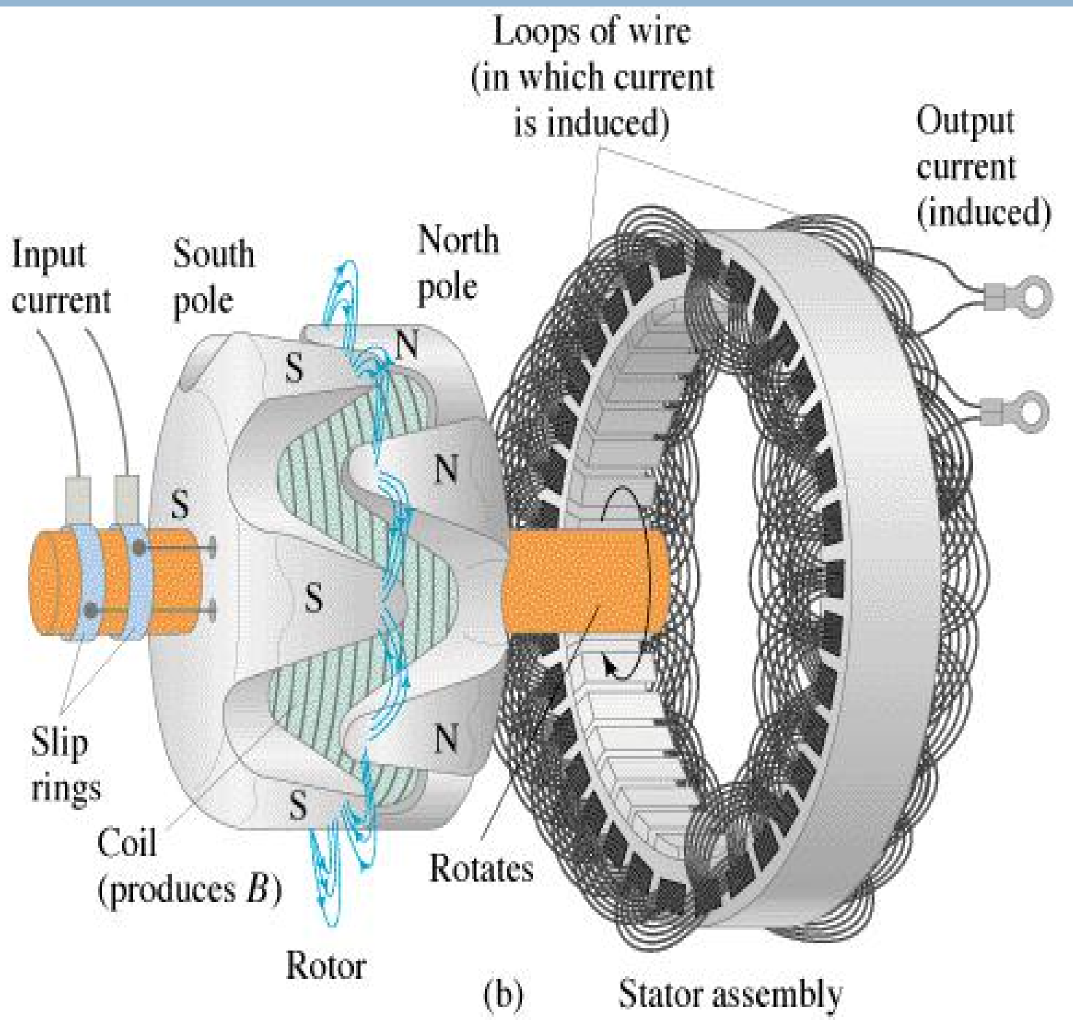


Difference between A.C. & D.C. Generator

- In A.C. Generator

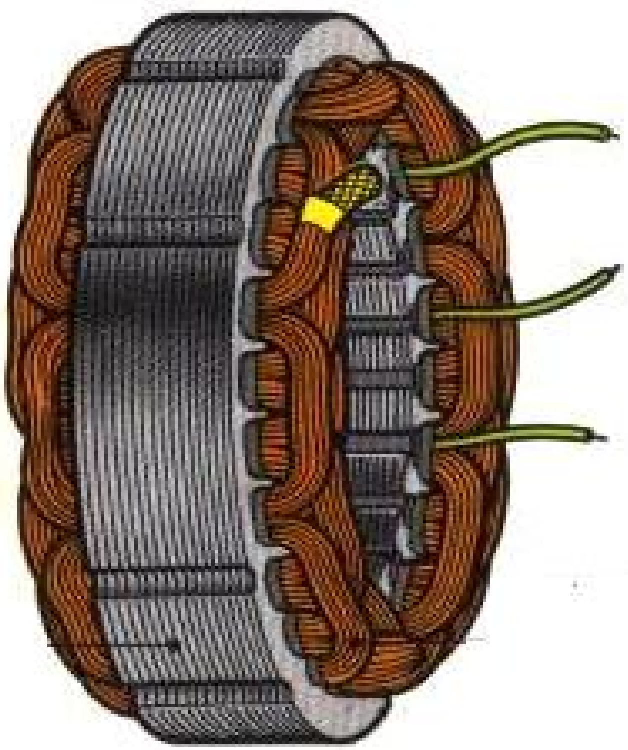
  Armature-- Stationary

  Field -- Rotating

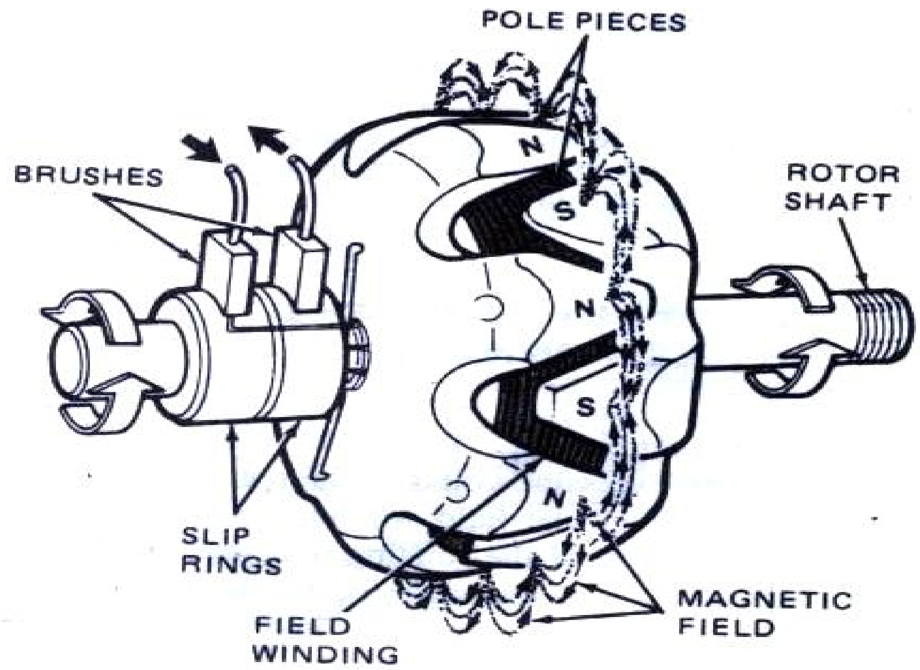


Main Parts

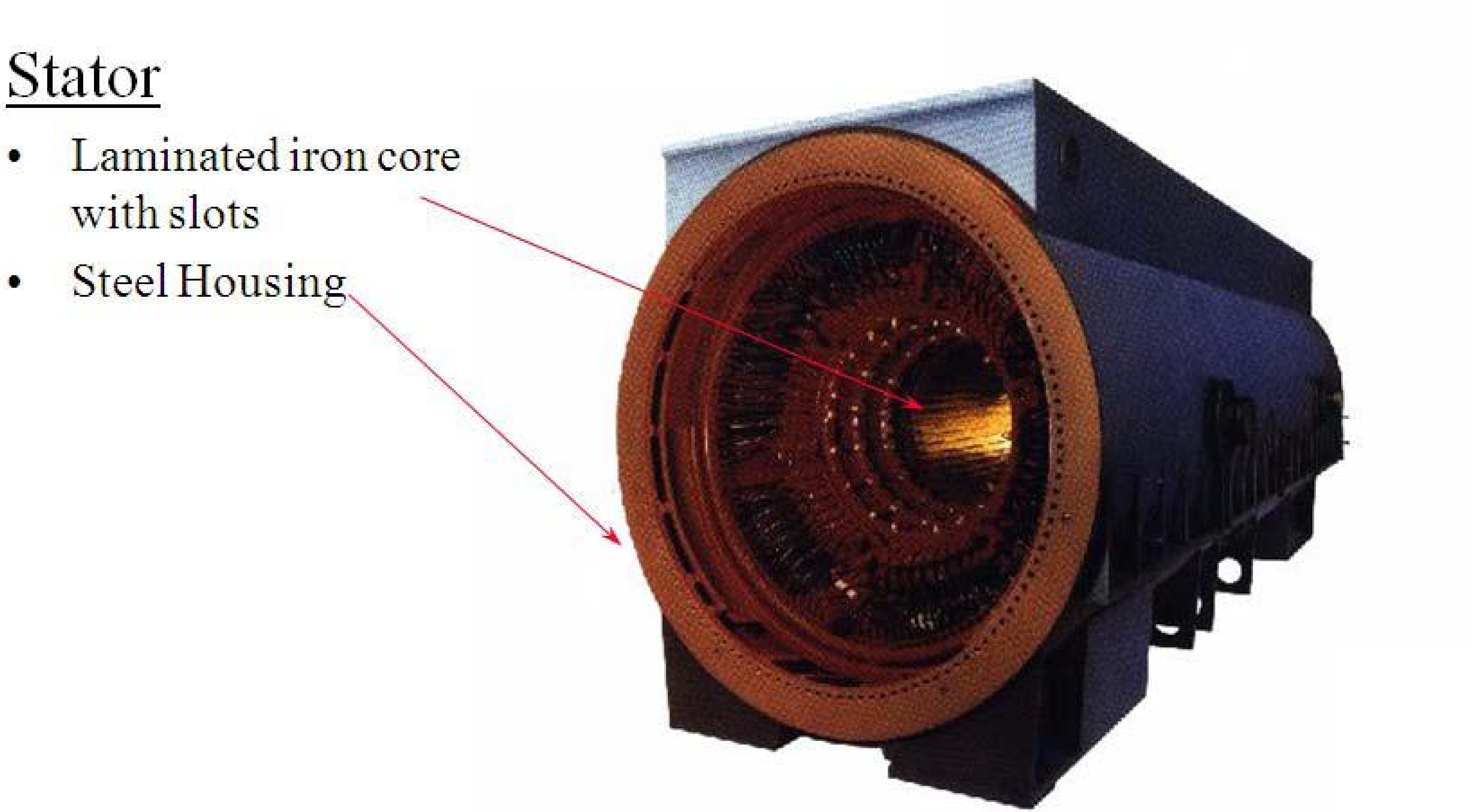
- Stator – Armature



- Rotor – Field



Stator



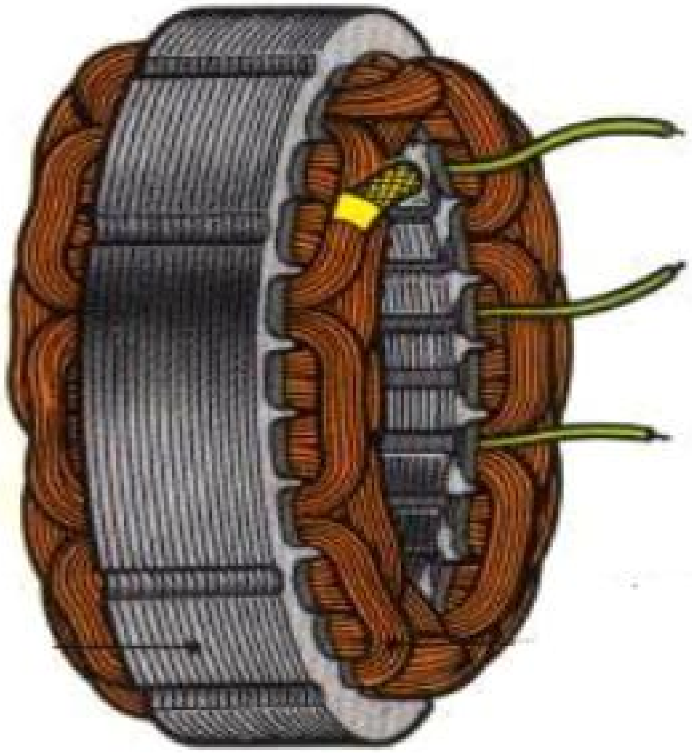
Construction

- The winding consists of copper bars insulated with mica and epoxy resin.
- The conductors are secured by steel wedges.
- The iron core is supported by a steel housing

Stator

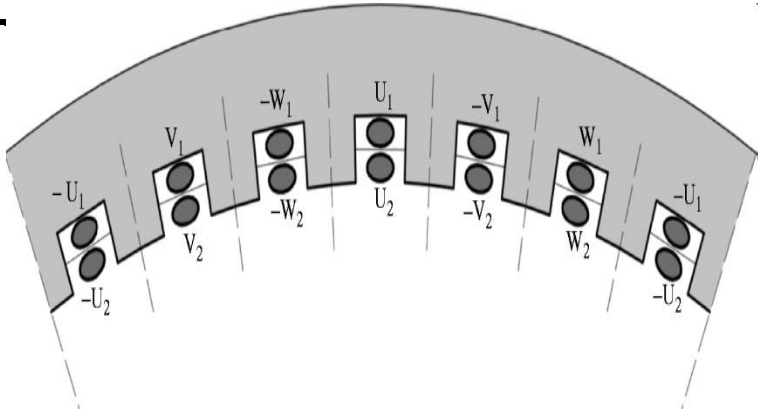
- From an electrical standpoint, the stator of a synchronous generator is identical to that of a 3-phase induction motor (cylindrical laminated core containing slots carrying a 3-phase winding).
- The nominal line voltage of a synchronous generator depends upon its kVA rating — the greater the power, the higher the voltage

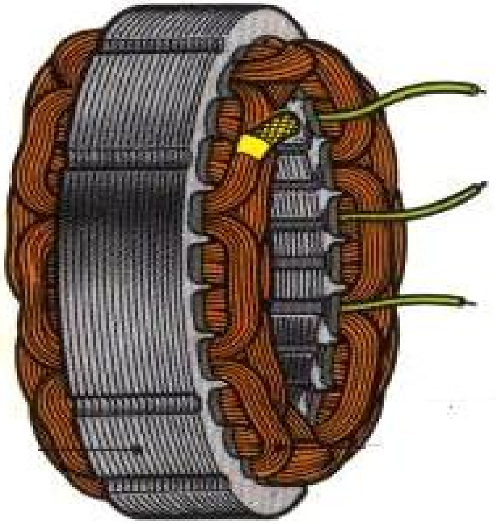
Coil / Armature



Stator

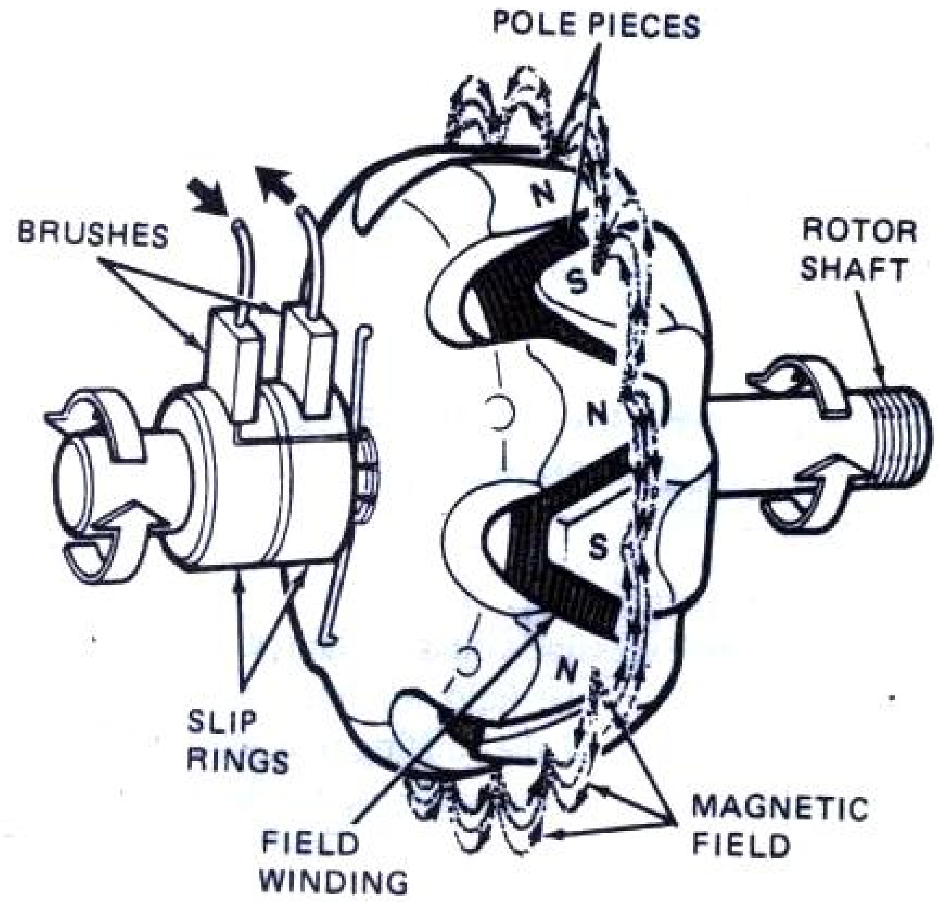
- Stationary armature
- Coils is placed in slots of stator core.
- Stator is made of laminates.
- Whole stator is fixed in the frar





Rotor

- Field winding
- External D.C.supply of 120-600 volt
- Supply by Brush & Slip ring
- N pole & S pole developed alternatively



Synchronous Generator: Rotor

Salient-pole rotors

— Used for low speed applications $(<300$rpm$)$ which require large number of poles to achieve required frequencies

Cylindrical rotor

— Used for high-speed applications

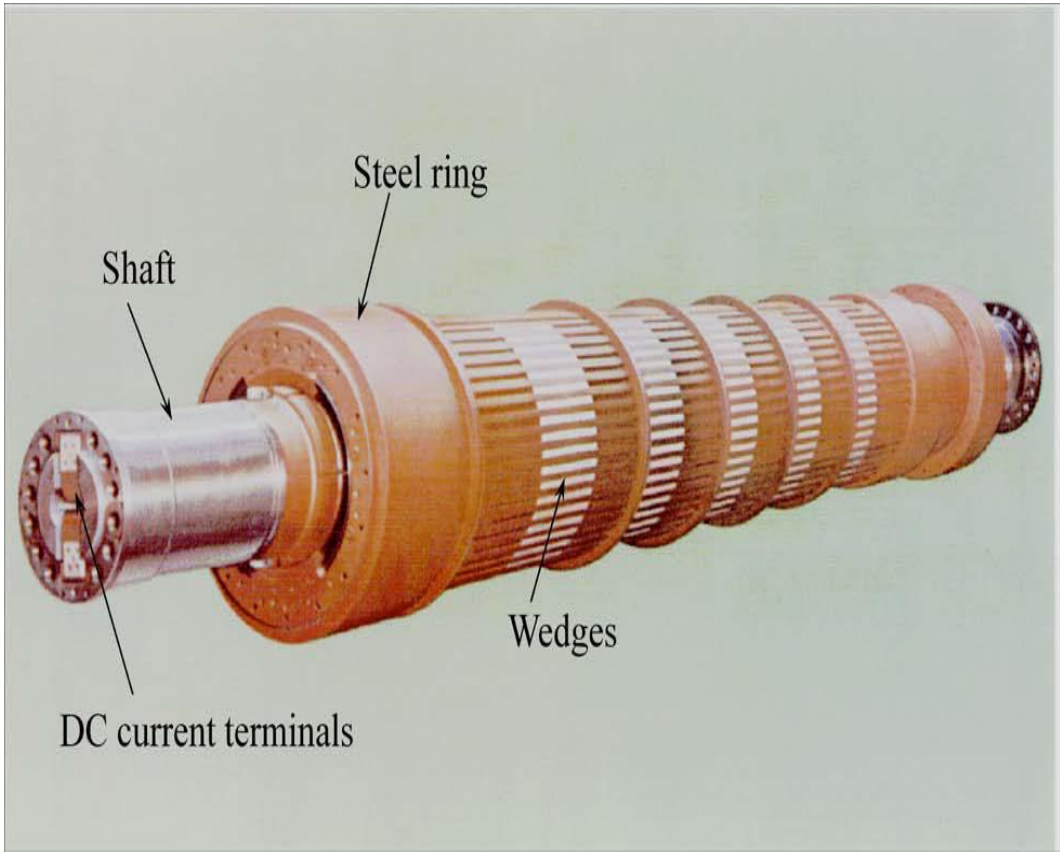
— Minimum number of poles is 2, so for 50Hz the maximum speed is 3000rpm.

— High speed of rotation produces strong centrifugal forces, which impose upper limit on the rotor diameter.

Cylindrical rotor Machines

Round Rotor Machine

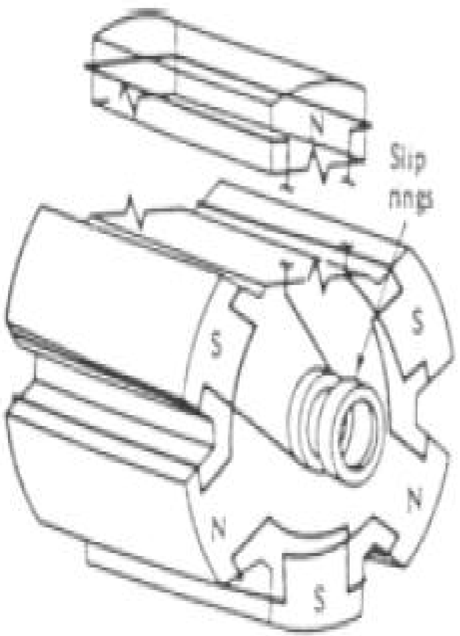
- The stator is a ring shaped laminated iron-core with slots.
- Three phase windings are placed in the slots.
- Round solid iron rotor with slots.
- A single winding is placed in the slots. Dc current is supplied through slip rings.



Salient Rotor Machine

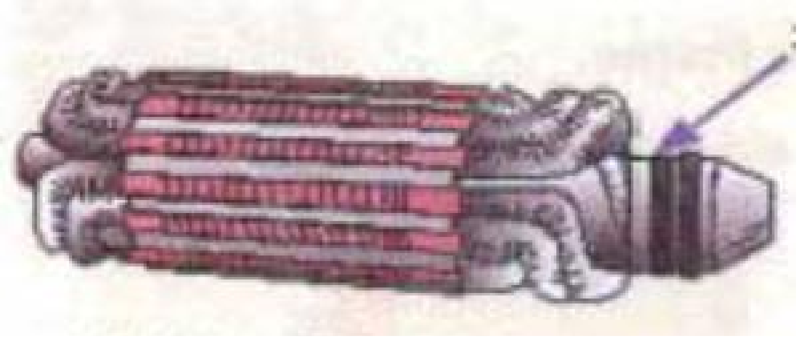
Salient Rotor Machine

- The stator has a laminated iron-core with slots and three phase windings placed in the slots.
- The rotor has salient poles excited by dc current.
- DC current is supplied to the rotor through slip-rings and brushes.
- The number of poles varies between 2 - 128.

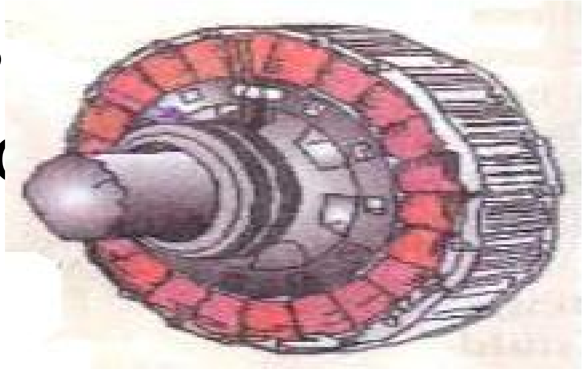


Difference B/W Cylindrical & Salient Pole Rotor

- **<u>Cylindrical Type</u>**
- Small diameter
- Large axial length
- High speed
- Steam turbine & motors are used as prime mover



- **<u>Salient Pole Type</u>**
- Large diameter
- Small axial length
- Low speed
- water turbines & IC engines. are us
  m



Field Excitation and Exciters

- DC field excitation is an important part of the overall design of a synchronous generator
- The field must ensure not only a stable AC terminal voltage, but must also respond to sudden load changes — rapid field response is important.
- Main and pilot exciters are used
- Brushless excitation systems employ power electronics (rectifiers) to avoid brushes & slip ring assemblies.

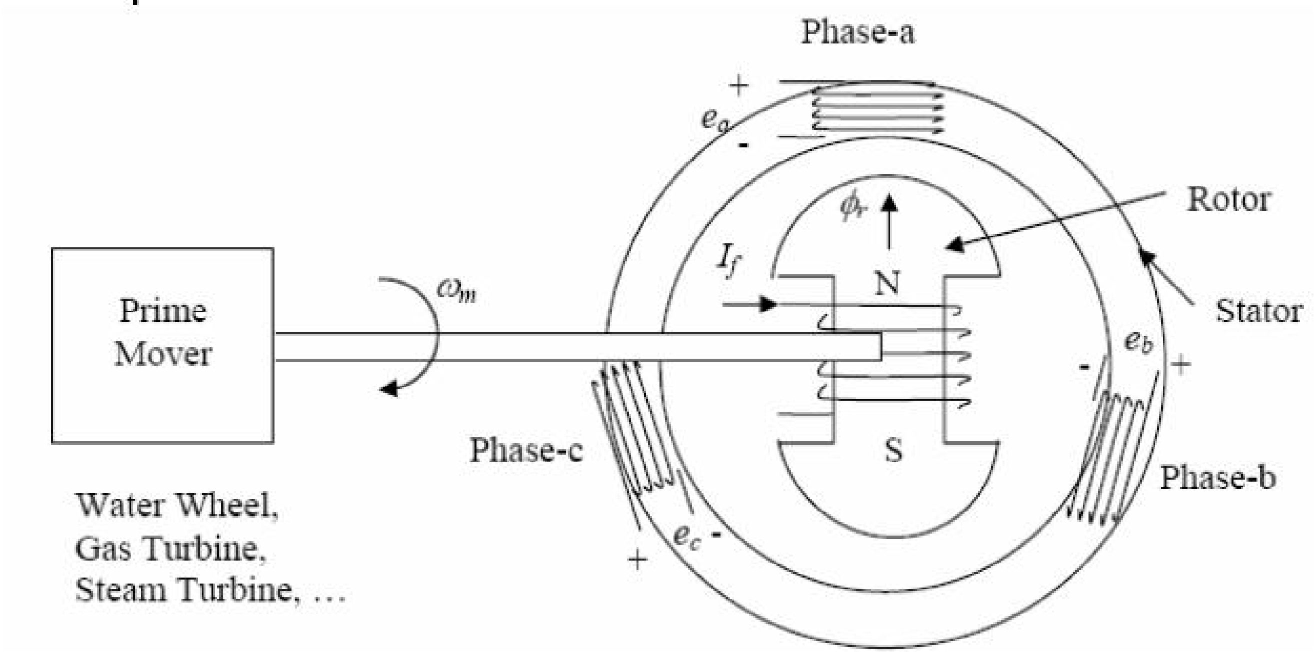
Three methods of excitation

1. **slip rings link the rotor's field winding to an external dc source**
2. **dc generator exciter**
   - a dc generator is built on the same shaft as the ac generator's rotor
   - a commutator rectifies the current that is sent to the field winding
3. **brushless exciter**
   - an ac generator with fixed field winding and a rotor with a three phase circuit
   - diode/SCR rectification supplies dc current to the field windings

Basic Principle of Operation

Principle of Operation

1) From an external source, the field winding is supplied with a DC current -> excitation.
2) Rotor (field) winding is mechanically turned (rotated) at synchronous speed.
3) The rotating magnetic field produced by the field current induces voltages in the outer stator (armature) winding. The frequency of these voltages is in synchronism with the rotor speed.

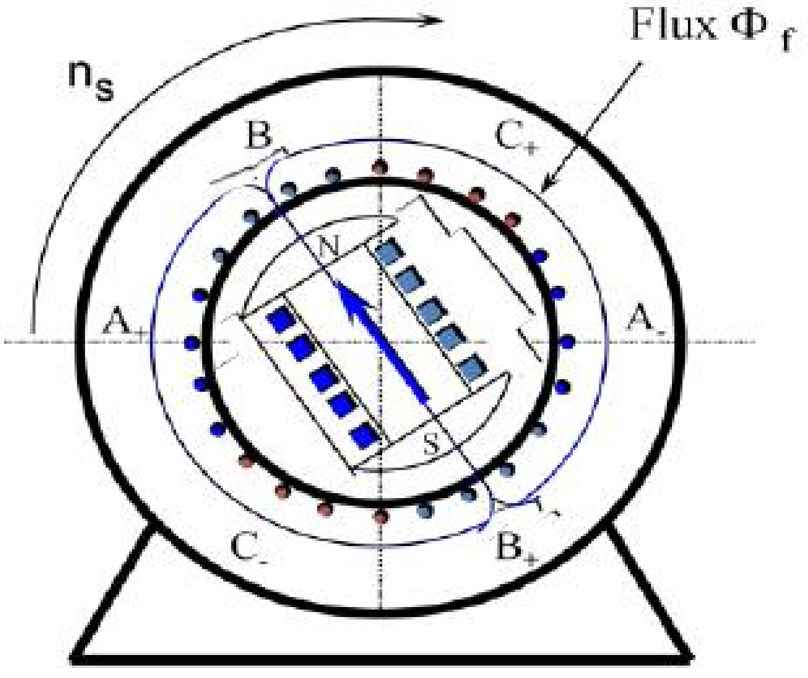


Basic Principle of Operation

Operation concept

- The rotor is supplied by DC current I_f that generates a DC flux Φ_f.
- The rotor is driven by a turbine with a constant speed of n_s.
- The rotating field flux induces a voltage in the stator winding.
- The frequency of the induced voltage depends upon the speed.

Operation (two poles)



- The frequency - speed relation is $\mathbf{f = (p / 120)\ n = p\ n / 120}$
  p is the number of poles.
- Typical rotor speeds are 3600 rpm for 2-pole, 1800 rpm for 4 pole and 450 rpm for 16 poles.

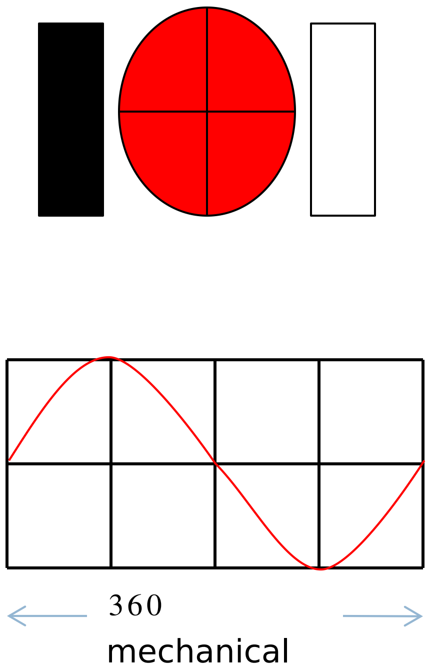
Ventilation or Cooling of an Alternator

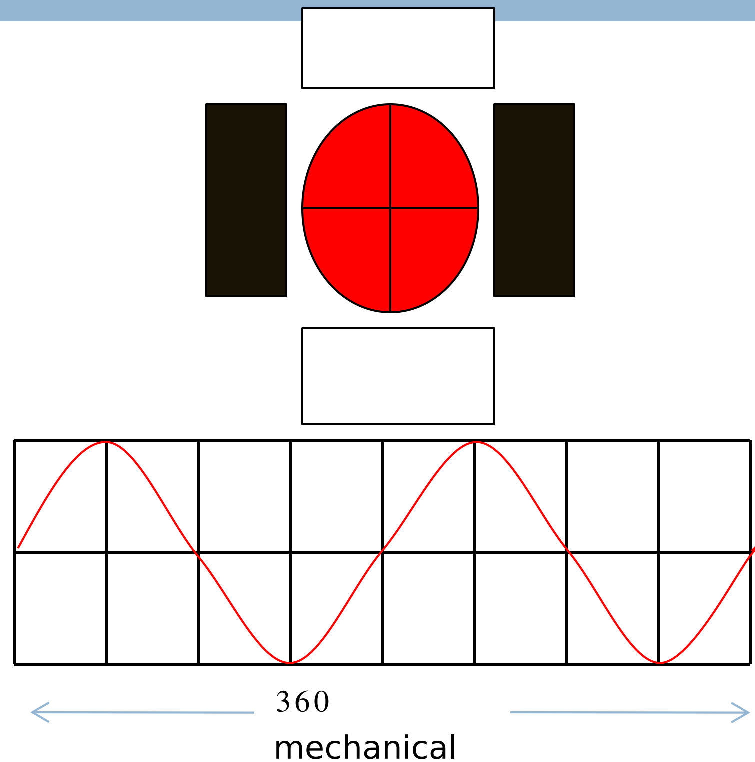
- The slow speed salient pole alternators are ventilated by the fan action of the salient poles which provide circulating air.
- Cylindrical rotor alternators are usually long, and the problem of air flow requires very special attention.
- The cooling medium, air or hydrogen is cooled by passing over pipes through which cooling water is circulated and ventilation of the alternator.
- Hydrogen is normally used as cooling medium in all the turbine-driven alternators because hydrogen provides better cooling than air and increases the efficiency and decreases the windage losses.
- Liquid cooling is used for the stators of cylindrical

Advantages of Alternator over D.C.Generator

- Generation of power at High level.
- Easy to collect High current.
- No commutation.
- Easy to provide Insulation & Cooling in stationary armature.
- Low voltage level in field so less insulation required.

Electrical & Mechanical Degree





For 2 pole
1 electrical cycle=1 mechanical cycle

For 4 pole
2 electrical cycle=1 mechanical cycle

360 mechanical = 360 **x** (**P**/2) **electrical**

1 **mechanical cycle** = (**P**/2) **electrical cycle**

Induce EMF Frequency

- 1 Mechanical Revolution = P/2 cycle of EMF
- P/2 cycles/revolution
- For N rpm, (N/60) revolutions/sec
- Frequency = cycles/sec = f
- f = (cycles/revolution)x (revolution/sec)

  = (P/2) x (N/60) Hz

  = (PN/120) Hz

For 50 Hz

P	2	4	8	12
N	3000	1500	750	500

EMF Equation

For one conductor

- Induced EMF/revolution = dø/dt volt
  = (P x ø)/(60/N) volt
  = 2fø volt
- For Coil, EMF/revolution = 4fø volt
- Average EMF/phase = (Turn/phase)x 4fø volt
  = $4føT_{PH}$ volt
- R.M.S. value of EMF = Form Factor x Avg EMF

Armature winding of alternator

Armature winding in an alternator may be either closed type open type.

There are some common properties of armature winding.

- Two sides of any coil should be under two adjacent poles. That means, coil span = pole pitch.
- The winding can either be single layer or double layer.
- Winding is so arranged in different armature slots, that it must produce sinusoidal emf.

Windings

- Some of the terms common to armature windings are described below:

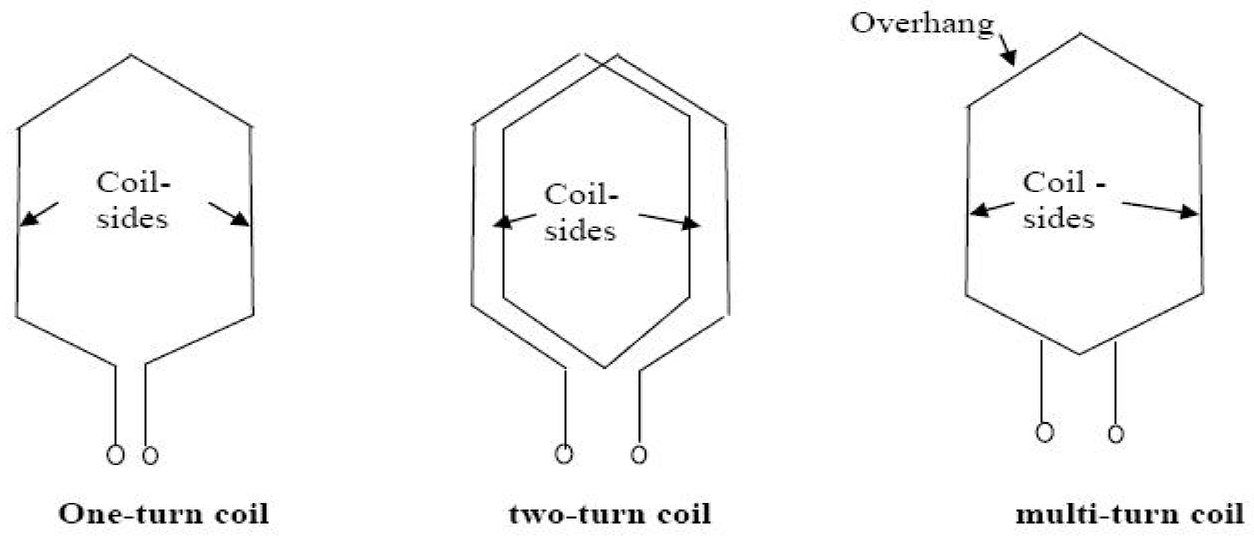
1. Conductor – A length of wire which takes active part in the energy conversion process is a called a conductor.

2 . Turn. – One turn consists of two conductors.

3 . Coil. – One coil may consist of any number of turns.

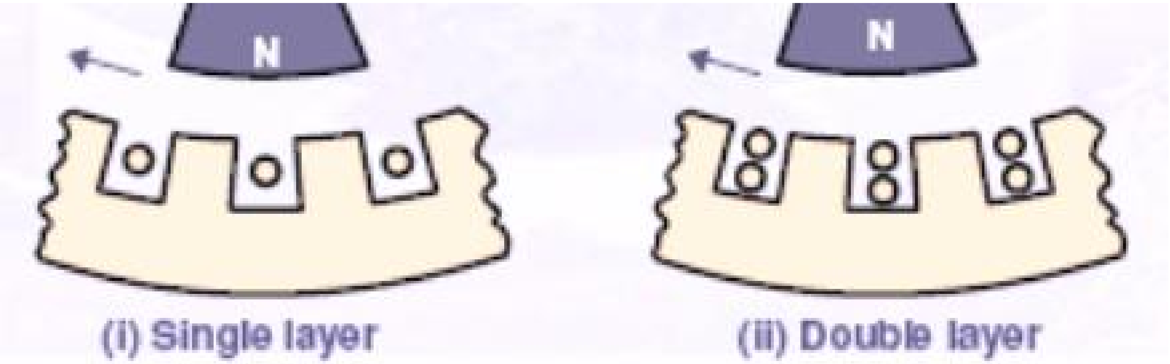
4. Coil side. – One coil with any number of turns has two coil – sides

The number of conductors (C) in any coil–side is equal to the number of turns (N) in that coil.



Types of Windings

5. Single layer & Double Layer



- **Single– layer winding**

  One coil–side occupies the total slot area

  Used only in small ac machines

- **Double– layer winding**

  Slot contains even number (may be 2,4,6 etc.) of coil-sides in two layers

  Double–layer winding is more common above about 5kW machines

Types of Windings

- **The advantages of double–layer winding over single layer winding are as follows**:

- **Easier to manufacture and lower cost of the coils**
- **Chorded–winding is possible**
- **Lower–leakage reactance and therefore , better performance of the machine**
- **Better emf waveform in case of generators**

Types of windings

Single phase armature winding can be either concentrated or distributed type.

- Concentrated & Distributed winging.

  In Concentrated Winding

  all the conductor of coil in 1 slot

  In Distributed winding

  all the conductor of coil in more than 1 slots

Concentrated Armature Wi

- Concentrated winding is employed where number of slots on the armature is equal to number of poles in the machine.
- This armature winding of alternator gives maximum output voltage but not exactly sinusoidal.

The most simple single *phase winding, is shown* . Here, number poles = number of slots = number of coil sides. Here, one coil side is inside one slot under one pole and other coil side inside other slot under next pole.

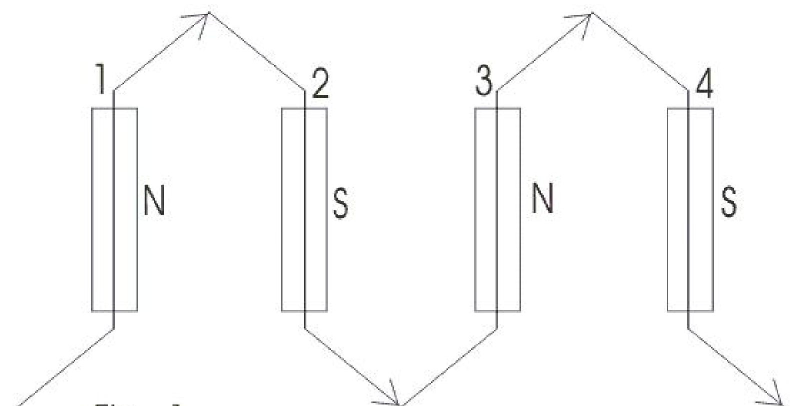


Fig - 1

Clearly the emf induced in one coil side is added to that of adjacent coil side.

Distributed Armature Winding of Alternator

- For obtaining smooth sinusoidal emf wave from, conductors are placed is several slots under single pole. This armature winding is known as distributed winding.

All the winding turns are arranged in several full pitch or fractional pitch coils

• These coils are then housed in the slots spread around the air – gap periphery to form phase or commutator winding

• Examples of distributed winding are

–Stator and rotor of induction machines
–The armatures of both synchronous

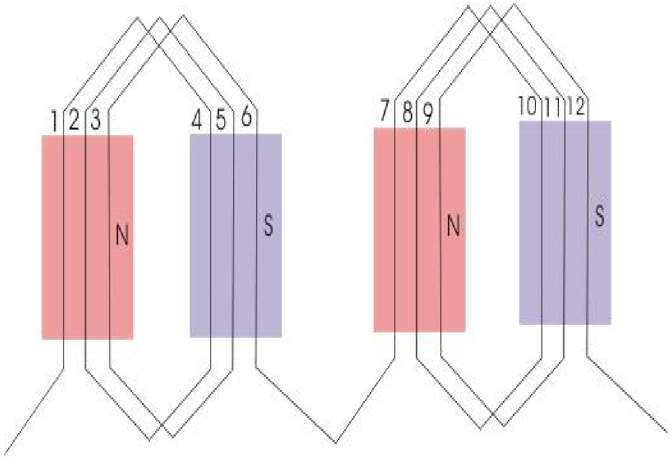
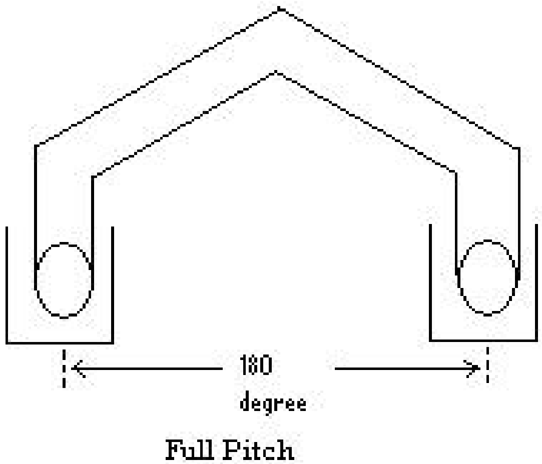


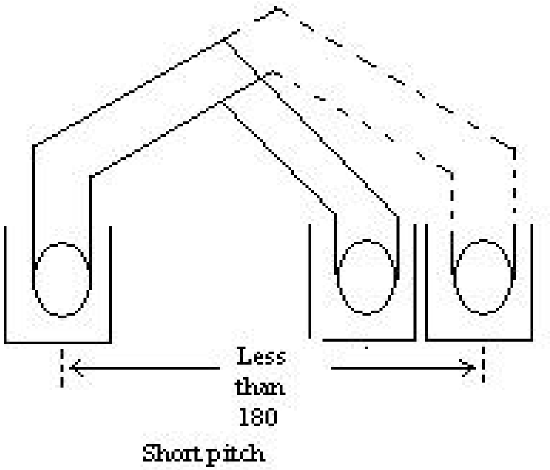
Fig - 4

Windings

- The distance b/w the two coil sides is called the coil span.
- The angular distance b/w the central line of one pole to the central line of the next pole is called pole pitch.

Full pitch & Short pitch winding



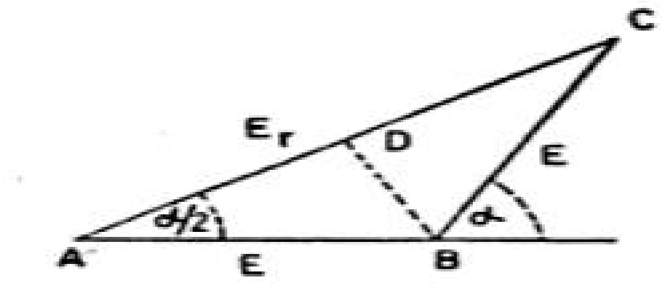


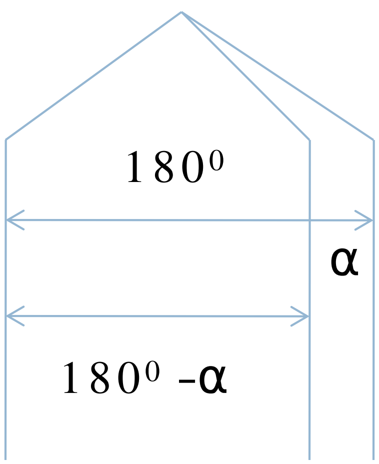
Pitch factor

- In short pitched coil, the induced emf of two coil sides is vectorically added to get, resultant emf of the coil
- In short pitched coil, the phase angle between the emfs induced in two opposite coil sides is less than $180°$ (electrical).
- In full pitched coil, the phase angle between the emfs induced in two coil sides is exactly $180°$ (electrical). Hence, the resultant emf of a full pitched coil is just arithmetic sum of the emfs induced in both sides of the coil.
- And the , vector sum or phasor sum of two quantities, is always less than their arithmetic sum. Pitch factor is the measure of resultant emf of short pitched coil

Pitch Factor/ Coil Span Factor K_c

- K_c = factor by which EMF get reduced due to short pitch
- α – short pitch angle
- Coil is shorted by angle α
- $K_c = \cos(\alpha/2)$





$$kc = \frac{\text{actual voltage generated in the coil}}{\text{voltage generated in the coil of span 180 electrical}}$$

$$= \frac{\text{phasor sum of the voltages of two coil sides}}{\text{arithmatic sum of the voltages of two coil sides}}$$

$$= \frac{AC}{2AB} = \frac{2AD}{2AB} = \cos\alpha/2$$

Advantage of Short pitching and chording

- Shortens the end of the winding and therefore there is saving in the conductor material.

- Reduces effects of distorting harmonics and thus the wave form of the generated voltage is improved and making it approach a sine wave.

Distribution Factor

- In distributed winding, coil sides per phase are displaced from each other by an angle equal to the angular displacement of the adjacent slots. Hence, the induced emf per coil side are not an angle equal to the angular displacement of the slots.

  So, the resultant emf of the winding is the phasor sum of the induced emf per coil side. As it is phasor sum, must be less than arithmetic sum of these induced emfs. are under one pole.

Distribution Factor K_d

$$kd = \frac{\text{phasor sum of the voltages of two coil sides}}{\text{arithmetic sum of the voltages of two coil sides}}$$

- K_d = factor by which EMF get reduced due to distributed winding.
- **n** = slots / pole
- **m** = slot / pole. phases
- Slot angle $\beta = 180/\mathbf{n}$
- $K_d = \dfrac{\sin(m\beta/2)}{m\sin(\beta/2)}$

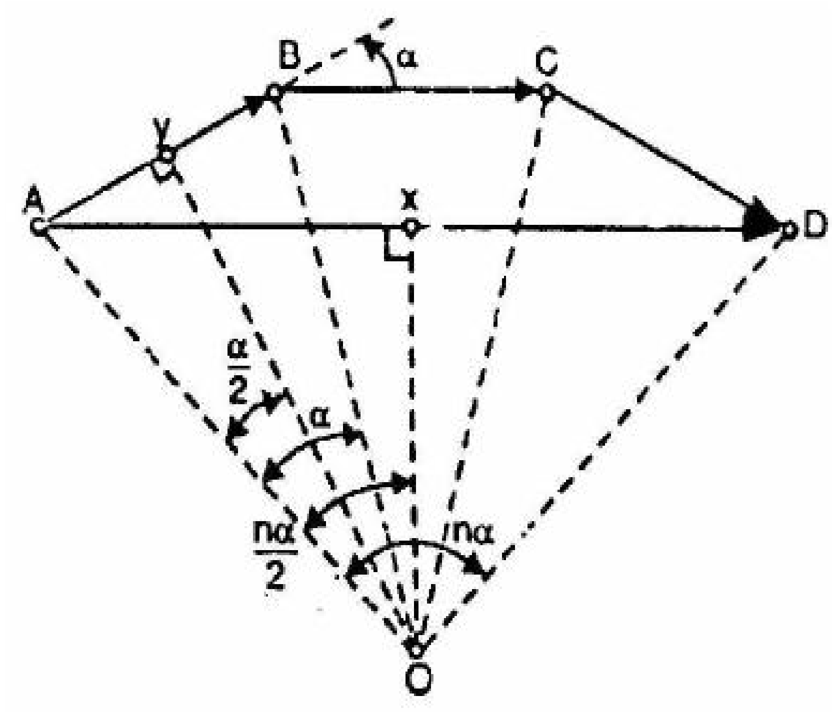
Distribution Factor K_d

$$kd = \frac{\text{phasor sum of the voltages of two coil sides}}{\text{arithmetic sum of the voltages of two coil sides}}$$

$$K_d = \frac{AD}{n \times AB} = \frac{2 \times Ax}{n \times (2Ay)} = \frac{Ax}{n \times Ay}$$

$$= \frac{OA \times \sin(n\alpha/2)}{n \times OA \times \sin(\alpha/2)}$$

$$K_d = \frac{\sin(n\alpha/2)}{n \sin(\alpha/2)}$$



Generalized EMF equation

- For full pitch & concentrated winding

  $E_{PH} = 4.44\, f \phi T_{PH}$ volt

- For short pitch & distributed winding

  $$E_{PH} = 4.44\, K_c\, K_d\, f\, \phi\, T_{PH} \text{ volt}$$

Voltage drop in Induced EMF

- Due to following resistance

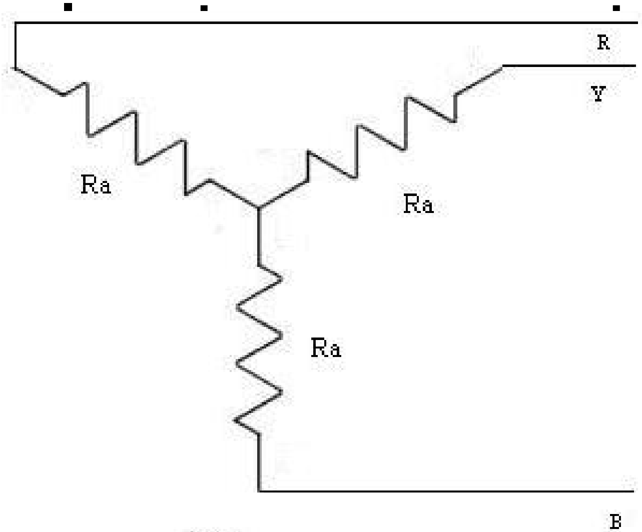
1. Armature resistance $\mathbf{R_a}$
2. Armature leakage reactance $\mathbf{X_l}$
3. Armature reaction $\mathbf{X_a}$

Voltage drop in Induced EMF

- 1.Armature resistance $\mathbf{R_a}$

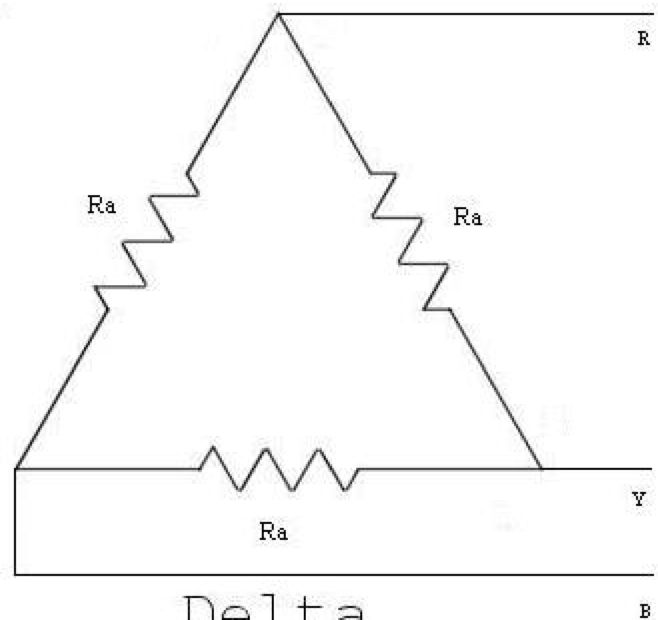
  Resistance offered by the armature winding

  on,



Star

$Ra = \frac{Rry}{2}$ ohm/phase



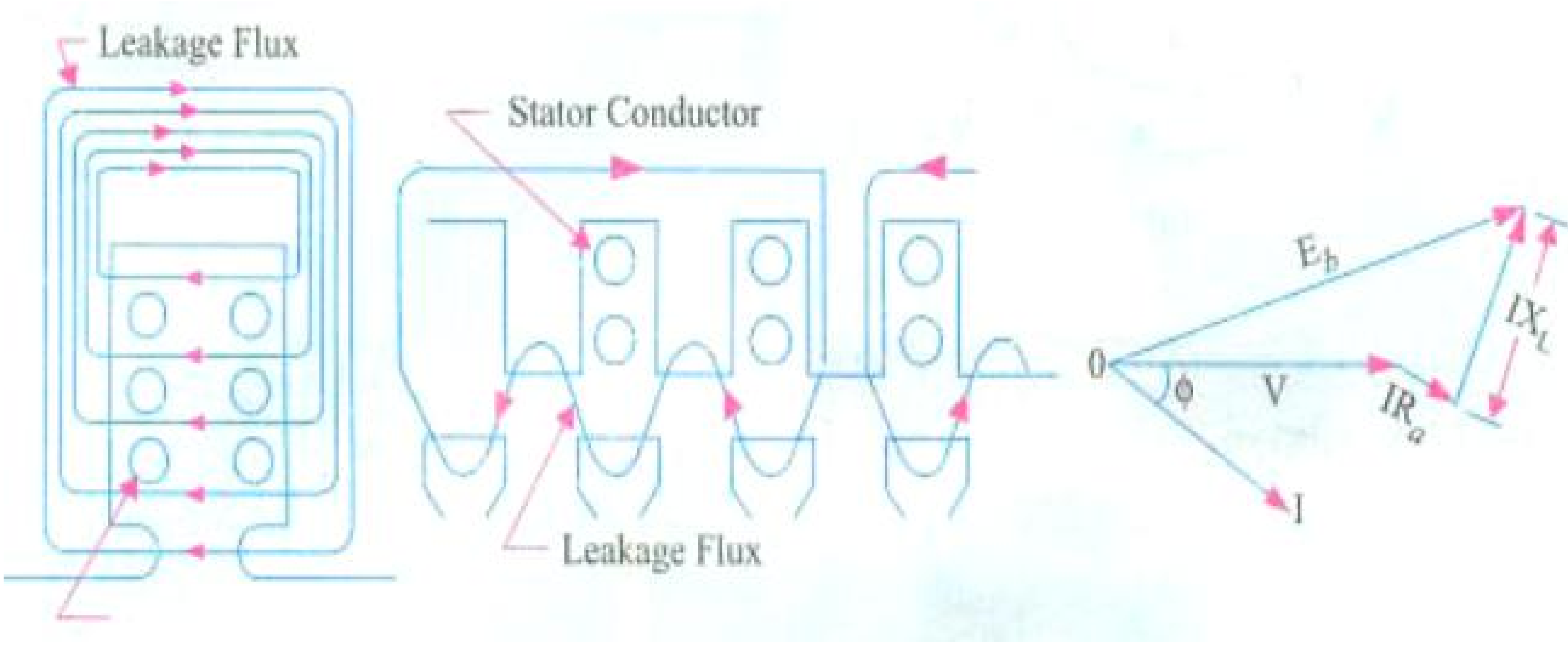
Delta

Ra = (3/2) Rry ohm/phase

Voltage drop in Induced EMF

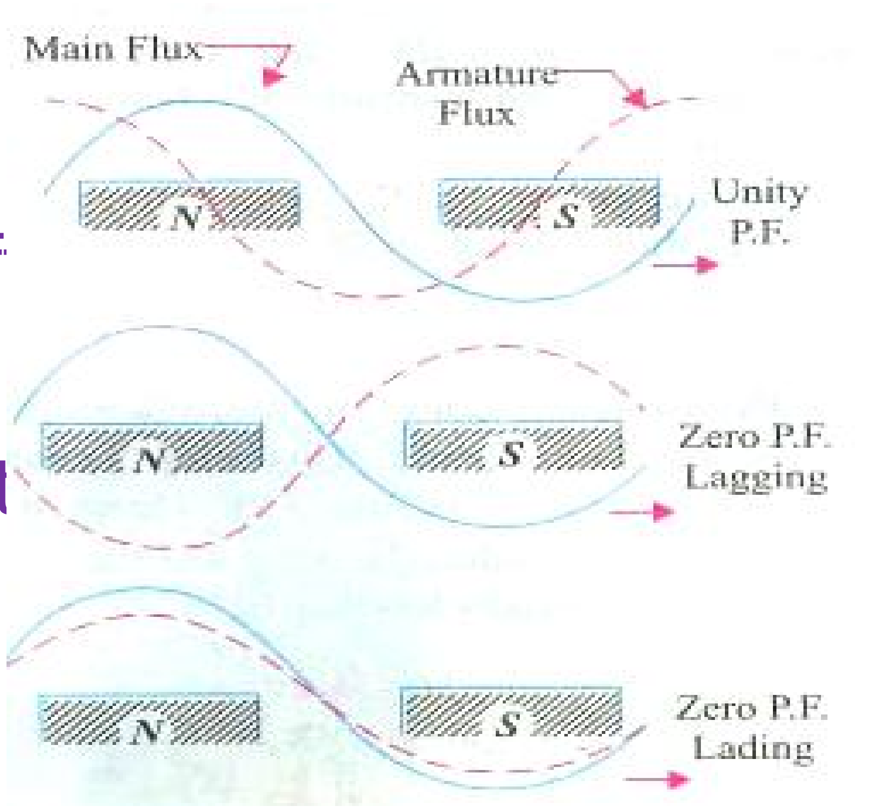
2.Armature leakage reactance X_l

- Armature flux develop by current carrying conductor
- Armature Flux do not crosses the air-gap but



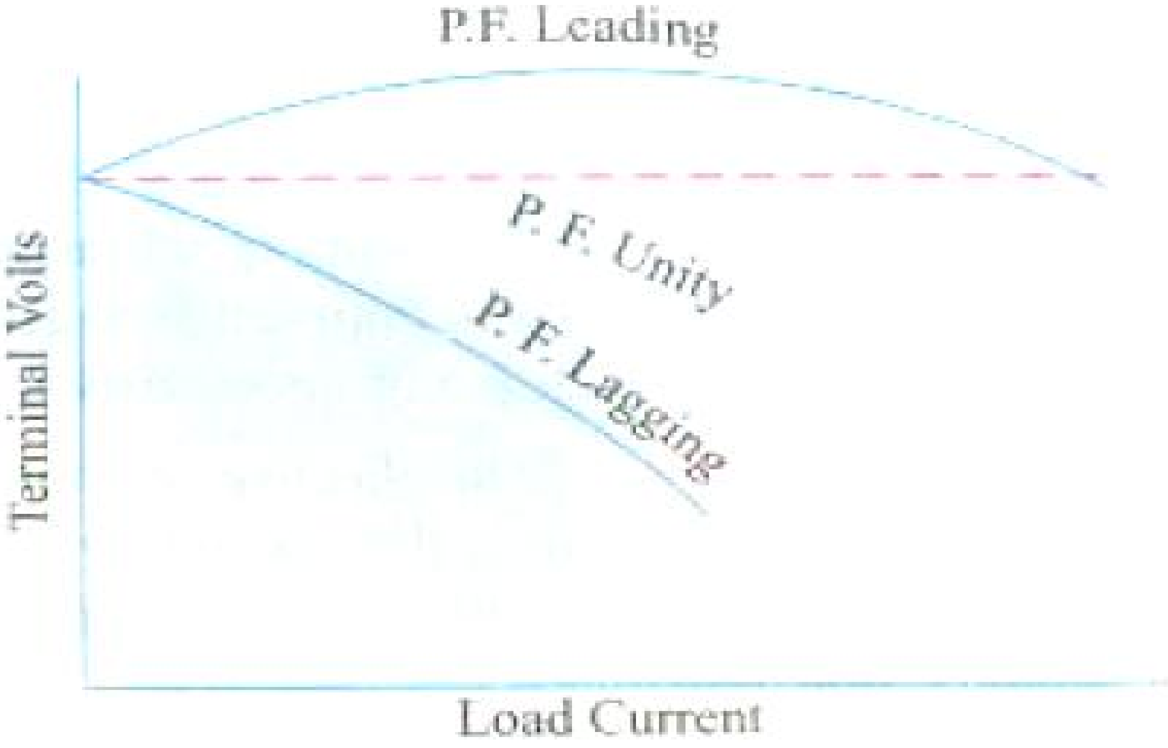
Voltage drop in Induced EMF

- Armature reaction X_a
- Effect of armature flux on the main field flux on loading condi
- For Unity p.f.
  cross magnetizing ef
- For zero p.f. lagging
  demagnetizing effect
- For zero p.f. leading
  magnetizing effect



Voltage Regulation

- $\% \text{ regulation} = \frac{E_0 - V}{V} \times 100$



Determination of voltage regulation

- Synchronous Impedance or emf Method
- The Ampere turn or MMF method
- Zero Power Factor or Potier Method

- All these methods requires
  - Armature resistance Ra
  - Open ckt/No load Characteristics
  - Short Ckt Characteristics

Determination of voltage regulation

- Value of Ra:
  - Ra can be measured directly by voltmeter and ammeter method or by wheatstone bridge.

- O.C Characteristic:
  - This is plotted by running machine on No load

- S.C Characteristic:
  - It is obtained by Short circuiting the armature winding through a low value of resistance ammeter. The excitation is so adjusted to give 1.5 to 2 times the value of full load current.

Synchronous Impedance Method

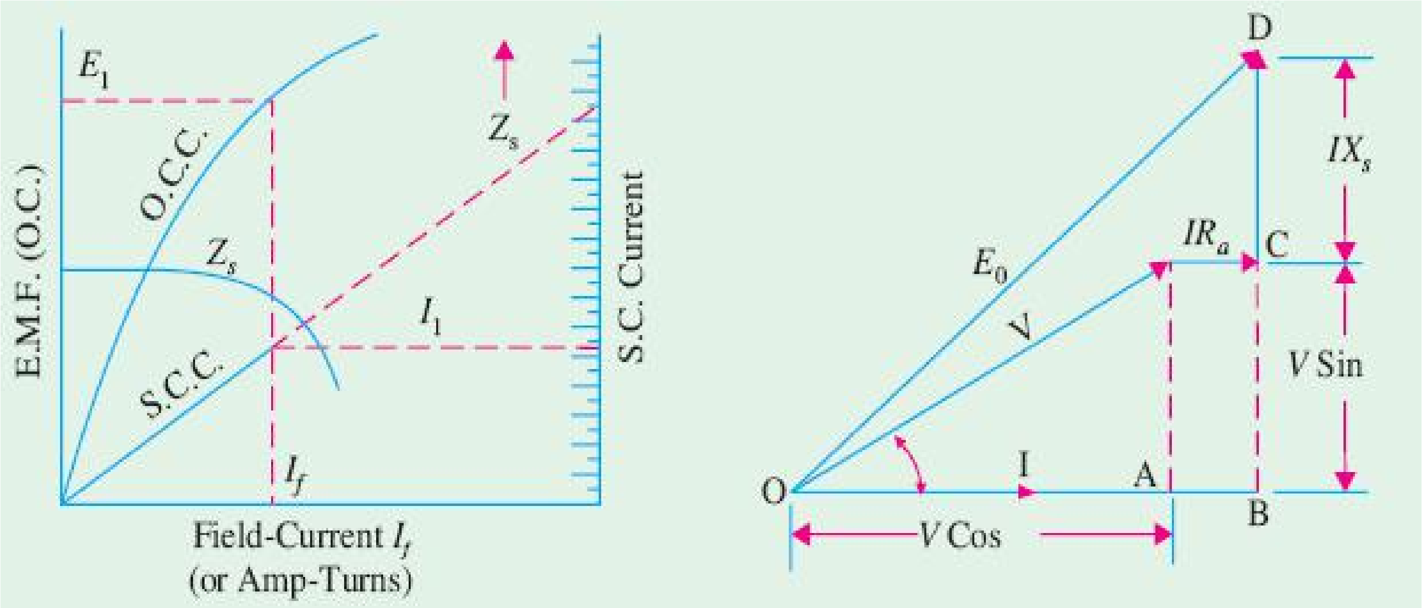
- OCC is plotted by running machine on No load.
- SCC is drawn from data given by SC test.
- Let I_f is the field current and O.C voltage corresponding to this field current is E_1.

$$E_1 = I_1 Z_S \qquad \therefore Z_S = \frac{E_1 \text{ (open-circuit)}}{I_1 \text{ (short-circuit)}}$$

- Ra can be obtained as

$$X_S = \sqrt{(Z_S^2 - R_a^2)}$$

Synchronous Impedance Method



$$OD = E_0 \quad \therefore E_0 = \sqrt{(OB^2 + BD^2)}$$

$$E_0 = \sqrt{[(V\cos\phi + IR_a)^2 + (V\sin\phi + IX_S)^2]}$$

$$\%\text{ regn. 'up'} = \frac{E_0 - V}{V} \times 100$$

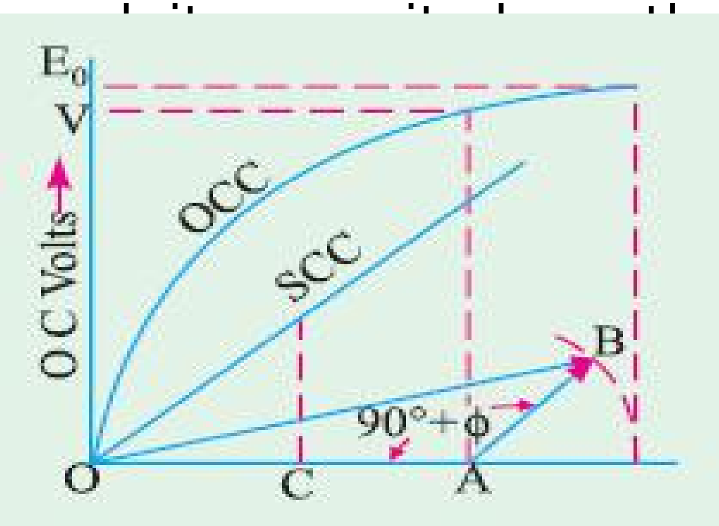
The Ampere turn or MMF method

- The ampere – turn /MMF method is the converse of the EMF method in the sense that instead of having the phasor addition of various voltage drops/EMFs, here the Phasor addition of MMF required for the voltage drops are carried out . Further the effect of saturation is also taken care of.

- Data required for MMF method are:
  - Effective resistance per phase of the 3-phase winding R
  - OCC at rated speed/frequency
  - SCC at rated speed/frequency

Steps:

- By suitable tests plot OCC and SCC
- From the OCC find the field current OA to produce rated voltage, V
- From SCC find the magnitude of field current to produce the required armature current.
- Draw field current at angle (90+Φ) from OA, where Φ is the phase angle of current from voltage. If current is leading, take the angle of field current as (90 – Φ).
- Find the resultant field current, If and … field current axis.
- From OCC. find the voltage correspond…
- to If, which will be E_0 .



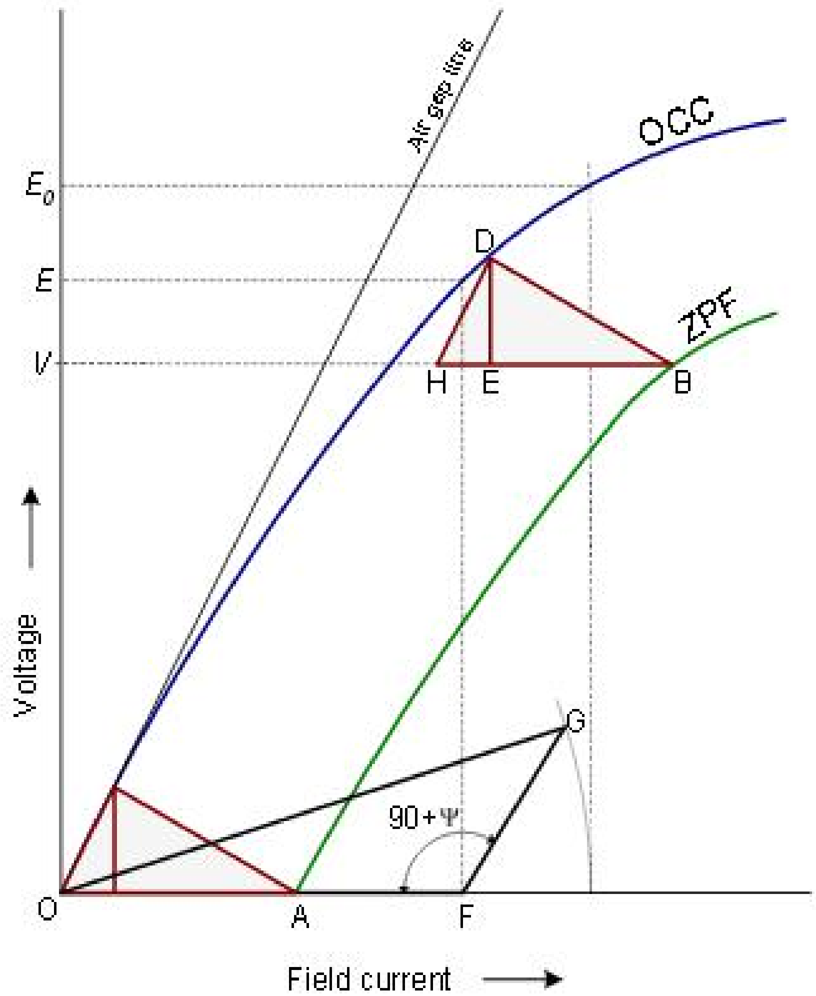
Zero Power Factor or Potier Method

- This method is based on the separation of armature leakage reactance drop and armature reaction effects. Hence, it gives more accurate results.
- Data required are:
  - No–load curve
  - Curve of terminal voltage against excitation when armature is delivering FL current at zero pf.

Zero Power Factor or Potier Method

Steps:

1. By suitable tests plot OCC and SCC
2. Draw tangent to OCC (air gap line)
3. Conduct ZPF test at full load for rated voltage and fix the point B.
4. Draw the line BH with length equal to field current required to produce full load current at short circuit.
5. Draw HD parallel to



6. Draw DE parallel to voltage axis. Now, DE represents voltage drop IXL and BE represents the field current required to overcome the effect of armature reaction. Triangle BDE is called Potier triangle and XL is the Potier reactance

7. Find field current corresponding to E.

8. Draw FG with magnitude equal to BE at angle (90+ Ψ) from field current axis, where Ψ is the phase angle of current from voltage vector E (internal phase angle).

9. The resultant field current is given by OG. Mark this length on field current axis.

10. From OCC find the corresponding E0

.

Parallel operation

- To full fill new increased load , two alternators connected in parallel with bus bar.

Following parameter should be same for incoming alternator & bus bar

1. Terminal voltage: The terminal voltage of incoming alternator must be equal to the bus-bar voltage.
2. Frequency: The frequency of generated voltage must be equal to the frequency of the bus-bar voltage.
3. Phase sequence : The phase sequence of the three phases of alternator must be similar to that of the grid or bus-bars.

Synchronization

- In an alternating current electric power system, **synchronization** is the process of matching the speed and frequency of a generator or other source to a running network.
- An AC generator cannot deliver power to an electrical grid unless it is running at the same frequency as the network.
- If two segments of a grid are disconnected, they cannot exchange AC power again until they are brought back into exact synchronization.

Synchronization

- In parallel operation of alternator the first condition of voltage equality can be satisfied by a voltmeter.
- To satisfy the conditions of equal frequency and identical phases, one of the following two methods can be used:
  (i) Synchronization using incandescent lamp
  (ii) Synchronization using synchroscope.
- In this process, new running alternator is connected to bus bar by matching frequency & V by “synchroscope”.

Synchroscope

The generator is turning at a lower frequency than the grid, the synchroscope needle rotates continually in the direction marked 'slow' or 'lag' on the dial to indicate that the generator is running slower than, or lagging behind, the grid.

- If the generator is running faster than the grid, the needle rotates continually in the opposite direction, marked 'fast' or 'lead'.
- Next, the plant operator adjusts the speed of the generator until it is running at precisely the same speed (frequency) as the grid.
- As the frequency of the generator nears that of the grid, the synchroscope needle slows down and when the frequencies match, the needle stops rotating.

Synchronization using incandescent lamp

- Three light bulbs were connected between the generator terminals and the system terminals .
- As the generator speed changes, the lights will flicker at the beat frequency proportional to the difference between generator frequency and system frequency.
- When the voltage at the generator is opposite to the system voltage (either ahead or behind in phase), the lamps will be bright.
- When the voltage at the generator matches the system voltage, the lights will be dark.
- At that instant, the circuit breaker connecting the generator to the system may be closed and the generator will then stay in synchronism with the