Electrical Equipment/
Electric Motors

Power and Electrical machine Dep.

Electric Machine and Drives

MSc Ahmed I.J.

ELECTRICAL MACHINE AND DRIVES
IRAQ

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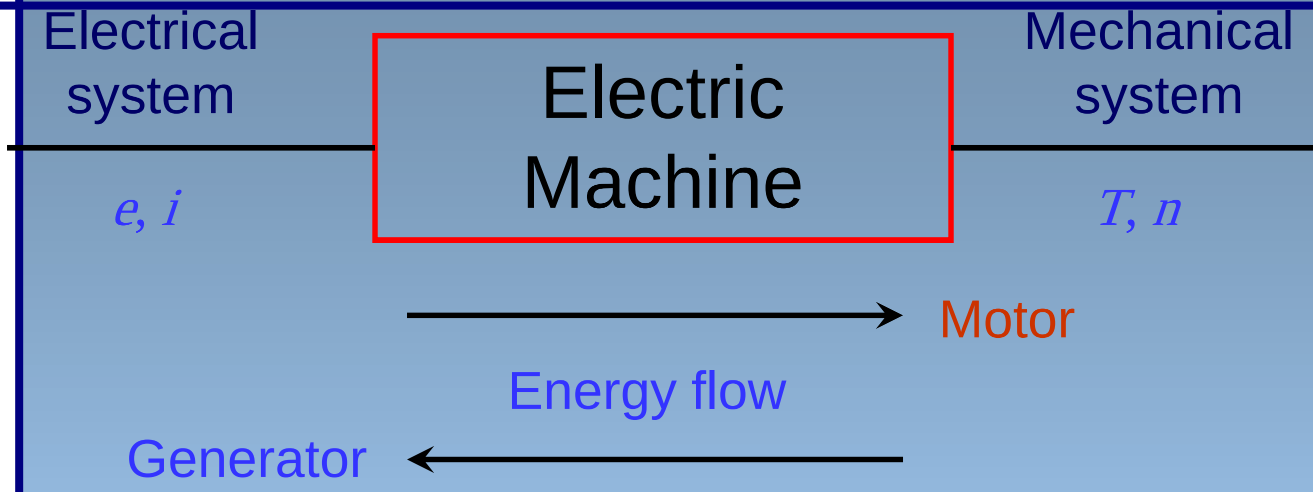
References:

- **TEXTBOOK OF ELECTRICALTECHNOLOGY B.L.THERAJA**
- **Electrical Machines and Drive Systems by J.Hindmarsh, Third Edition, 1998.**
- **Electrical Drives S.K.Pillai**

1. Basic Construction



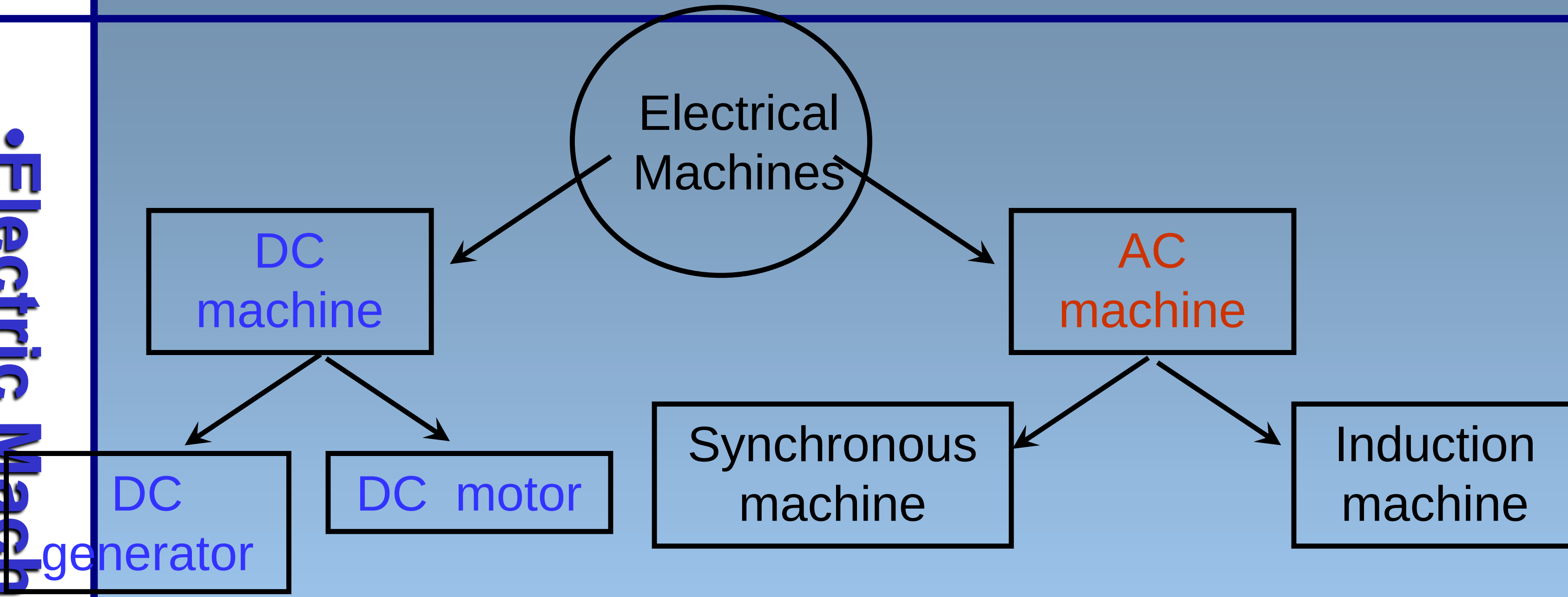
•An electrical machine is link between an electrical system and a mechanical system.

•Conversion from mechanical to electrical: generator

•Conversion from electrical to mechanical: motor

Power and Electrical machine Dep.

1. Basic Construction



•Machines are called AC machines (generators or motors) if the electrical system is AC.

•DC machines (generators or motors) if the electrical system is DC.

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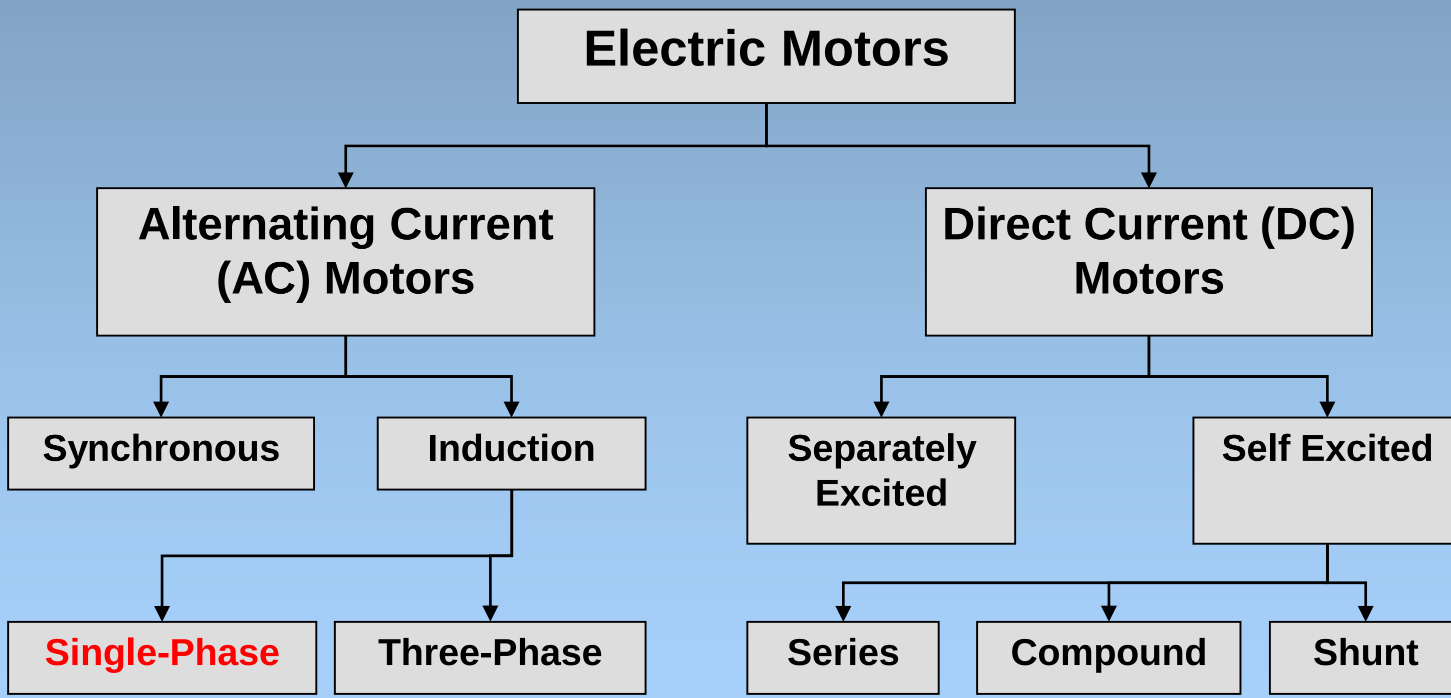
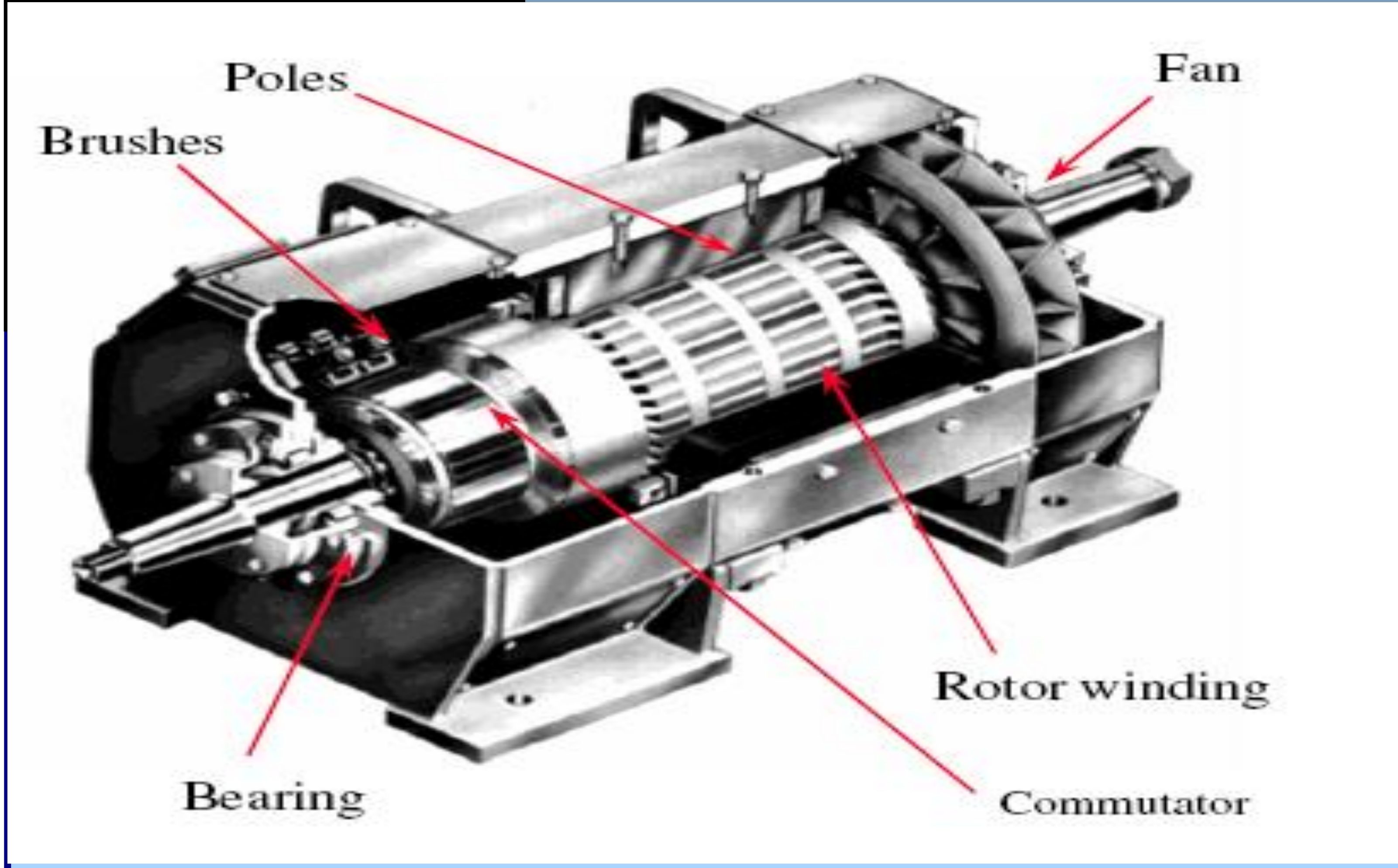
Type of Electric Motors

Classification of Motors

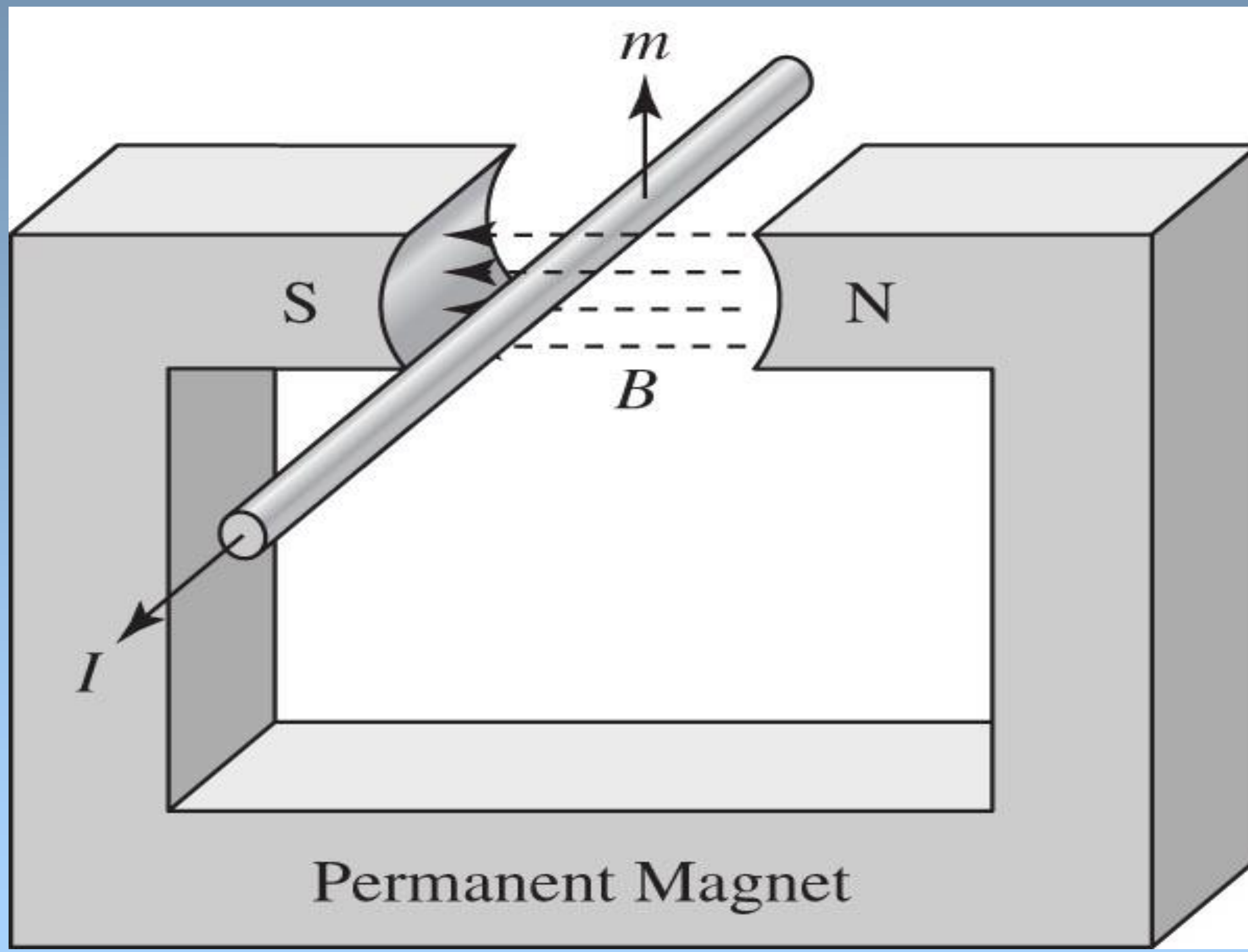


Type of Electric Motors

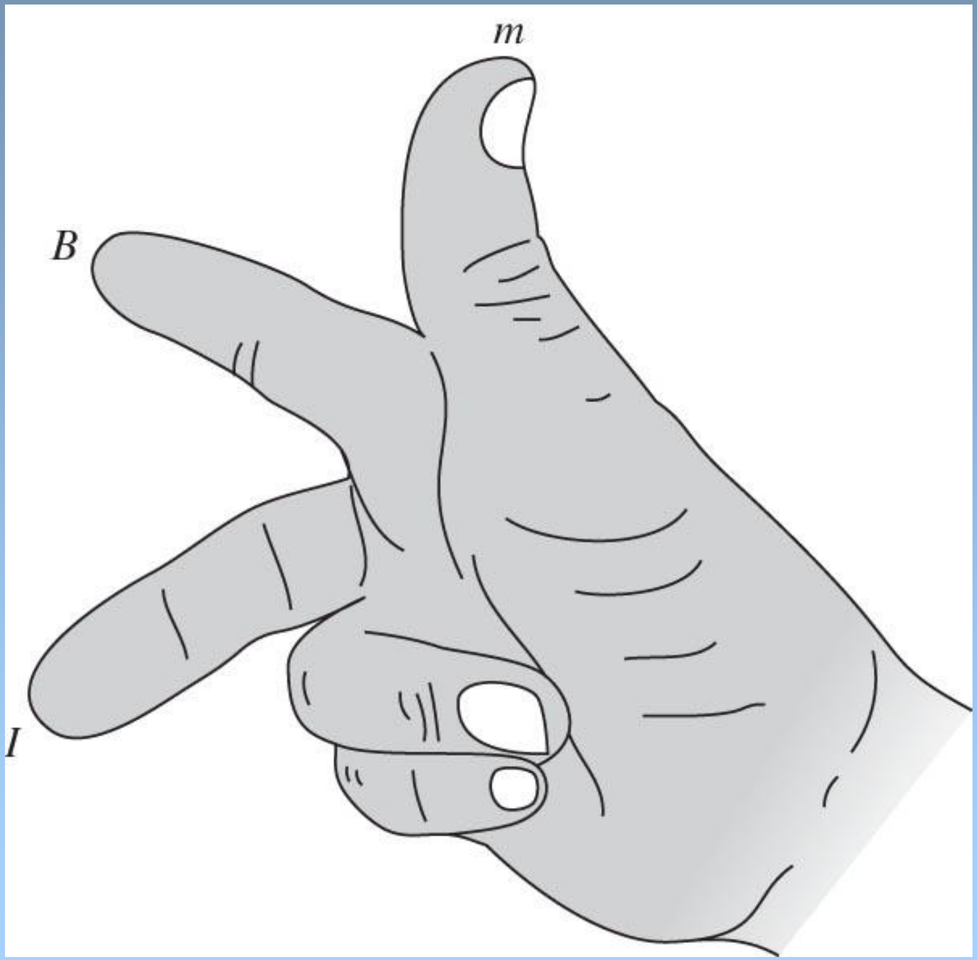
DC Motors – Components



Magnetic induction in a wire moving in a field.



Right-hand rule for magnetic induction.



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Type of Electric Motors

DC motors

- **Relationship between speed, field flux and armature voltage**

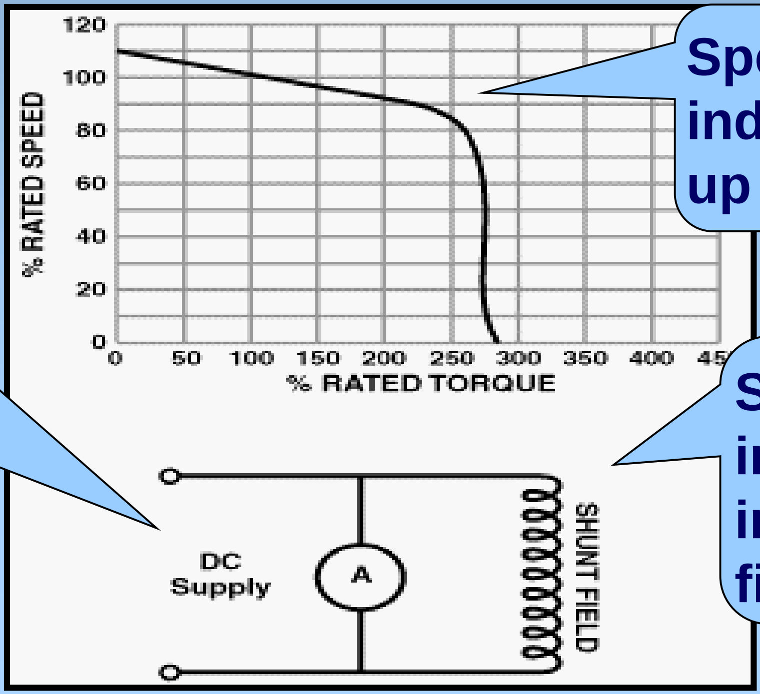
Back electromagnetic force: $E = K\Phi N$
Torque: $T = K\Phi I_a$

E = electromagnetic force developed at armature terminal (volt)
Φ = field flux which is directly proportional to field current
N = speed in RPM (revolutions per minute)
T = electromagnetic torque
Ia = armature current
K = an equation constant

Type of Electric Motors

DC motors

- **Separately excited DC motor: field current supplied from a separate force**
- **Self-excited DC motor: shunt motor**



Speed constant independent of load up to certain torque

- **Field winding parallel with armature winding**
- **Current = field current + armature current**

Speed control: insert resistance in armature or field current

(Rodwell Int. Corporation, 1999)

Type of Electric Motors

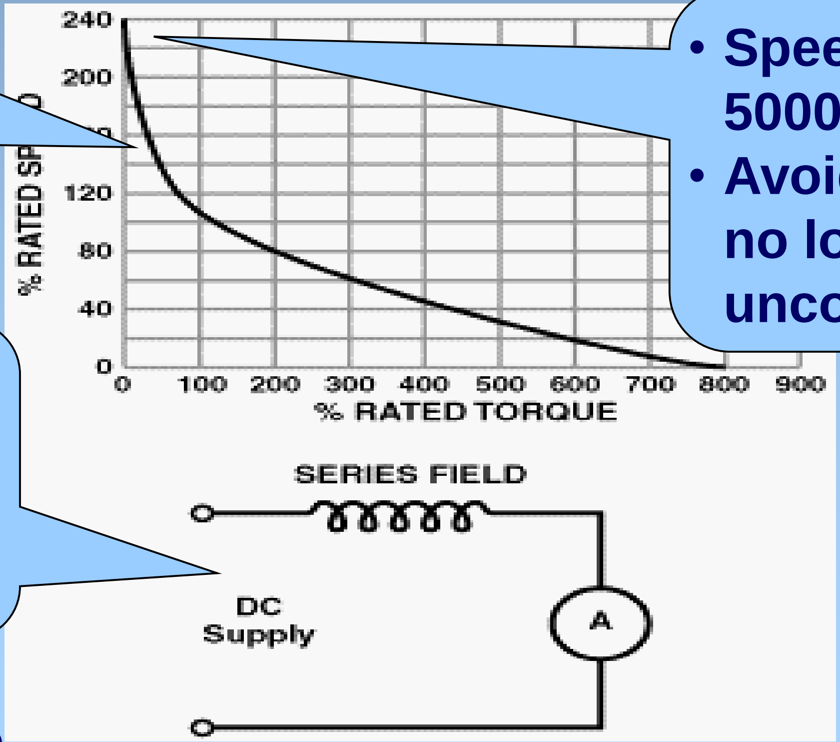
DC motors

Self-excited DC motor: series motor

Electrical Equip...
Electric Mot...

Suited for high starting torque: cranes, hoists

- Speed restricted to 5000 RPM
- Avoid running with no load: speed uncontrolled



- Field winding in series with armature winding
- Field current = armature current

(Rodwell Int. Corporation, 1999)

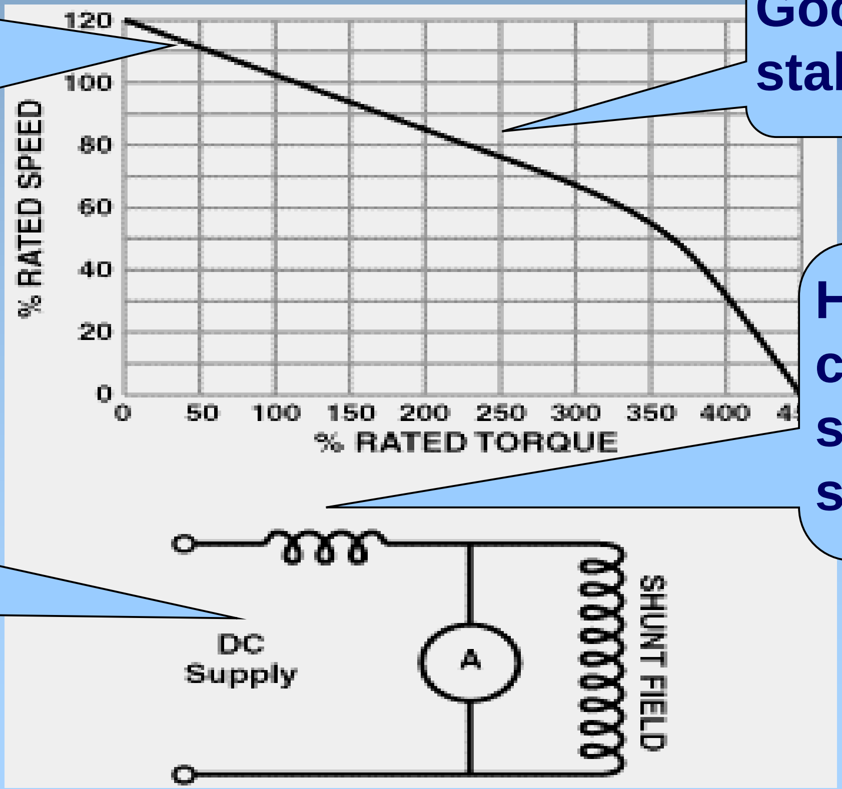
Type of Electric Motors

DC motors

DC compound motor

Suited for high starting torque if high % compounding: cranes, hoists

Good torque <u>and</u> stable speed

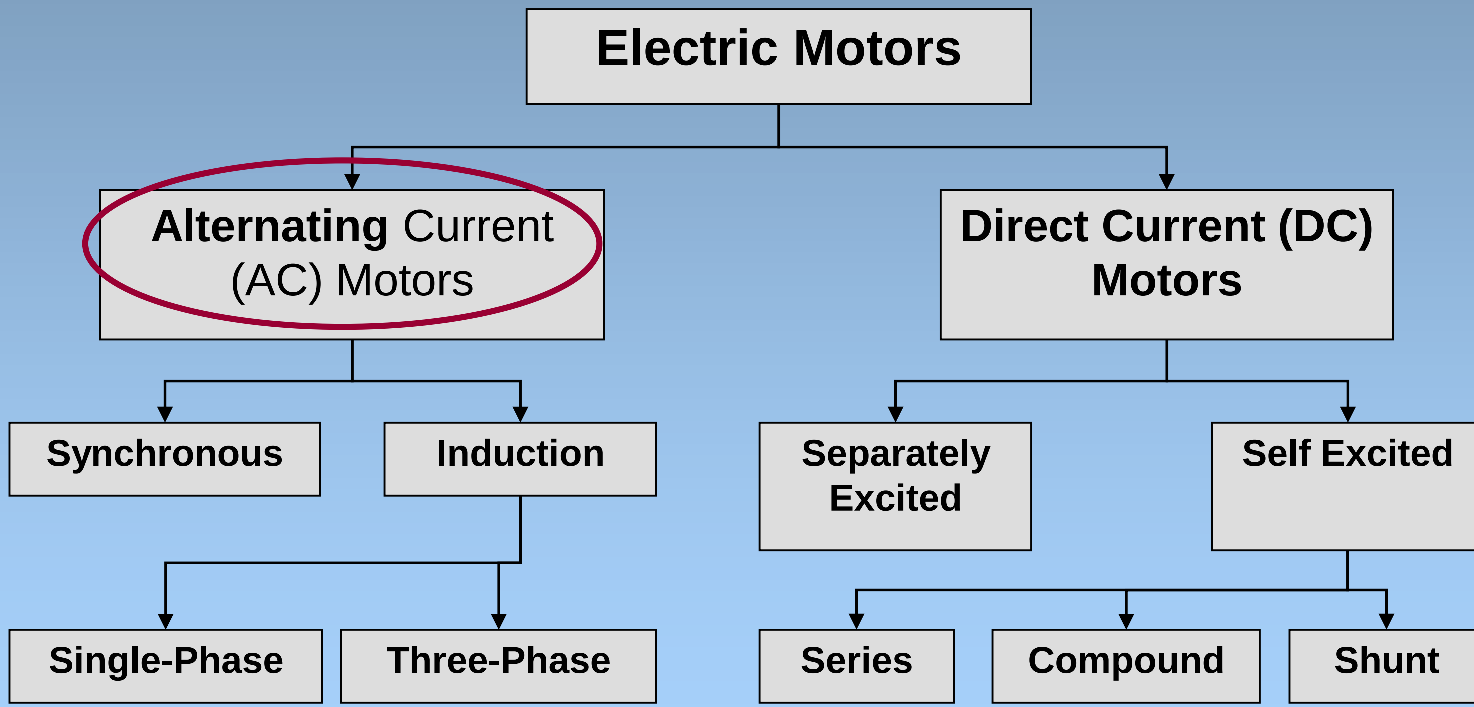


Higher % compound in series = high starting torque

Field winding in series <u>and</u> parallel with armature winding

Type of Electric Motors

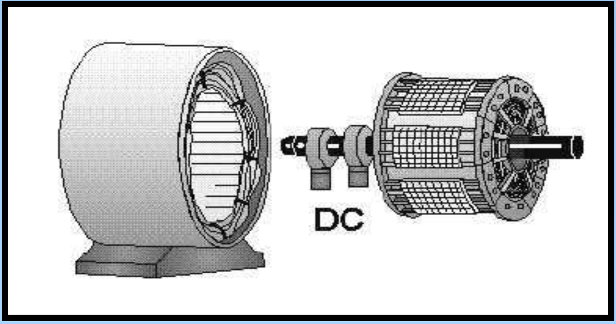
Classification of Motors



Type of Electric Motors

AC Motors

- Two parts: stator and rotor
  - Stator: stationary electrical component
  - Rotor: rotates the motor shaft
- Speed difficult to control
- Two types
  - Synchronous motor
  - Induction motor



Type of Electric Motors

AC Motors – Synchronous motor

- **Constant speed fixed by system frequency**
- **DC for excitation and low starting torque: suited for low load applications**
- **Can improve power factor: suited for high electricity use systems**
- **Synchronous speed (Ns):**

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$$Ns = 120 f / P$$

F = supply frequency
P = number of poles

Electrical Equipment/
Electric Motors

Type of Electric Motors

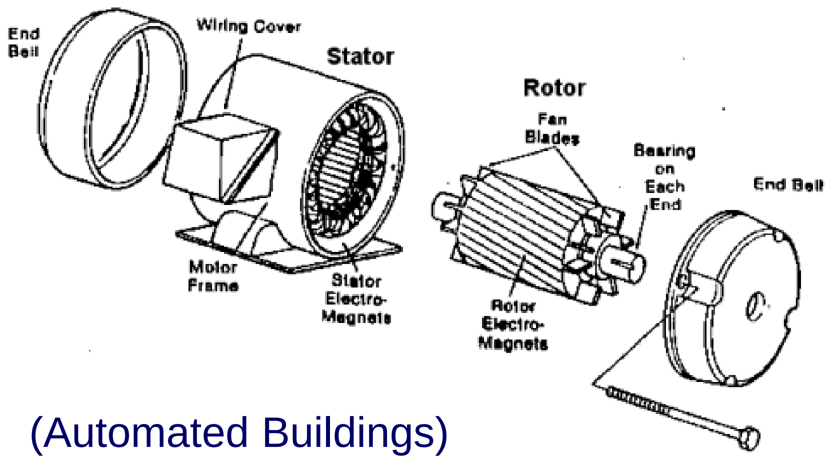
AC Motors – Induction motor

- **Advantages:**
  - Simple design
  - Low cost
  - High power to weight ratio
  - Easy to maintain
  - Direct connection to AC power source

Type of Electric Motors

AC Motors – Induction motor

Components



(Automated Buildings)

- **Rotor**
  - **Squirrel cage: conducting bars in parallel slots**
  - **Wound rotor: 3-phase, double-layer, distributed winding**
- **Stator**
  - **Stampings with slots to carry 3-phase windings**
  - **Wound for definite number of poles**

Type of Electric Motors

AC Motors – Induction motor

Speed and slip

- **Motor never runs at synchronous speed but lower "base speed"**
- **Difference is "slip"**
- **Install slip ring to avoid this**
- **Calculate % slip:**

$$\% \text{ Slip} = \frac{Ns - Nb}{Ns} \times 100$$

Ns = synchronous speed in RPM
Nb = base speed in RPM

Single Phase motor

Types of Single-Phase Motors

Single-phase motors may be classified as under, depending on their construction and method of starting

1. *Induction Motors* (split-phase, capacitor and shaded-pole etc.)

2. *Repulsion Motors* (sometime called Inductive-Series Motors)

3. *A.C. Series Motor*

4. *Un-excited Synchronous Motors*

Single-phase Induction Motor

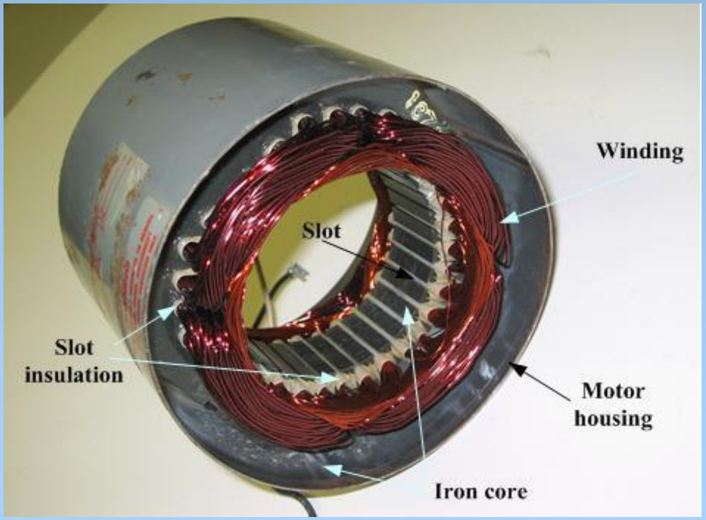
•Electric Machine and
•Drives

Constructionally, this motor is, more or less, similar to a polyphase induction motor, except that
(i) its stator is provided with a single-phase winding
(*ii*) a centrifugal switch is used in some types of motors, in order to cut out a winding, used only for starting purposes. It has distributed stator Winding
the motor has been explained in two ways :
(i) by two -field or doublefield revolving theory
(*ii*) by cross-field theory.

Single-phase Induction Motor

•Electric Machine and
•Drives

Single-phase induction motor



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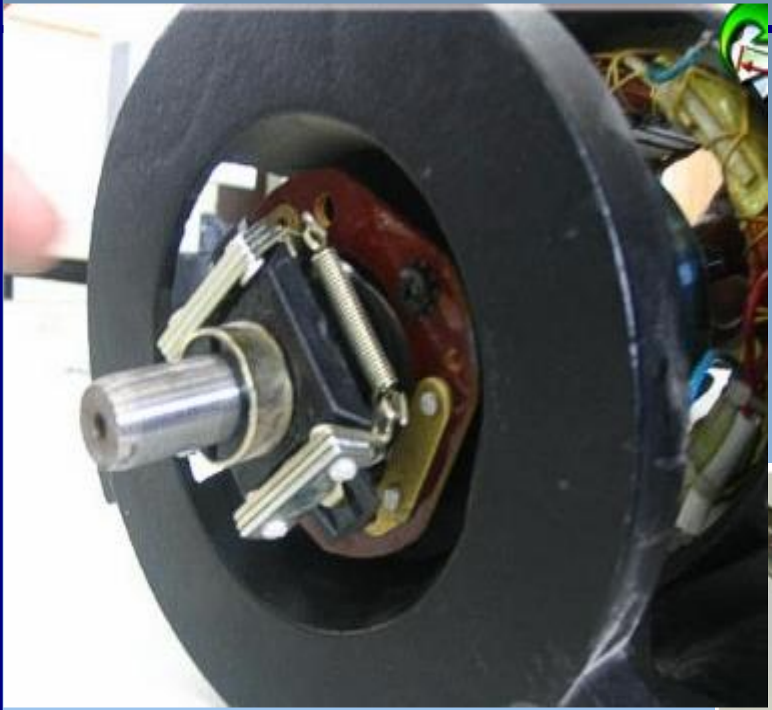
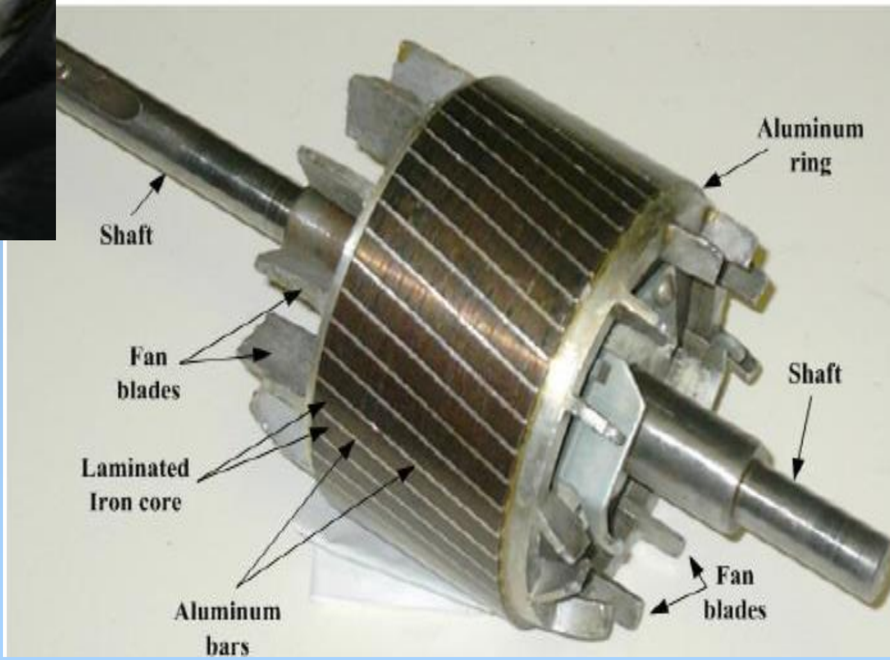
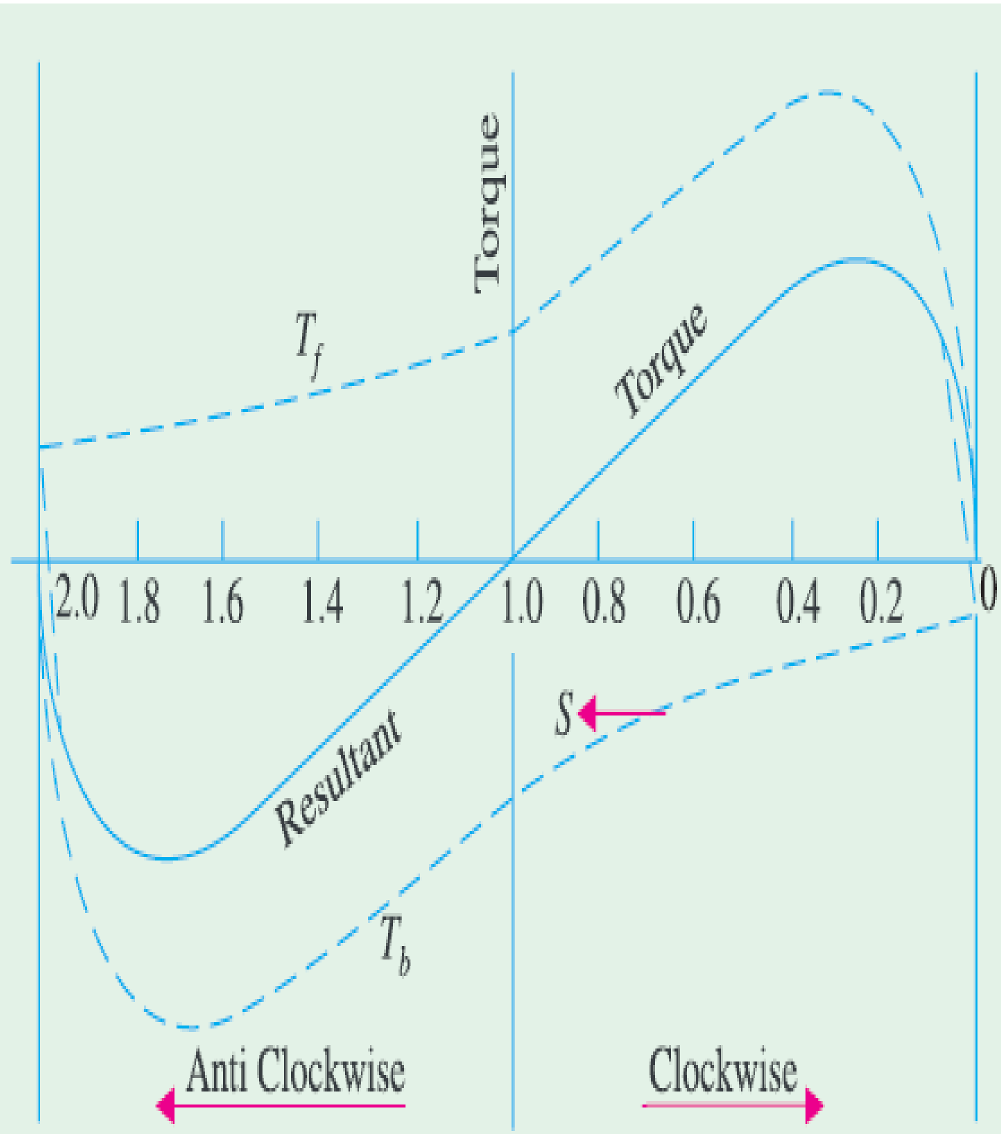
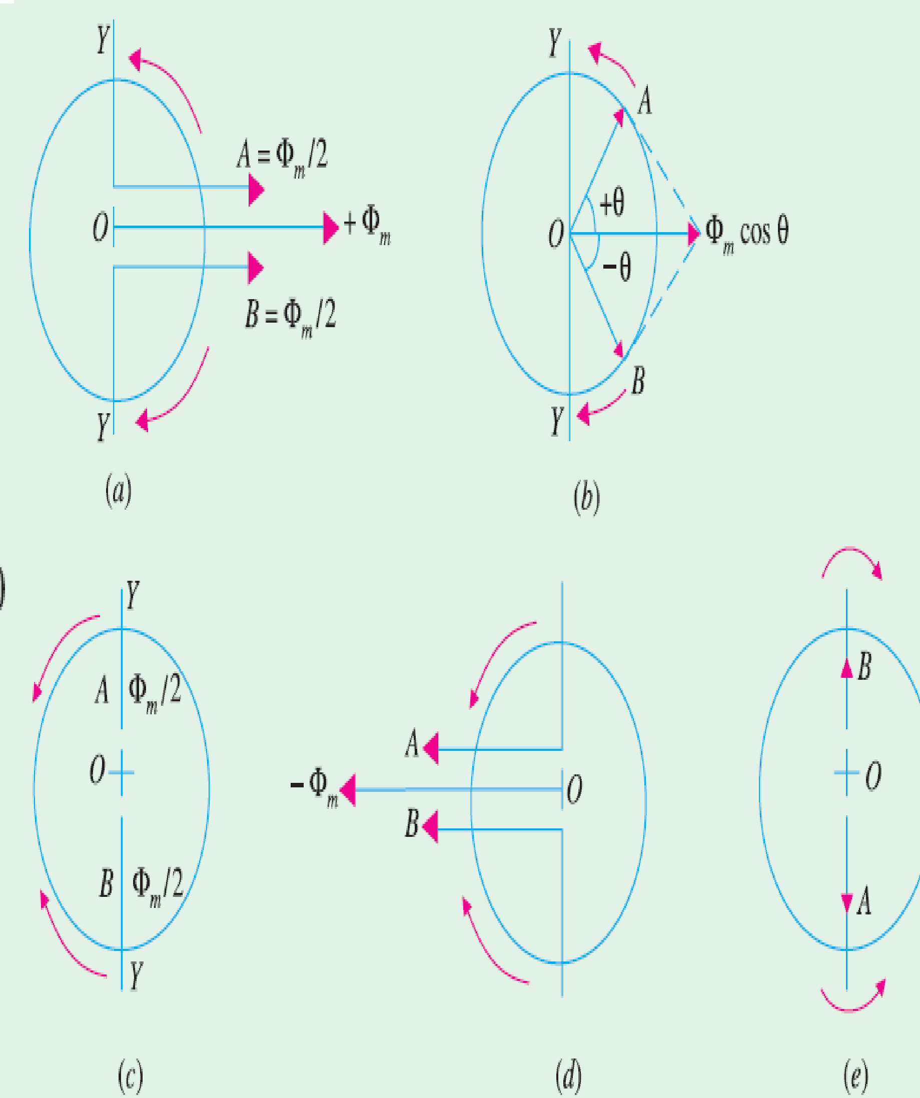
Construction of rotor part Single Phase Induction Motor





Double-field Revolving Theory



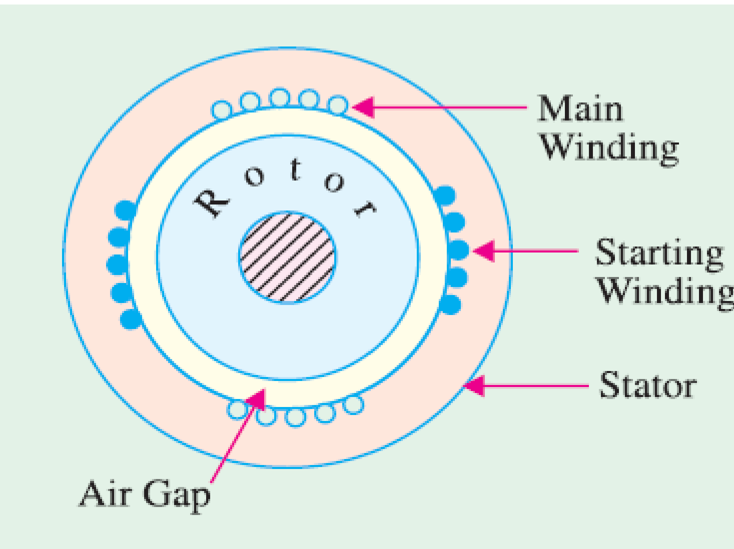


Making Single-phase Induction Motor Self-starting

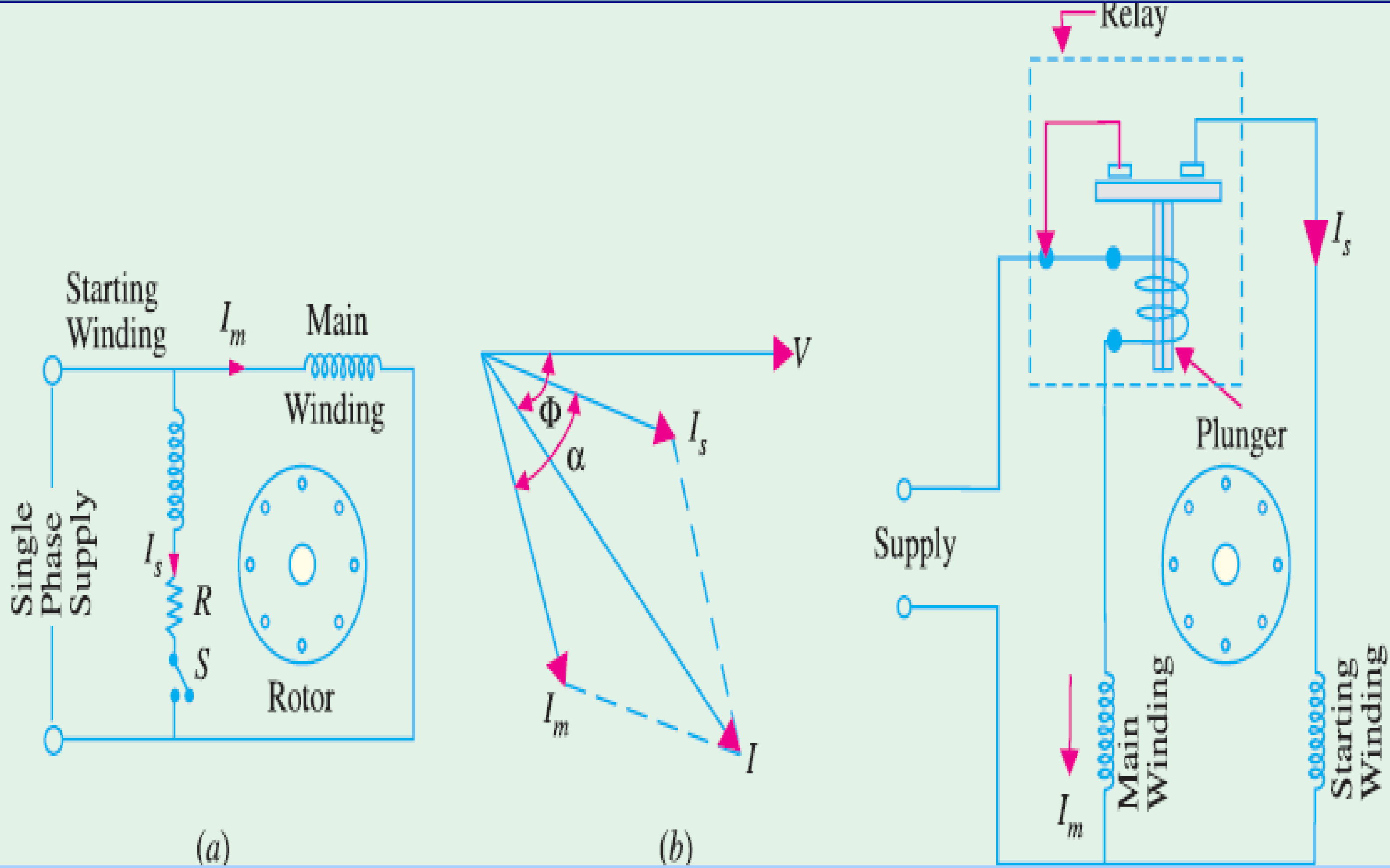
There are many methods by which the necessary phase-difference between the two currents can be created

(*i*) In *split*-phase machine

the main winding has low resistance but high reactance whereas the starting winding has a high resistance, but low reactance. The resistance of the starting winding may be increased either by connecting a high resistance *R* in series with it or by choosing a high -resistancefine copper wire for winding purposes.

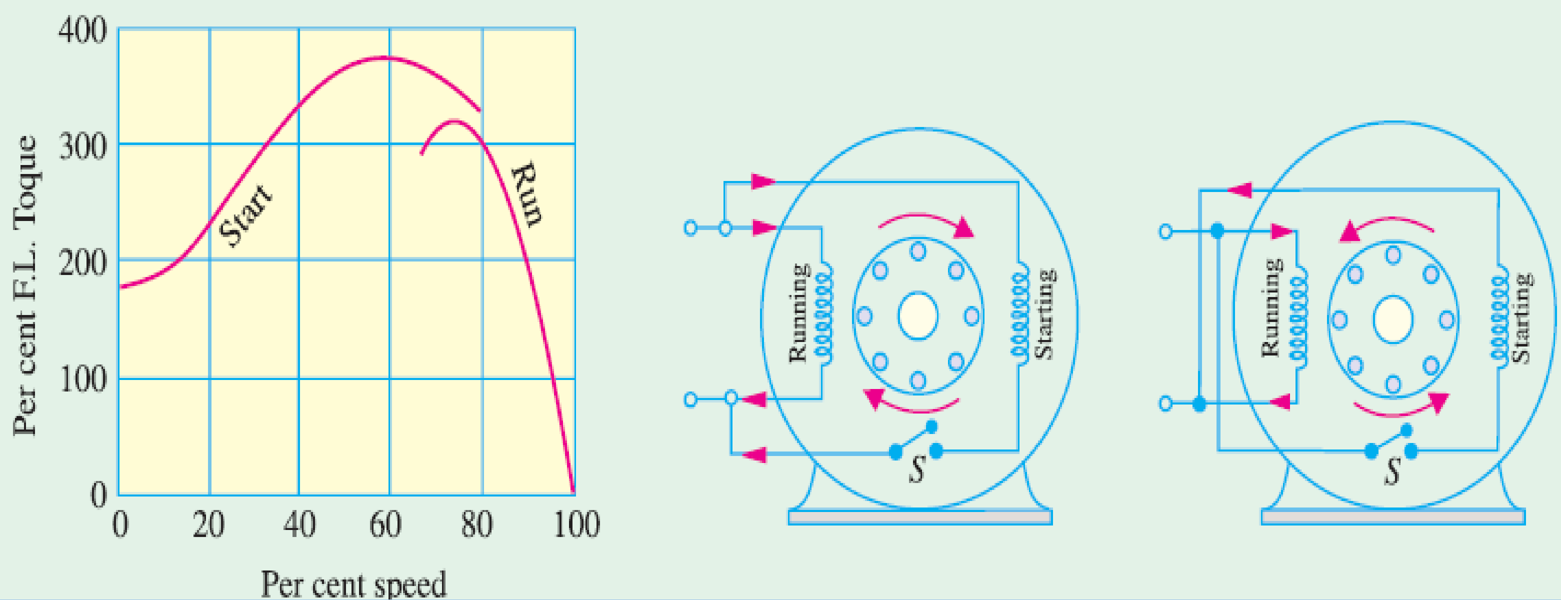


(*i*) In *split*-phase machine



Electric Machine and Drives

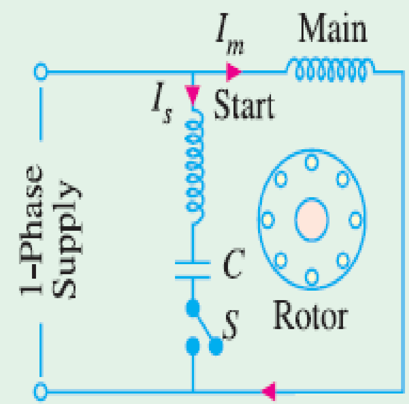
(*i*) In *split*-phase machine

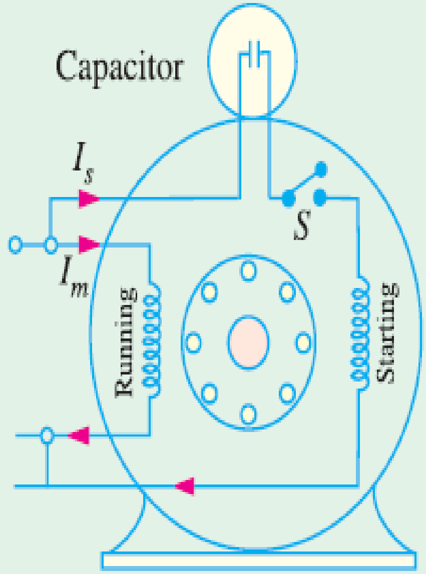


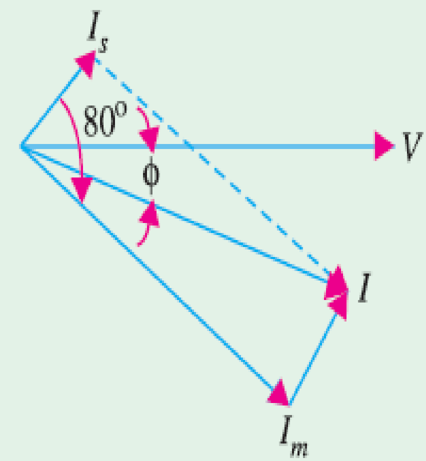
Typical applications are : fans and blowers, centrifugal pumps and s, washing machines, small machine tools, duplicating machines and domestic refrigerators and oil burners etc

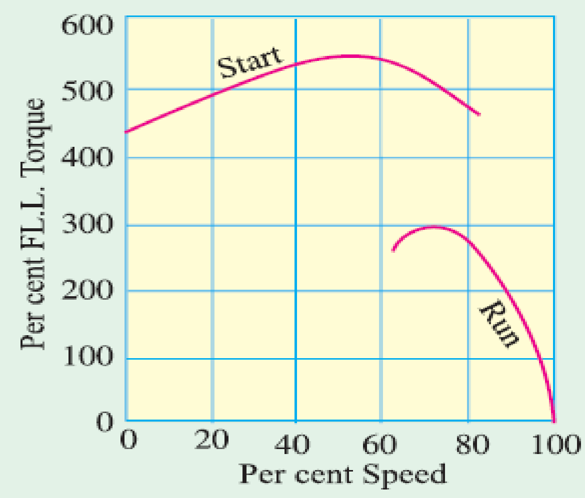
(*ii*) Capacitor-start Induction-run motors

•Electric Machine and
•Drives



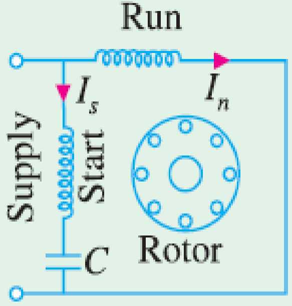


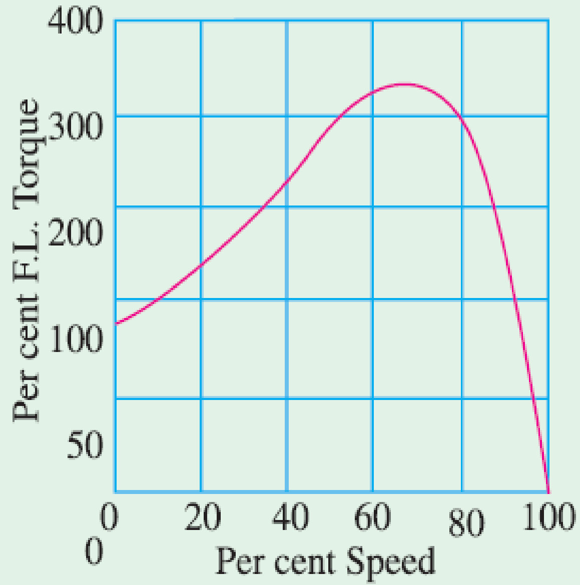


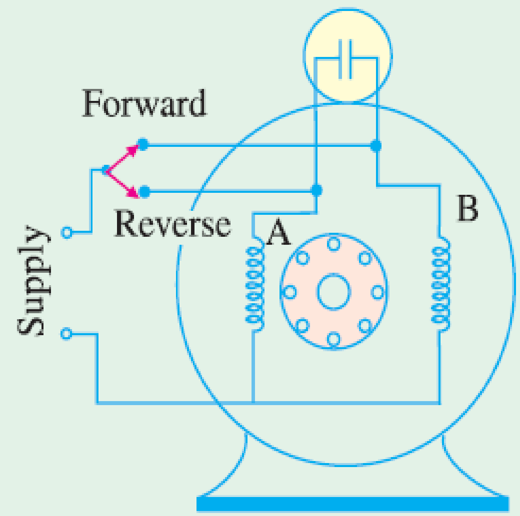


Capacitor Start-and-Run Motor

(*i*) Single-value capacitor-Run Motor







(*iii*) Capacitor-start ,capacitor-run motors

This motor is similar to the capacitor-start motor [Art.36.4 (*ii*)] except that the starting winding and capacitor are connected in the circuit at ***all times***. The advantages of leaving the capacitor permanently in circuit are

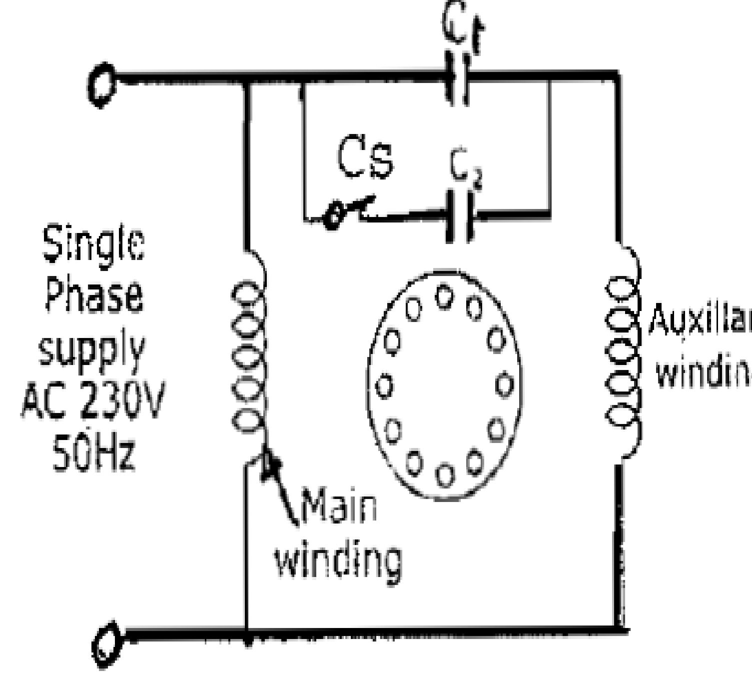
(*i*) improvement of over-load capacity of the motor

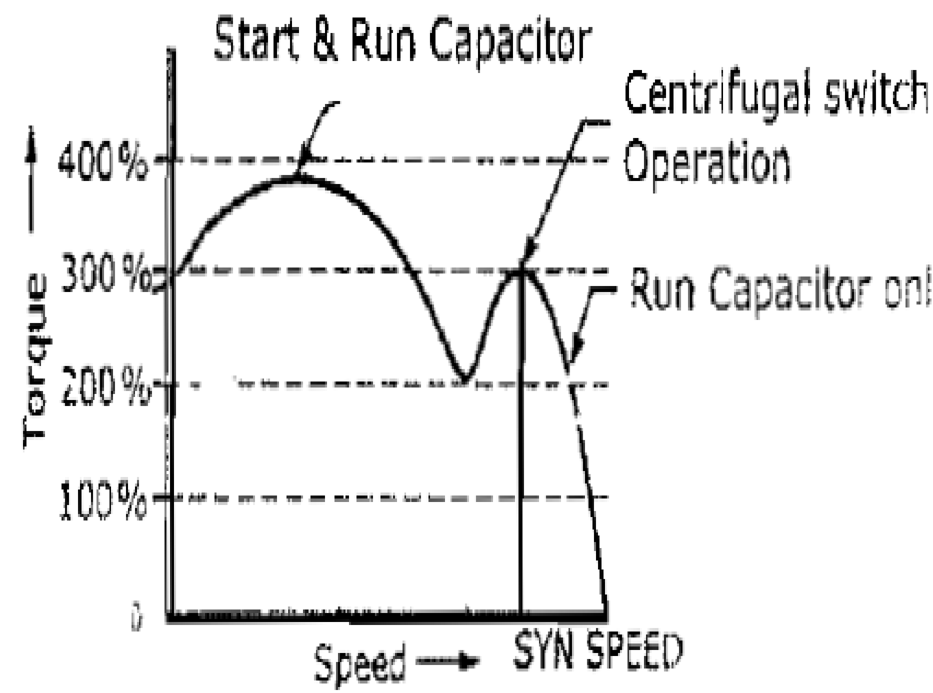
(*ii*) a higher power factor ***iii*)** higher efficiency

(*iv*)quieter running of the motor which is so much desirable for small power drives in offices and laboratories

APPLICATION

- Used for compressors, refrigerators, air-conditioners, etc.
- Higher starting torque.
- High efficiency, higher power factor and overloading.
- Costlier than the capacitor-start – Induction run motors of the same capacity.





Equivalent Circuit

•Electric Machine and

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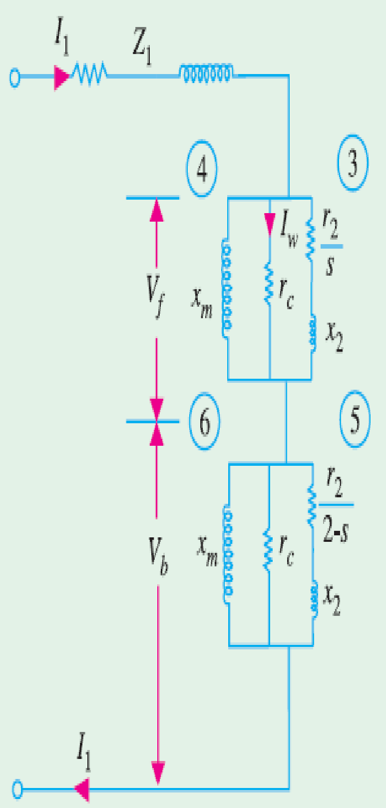
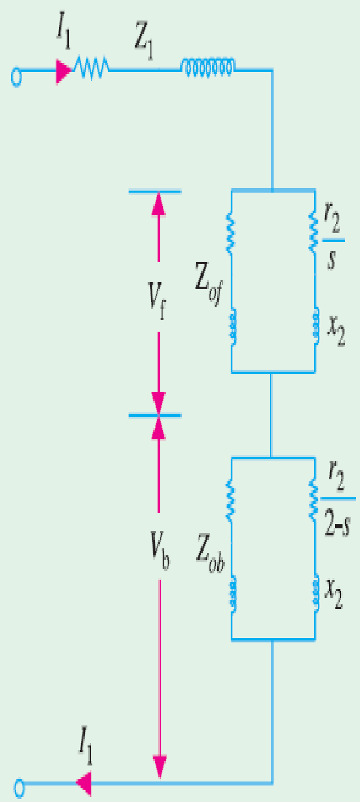
Equivalent Circuit–With Core Loss

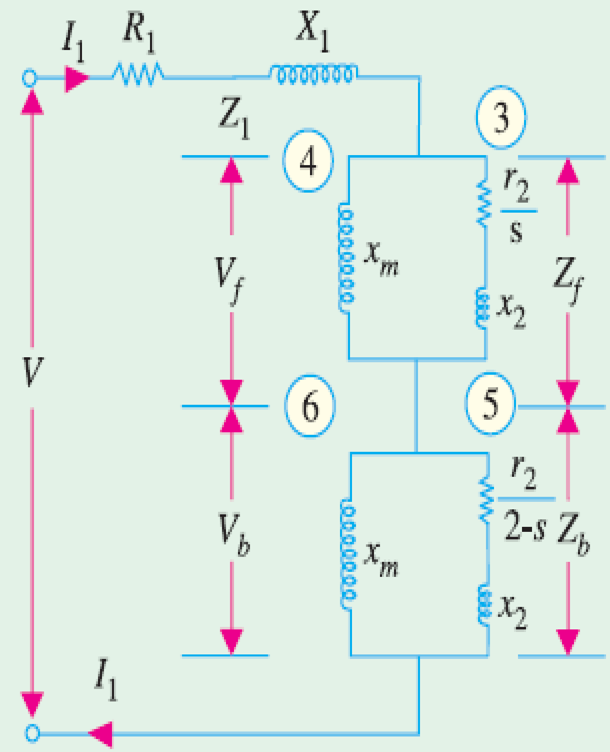


(a)



(b)

Equivalent Circuit of a Single-phase Induction Motor–Without Core Loss

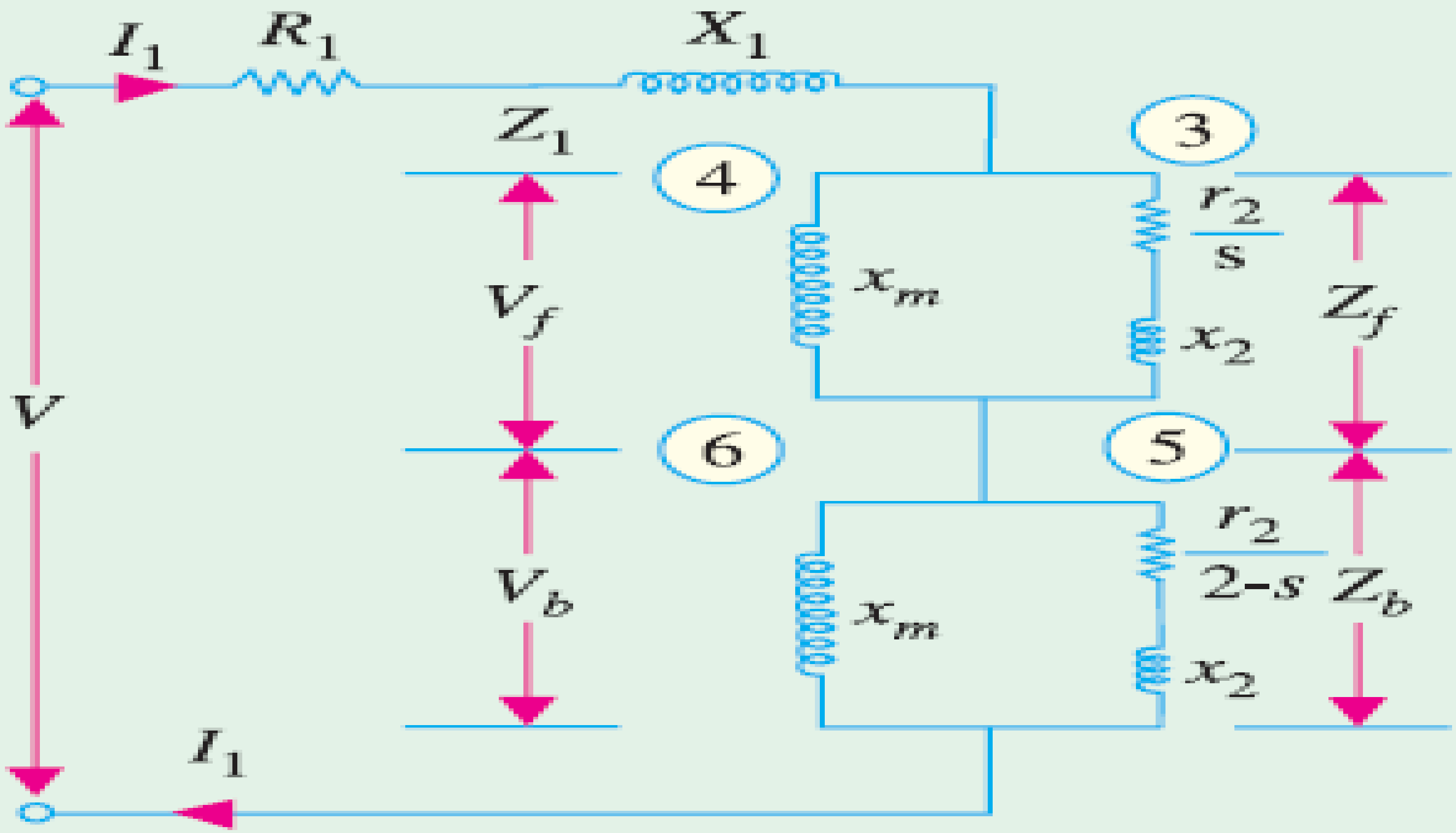


Example

Discuss the revolving field theory of single-phase induction motors. Find the mechanical power output at a slip of 0.05 of the 185-W, 4-pole, 110-V, 60-Hz single-phase induction motor, whose constants are given below:

Resistance of the stator main winding R1 = 1.86 ohm
Reactance of the stator main winding X1 = 2.56 ohm
Magnetizing reactance of the stator main winding Xm = 53.5 ohm
Rotor resistance at standstill R2 = 3.56 ohm
Rotor reactance at standstill X2 = 2.56 ohm

Equivalent Circuit



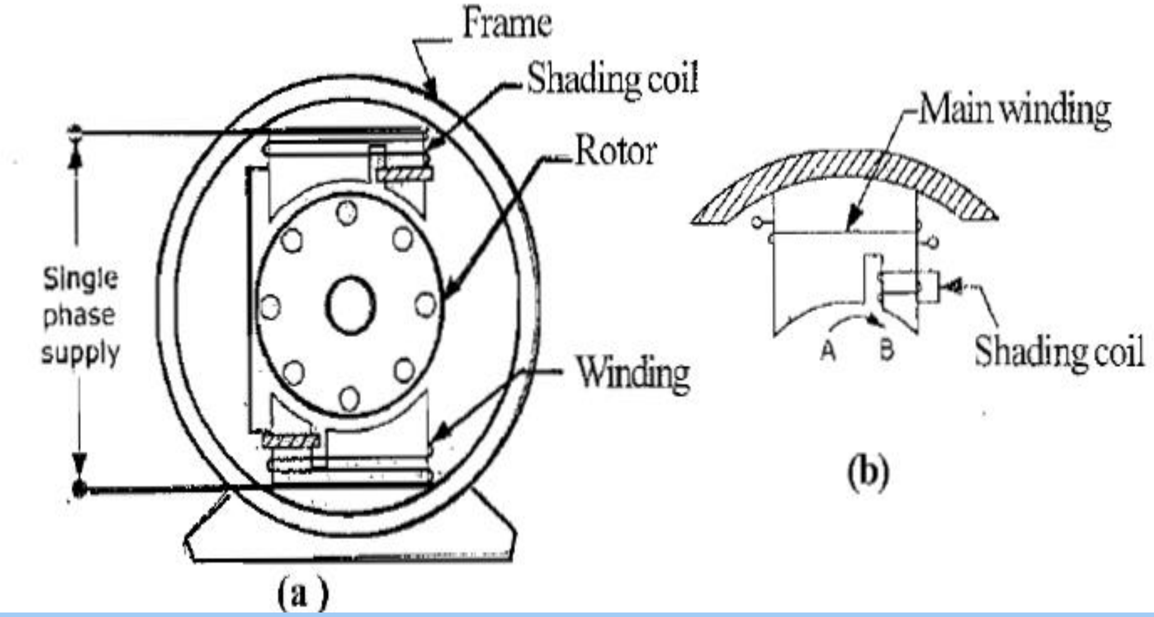
Equivalent Circuit

Example 36.3. ***A 250-W, 230-V, 50-Hz capacitor-start motor has the following constants for the main and auxiliary windings: Main winding, Zm = (4.5 + j 3.7) ohm. Auxiliary winding Za = (9.5 + j 3.5) ohm. Determine the value of the starting capacitor that will place the main and auxiliary winding currents in quadrature at starting.***

Shaded-pole Single-phase Motor

The motor consists of a yoke to which salient poles are fitted as shown in Fig:12.8(a) and it has a squirrel cage type rotor.

disadvantages of
(*i*) low starting torque
(*ii*) very little overload capacity and
(*iii*) low efficiency



A shaded pole made of laminated sheets has a slot cut across that lamination bout one third the distance from the edge of pole

Shaded-pole Single-phase Motor

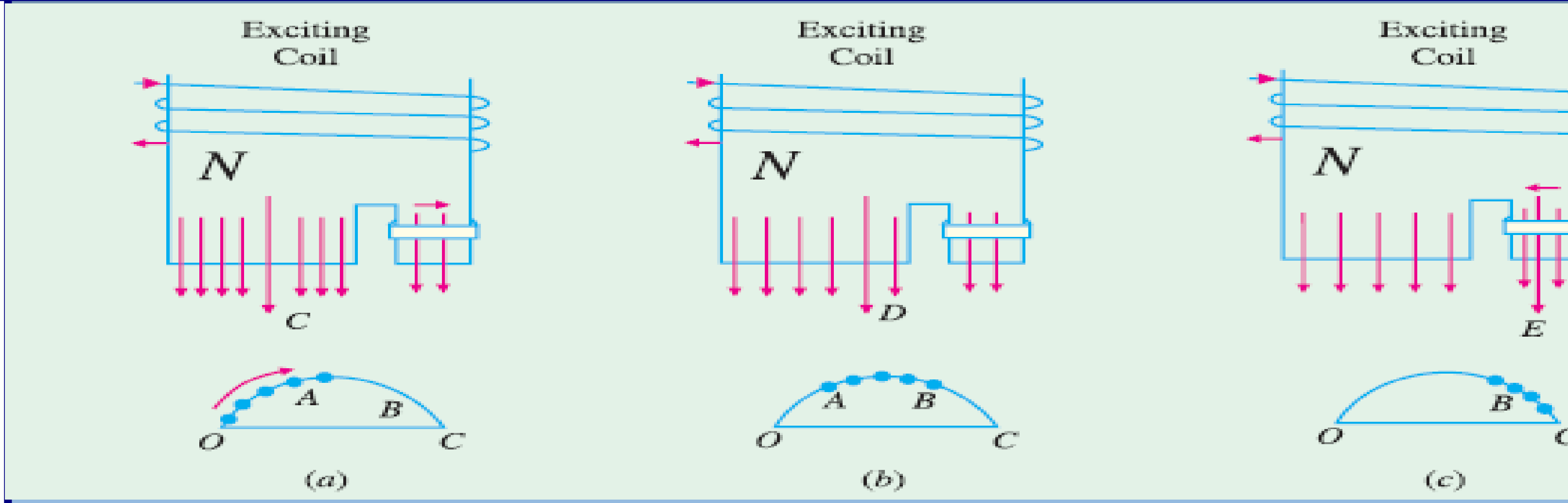
A round the poles exited coil are place to which an AC supply is connected. When AC supply is effected to the exiting coil ,the magnetic axis shift from the un shaded part of the pole to the shaded part as will be explain in details in the next paragraph .this shifting of axis is equivalent to the physical which is movement of the pole .the magnatic axis which is moving cuts the rotor a rotating torque is develop in the rotor.

SHIFTING OF THE MAGNETIC FLUX

As the shaded coil is of thick copper it will have very low resistance and high reactance .when the exiting winding winding is connected to an AC supply ,a sine wave current through it. Let us consider the positive half cycle of the AC current

Shaded-pole Single-phase Motor

•Electric Machine and
•Drives



When the current raises from (zero)value point (a) the change in current is very fast (rapid) .hence it reduces an emf in the shaded coil o the baisc faraday low

Shaded-pole Single-phase Motor

The induced emf in the shaded coil produces a current which, in turn, produces a flux in accordance with Lenz Law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig:12.9.

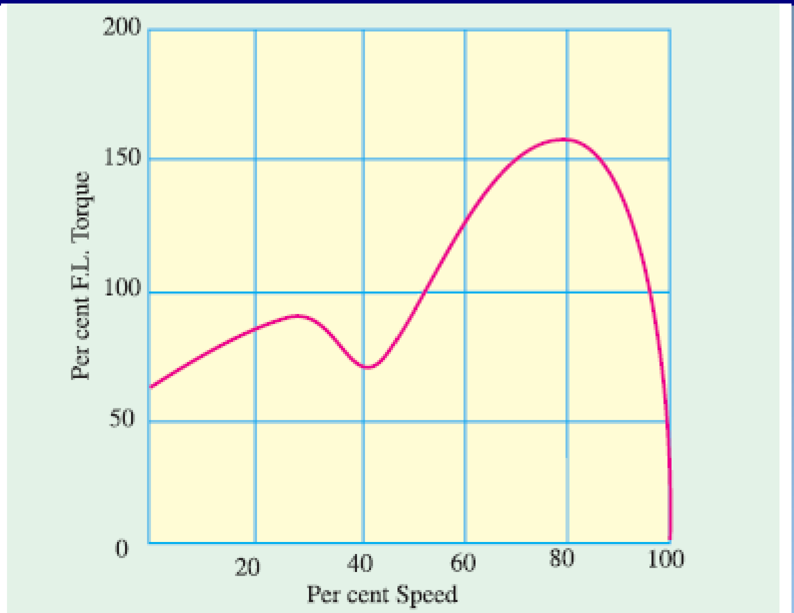
This makes the magnetic axis to be in the center of the unshaded portion as shown by the arrow in part of fig:12.9. On the other hand as shown in part 2 of 3 when the current raises from point "a" to point "b" the change in current is slow the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shade portion.

This makes the magnetic axis to be shifted to the center of the whole pole as shown in by the arrow in part 2 of Fig:12.9.

In the next instant, as shown in part 3 of Fig:12.9. When the current falls from "b" to "c" the change in current is fast but the change of current is from maximum to minimum.

Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the right portion of the shaded part as shown by the arrow in part.

Shaded-pole Single-phase Motor



APPLICATIONS

- Record players
- Fans
- Hair driers.

Repulsion Motor

Constructionally, it consists of the following

1. Stator winding.

2. A rotor (slotted core type)

3. A commutator ,

two types : an axial commutator with bars parallel to the shaft or a radial or vertical commutator having radial bars on which brushes press horizontally.

4. Carbon brushes (fitted in brush holders)

To understand how torque is developed by the repulsion principle, consider Fig. 36.37 which shows a 2-pole salient pole motor with the magnetic axis vertical

Repulsion Motor

•Electric Machine and
•Drives

The alternating flux produced by the stator winding will induce e.m.f. in the armature conductors by transformer action. The direction of the induced e.m.f. can be found by using Lenz's law and is as shown in Fig. 36.37 (*a*).

- direction of the ***induced*** currents in the armature conductors will depend on the ***positions of the short circuited brushes***

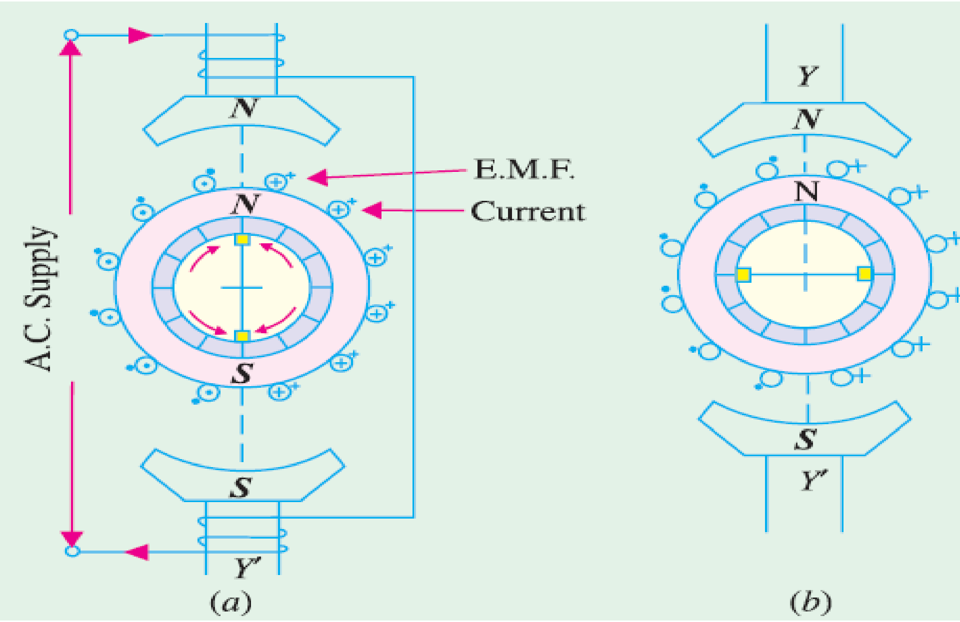


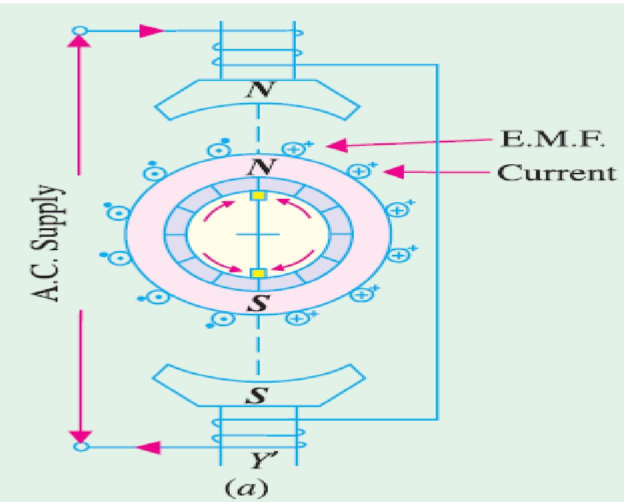
Fig. 36.37

Repulsion Motor

•Electric Machine and

•Drives

If brush axis is colinear with magnetic axis of the main poles, the directions of the induced currents (shown by dots and arrows) will be as indicated in Fig. 36.37 (*a*)*. As a result, the armature will become an electromagnet with a *N*-pole on its top, directly under the main *N*-pole and with a *S*-pole at the bottom, directly over the main *S*-pole. Because of this face-to face positioning of the main and induced magnetic poles, no torque will be developed



(*a*)

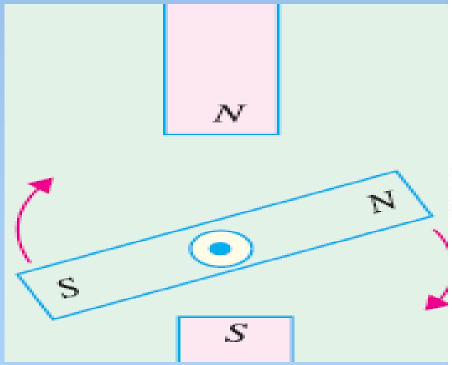
Repulsion Motor

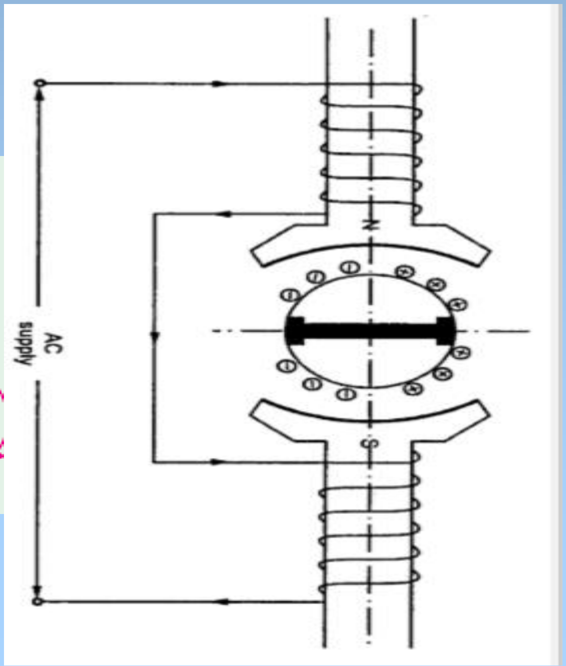
•Electric Machine and

•Drives

If brushes are shifted by90º , so the conductors undergoing short circuit are also changed. The induced emf are in the same direction as before. The arrangement is shown in the Fig.2.the remaining armature winding gets divided into two parallel paths. emfs are balanced and the resultant emf is zero, no current ,T zero

If the brushes are in the position shown in the Fig.3 In this case,



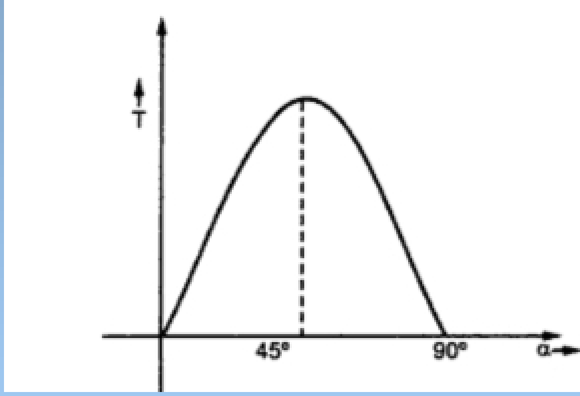


Repulsion Motor

Again the emf will be induced in the armature conductors and there will be net voltage across brush terminals which will produce current in the armature. Thus the armature will also produce its own magnetic field with the poles The N and S poles of stator and rotor will attract each other and there will be net torque available which will run the motor in the clockwise direction we can say that the N pole formed by armature winding will be repelled by the north pole formed by the main field winding and similarly the south pole will be repelled by south pole formed by the main field winding and the motor runs in clockwise direction. As the forces are of repulsion which contributes in the motion so the name of the motor is repulsion motor. If the brush is given shift in the opposite direction to that shown

Repulsion Motor

Fig.4 then motor runs in anticlockwise direction which can also be explained on the similar lines. Hence the position of brushes decides the direction of rotation. he torque produced by the motor depends on the brush shift angle α.



Characteristics

(i) These motors have poor torque,

(ii) power factor and efficiency.

(ii) These motors cannot accelerate high-inertia loads to synchronous speed.

(iii) The pull-in and pull-out torques of such motors are weak.

Type of the Repulsion Motor

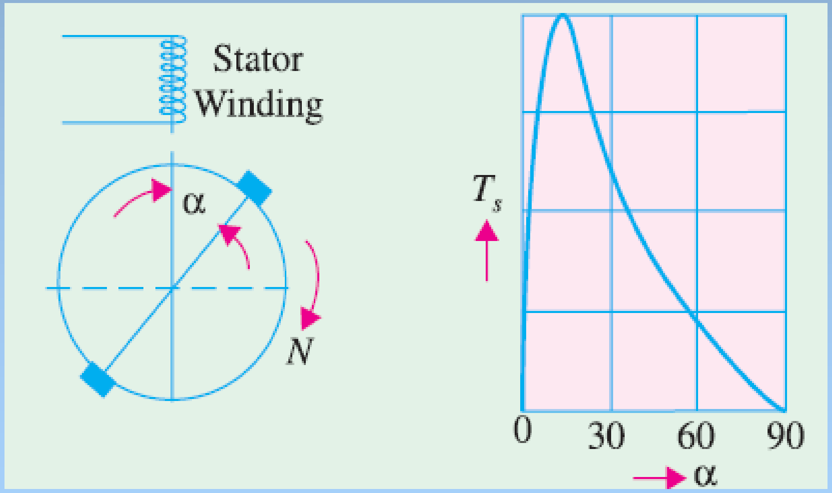
- **Compensated Repulsion Motor**

It has an additional stator winding, called compensating winding whose purpose is

(i) to improve power-factor and

(ii) to provide better

(iii) speed regulation



Type of the Repulsion Motor

- **Repulsion-start Induction-Run Motor**

this motor starts as an ordinary repulsion motor, but after it reaches about 75 per cent of its full speed, centrifugal short-cicuit

rcuiting device short-circuits its commutator.

- **Repulsion Induction Motor**

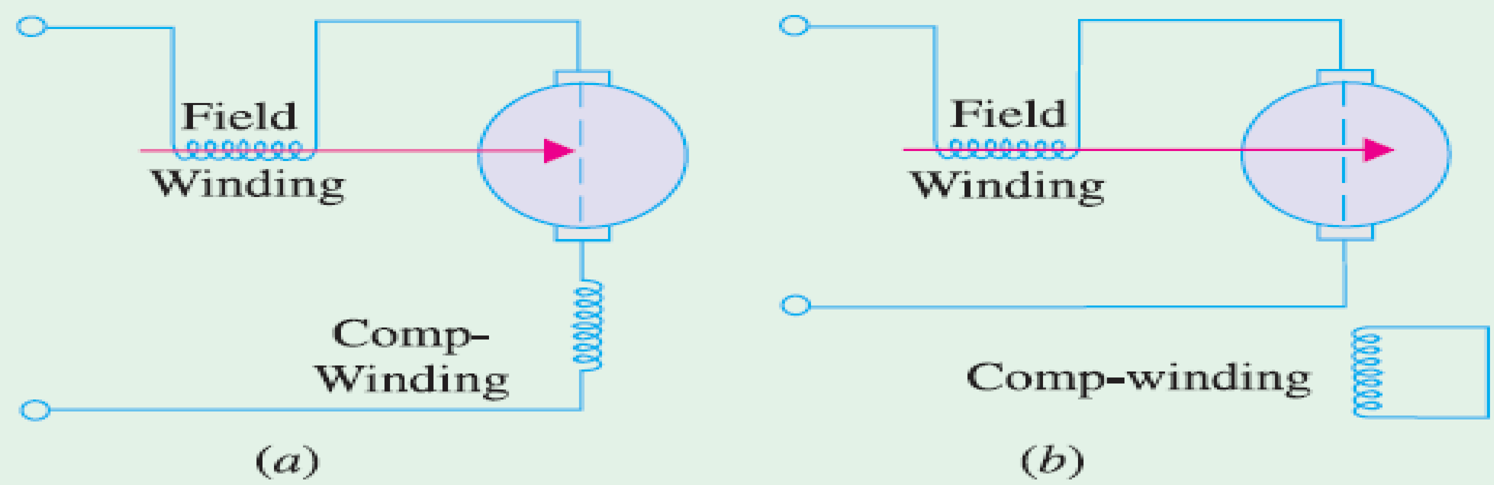
It has the usual stator winding as in all repulsion motors. But there are two separate and independent windings in the rotor

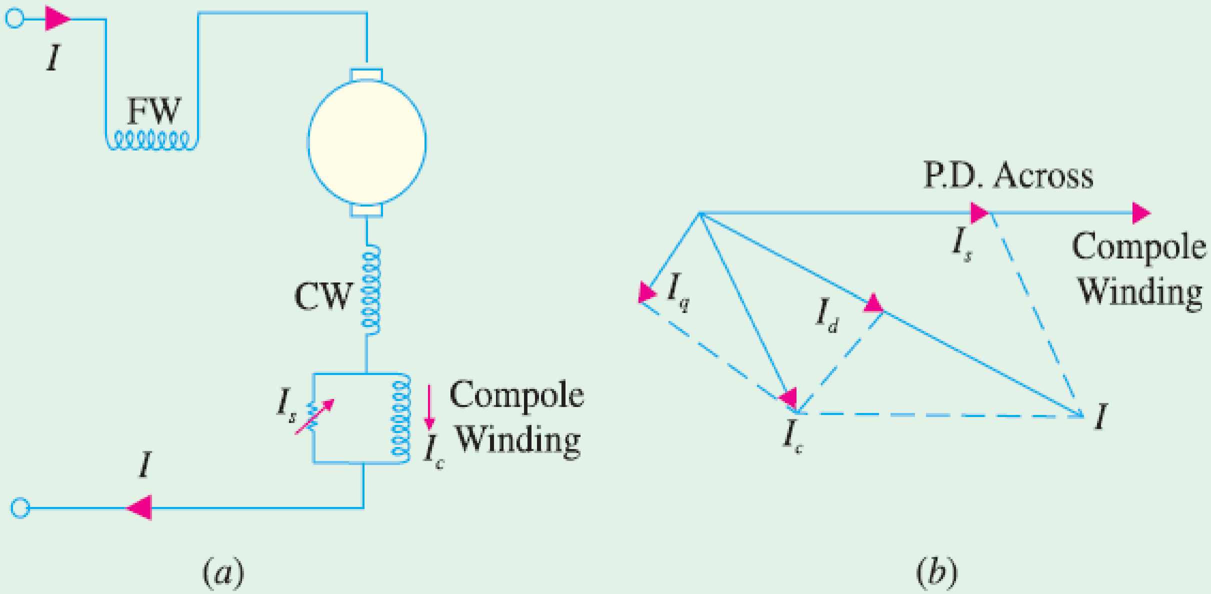
- **(*i*)** a squirrel-cage winding and
- **(*ii*)** commutated winding similar to that of a d.c. armature.

A.C. Series Motors

If an ordinary d.c. series motor were connected
to an a.c. supply, it will rotate and exert unidirectional torque because the current flowing both in he armature and field reverses at the same time. But the performance of such a motor will not be satisfactory for the following reasons :

•Electric Machine and
•Drives





Universal Motor

A universal motor is defined as a motor which may be operated either on direct or single-phase a.c. supply at approximately the same speed and output.

types:

- ***concentrated-pole, non-compensated type***
- ***distributed-field compensated type***

Electric Motors

THANK YOU

FOR YOUR ATTENTION