Practical

Electric Motors I

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- Construction and principle of operation
- Types and applications
- Starting, operation, braking and control methods

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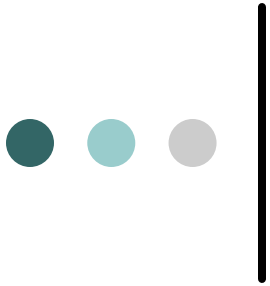
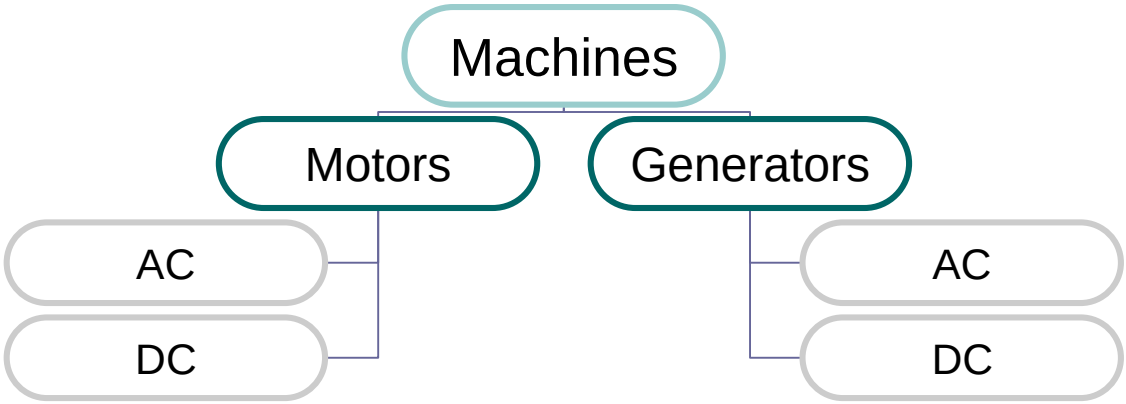
- Construction and principle of operation
- Types and applications



INTRODUCTION

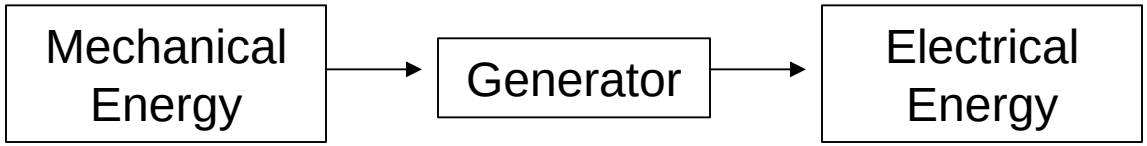
Introduction

Types of Machines

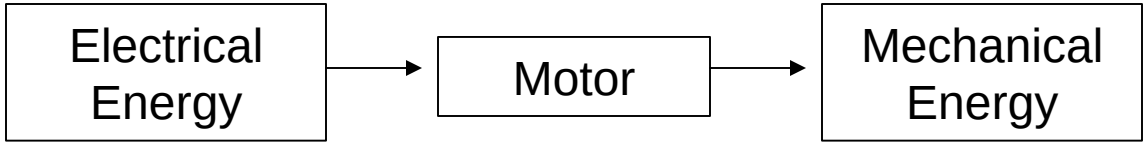


Energy Conversion

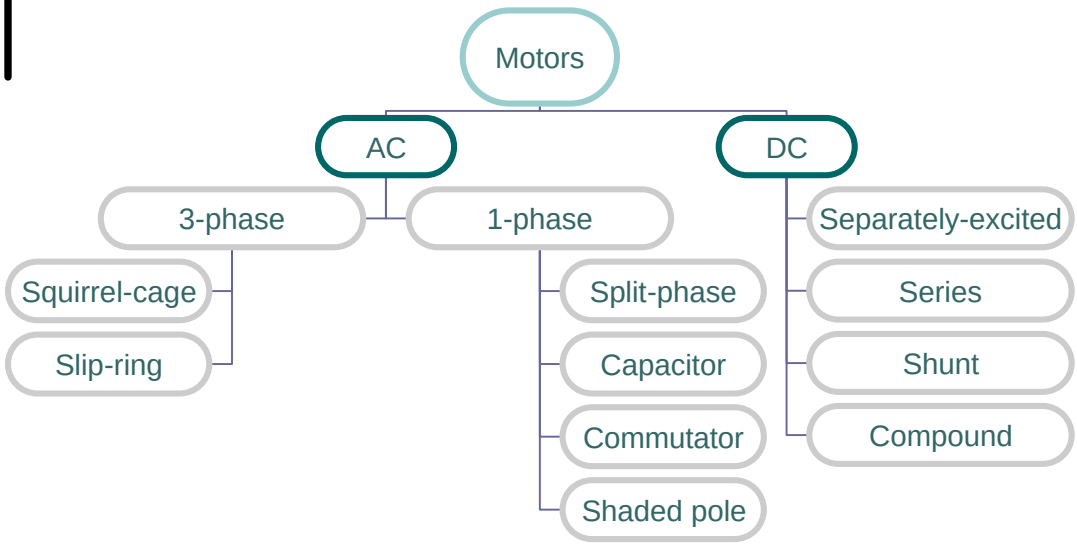
Generation



Motoring



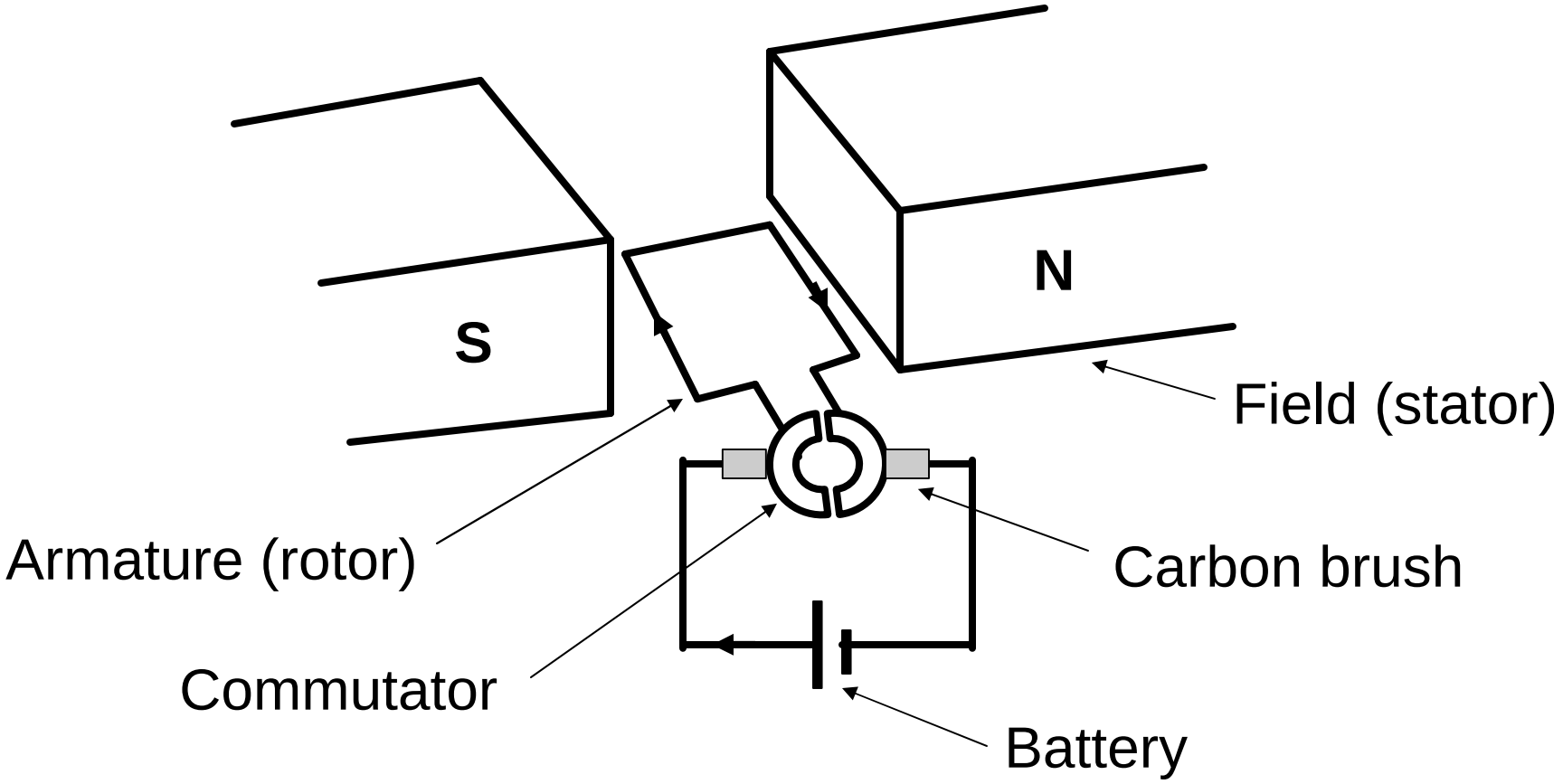
Types of Motors



DC MOTORS

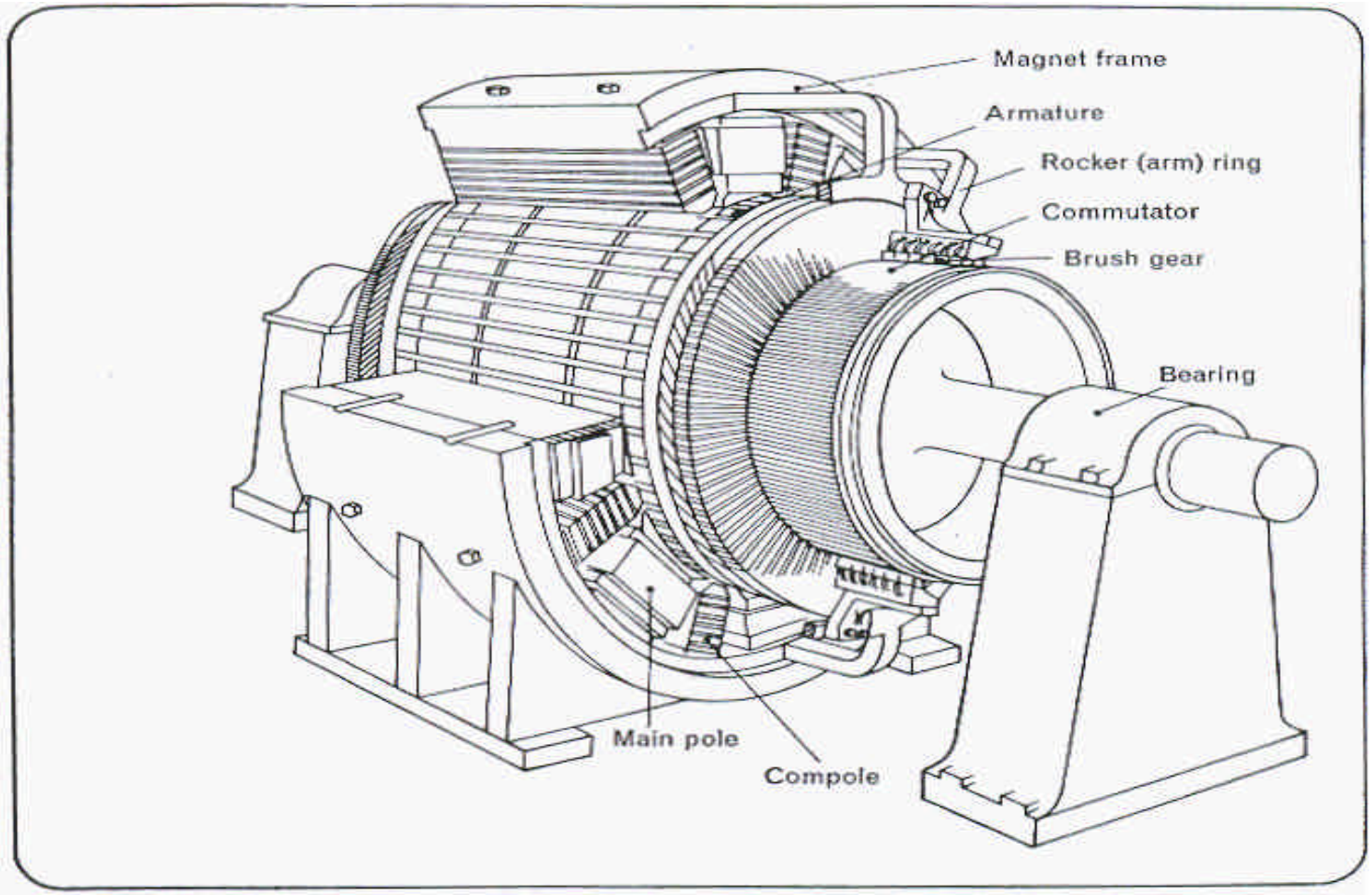
DC Motors

Elementary Construction



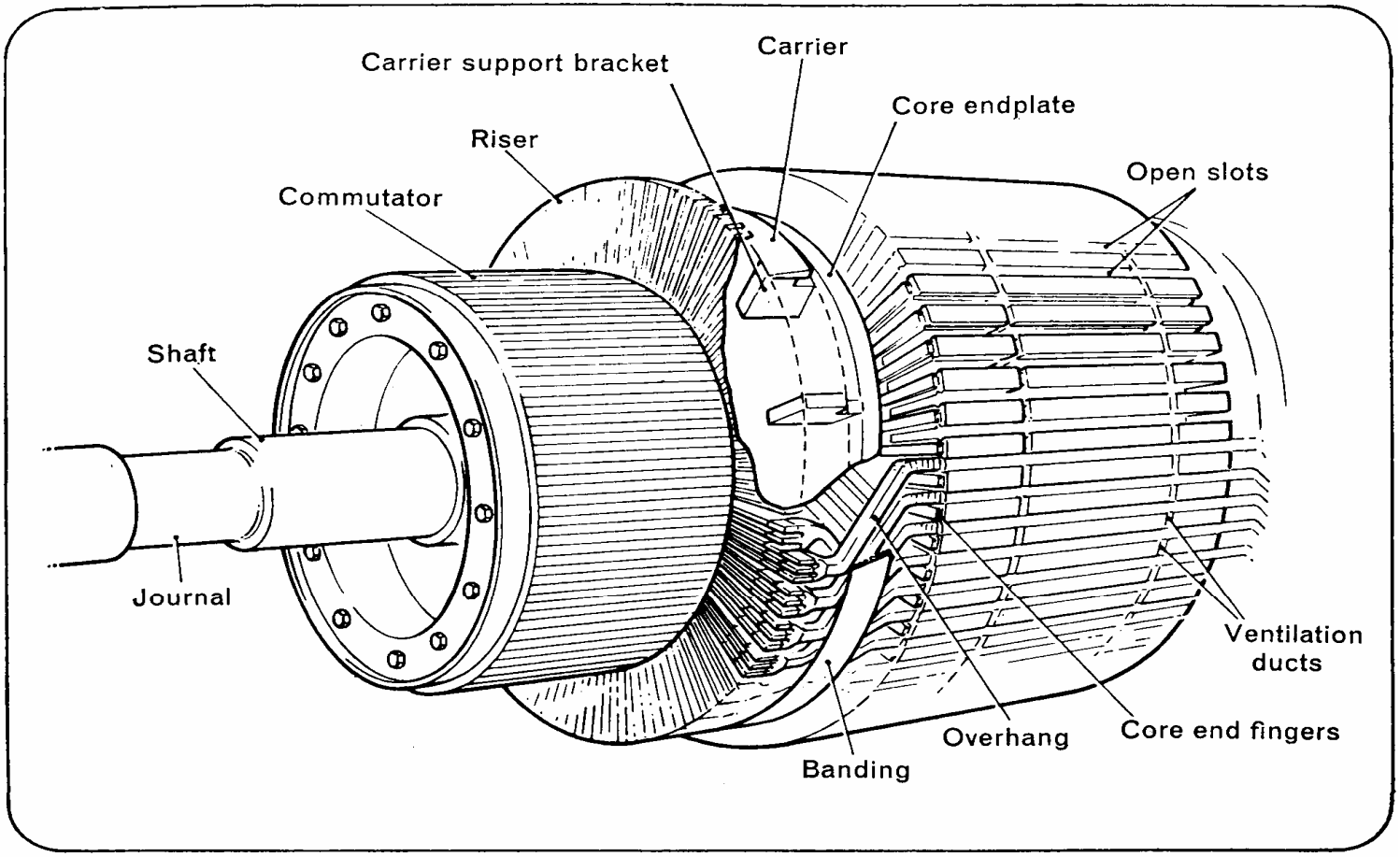
DC Motors

Actual Construction



DC Motors

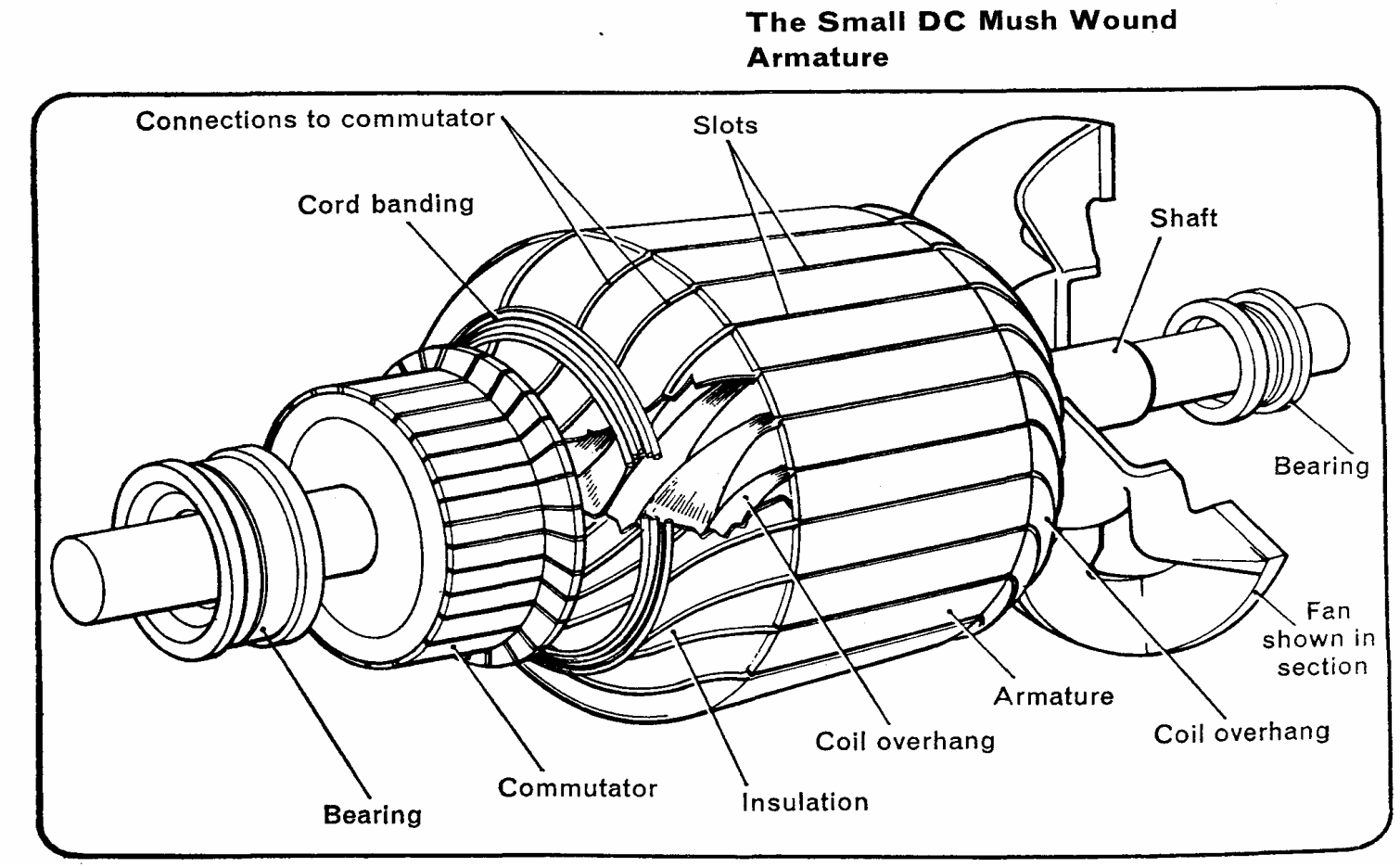
Actual Construction



A dc armature

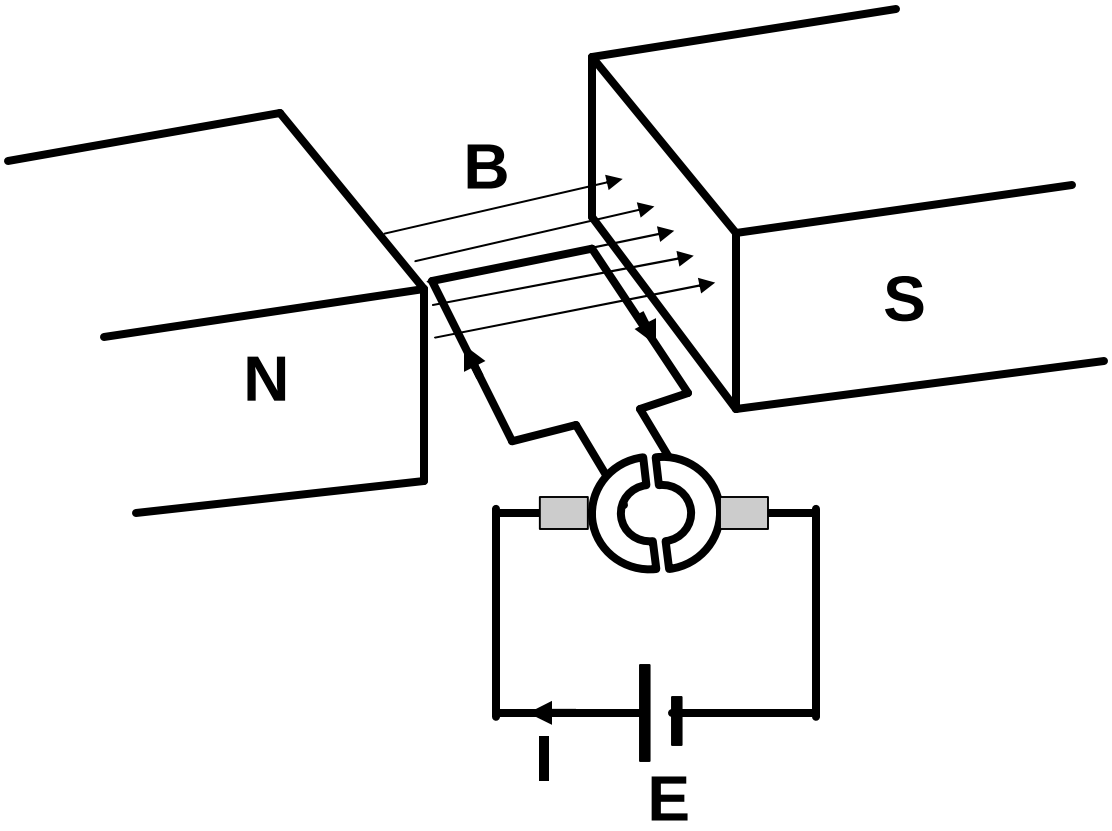
DC Motors

Actual Construction



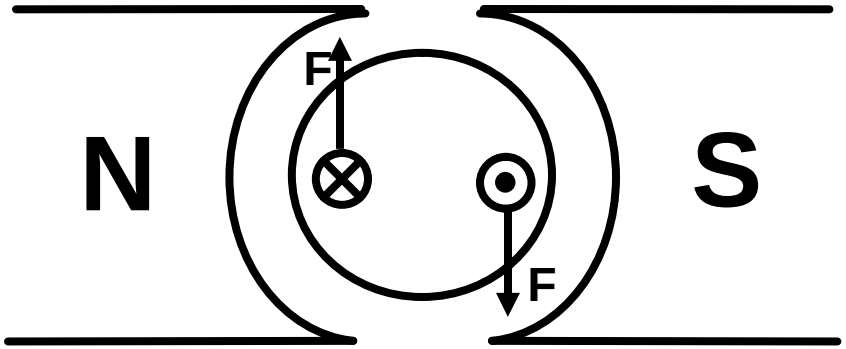
DC Motors

Principle of operation



DC Motors

Principle of operation



Interaction between stator field and armature field (due to current) produces two vertical forces opposite in direction. So torque is produced.

$$F = (B \times l) \times I$$

B = magnetic flux density (Tesla)

l = length of coil wire (meters)

I = armature current (amperes)

DC Motors

Applications

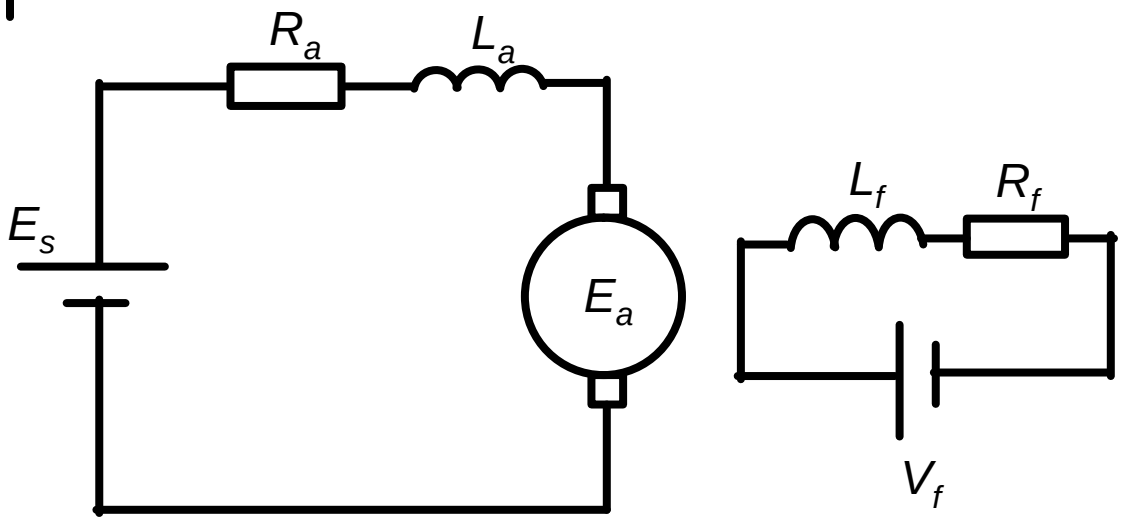
- **Residential and commercial:** Clocks, timers, toys, cars, fans, pumps, medical equipment
- **Industrial:** steel and paper mills, conveyors, textile machines, printing presses, packaging machines, extruders, material handling, mining, marine generation and propulsion

Each type has different applications. Most commercially applied types are the separately-excited and series motors. In the industry, series, shunt and compound motors are available.

However, in the near future, DC motors will be replaced by AC motors in the industry but DC motors will still exist in commercial applications.

DC Motors

Equivalent Circuit



R_a , L_a = armature resistance and inductance

R_f , L_f = field resistance and inductance

E_a = back e.m.f induced in armature

E_s = stator supply voltage

V_F =field voltage (stator supply voltage)

DC Motors

Motor Nameplate

Any DC motor has a nameplate that contains the maximum values of the following quantities:

1. Power (in kW)
2. Armature voltage (in volts)
3. Armature current (in amperes)
4. Field voltage in (volts)
5. Field current (in amperes)
6. Speed (in rpm)
7. Generated torque (in N.m)

These quantities must not be exceeded.

DC Motors

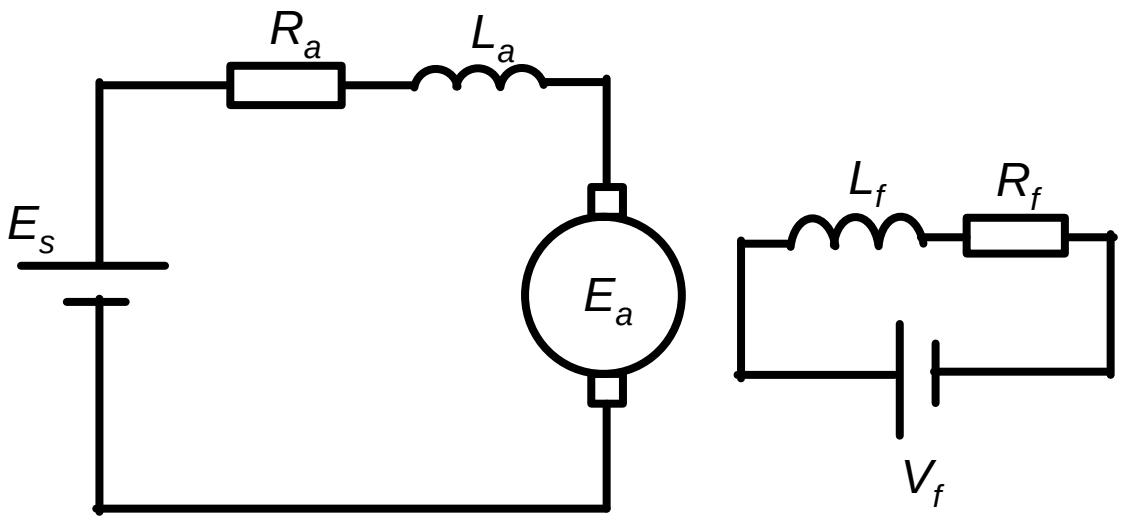
Types

Motors differ according to how field winding is connected with armature winding. These are the basic types:

1. Separately-excited
2. Series
3. Shunt
4. Compound

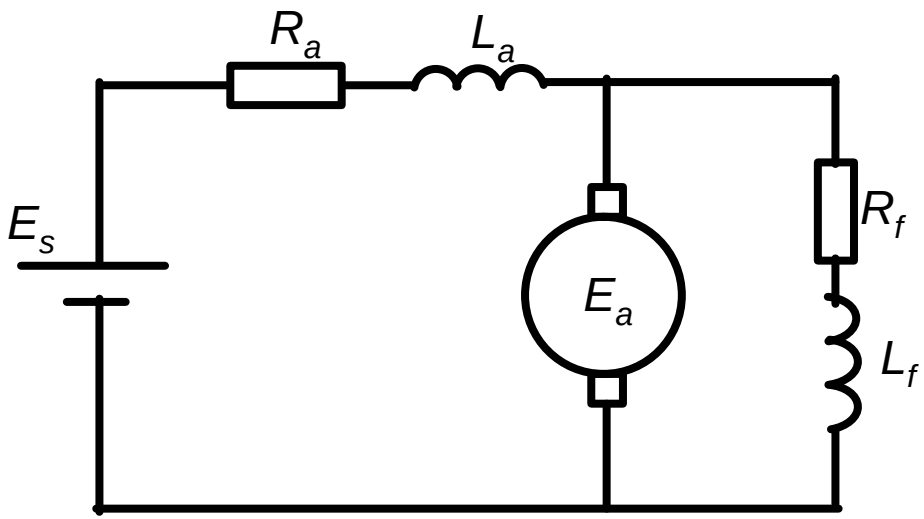
DC Motors

Separately-excited



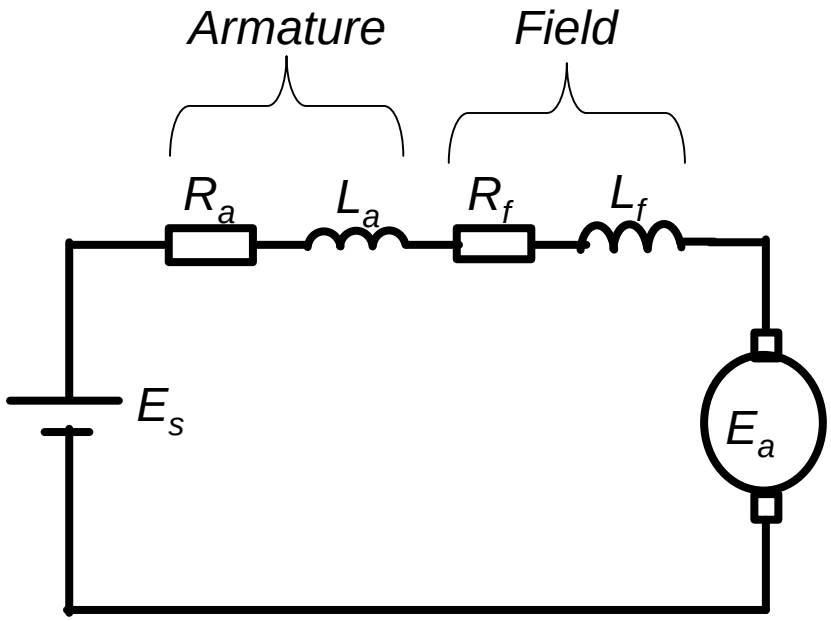
DC Motors

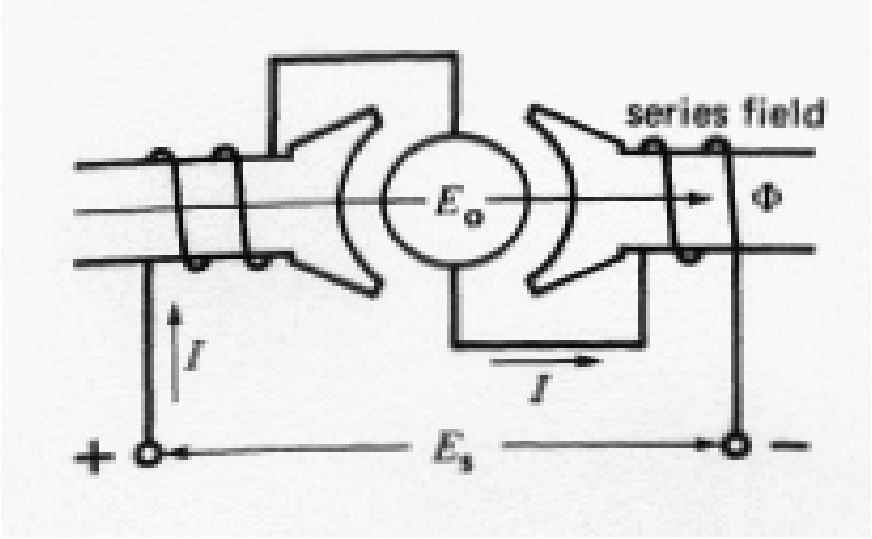
Shunt



DC Motors

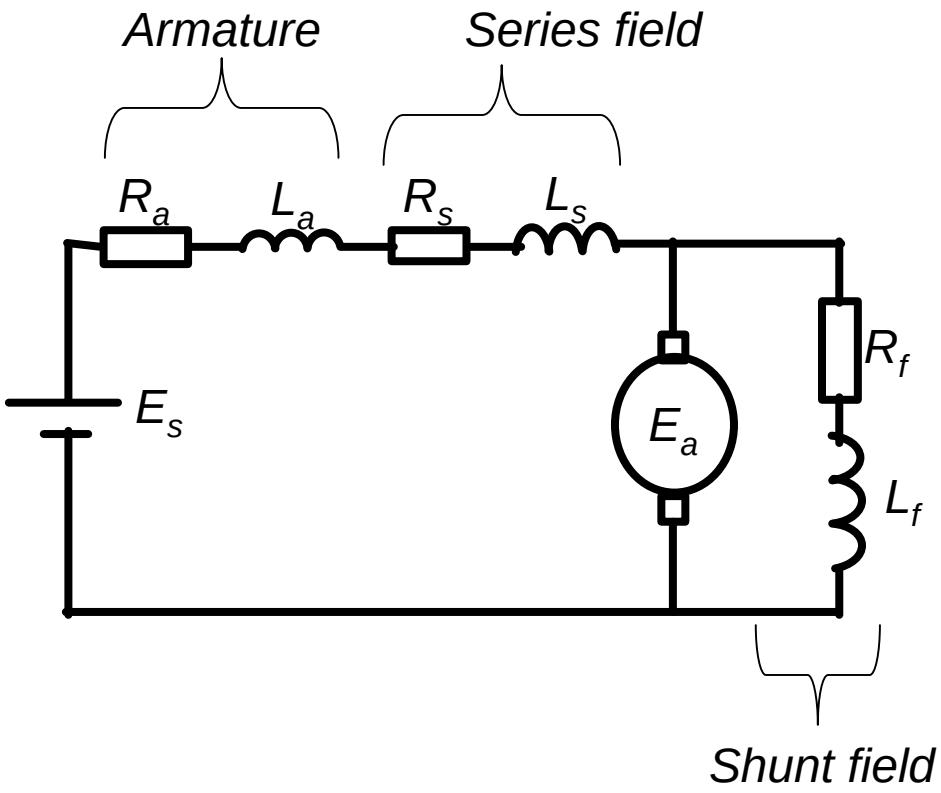
Series

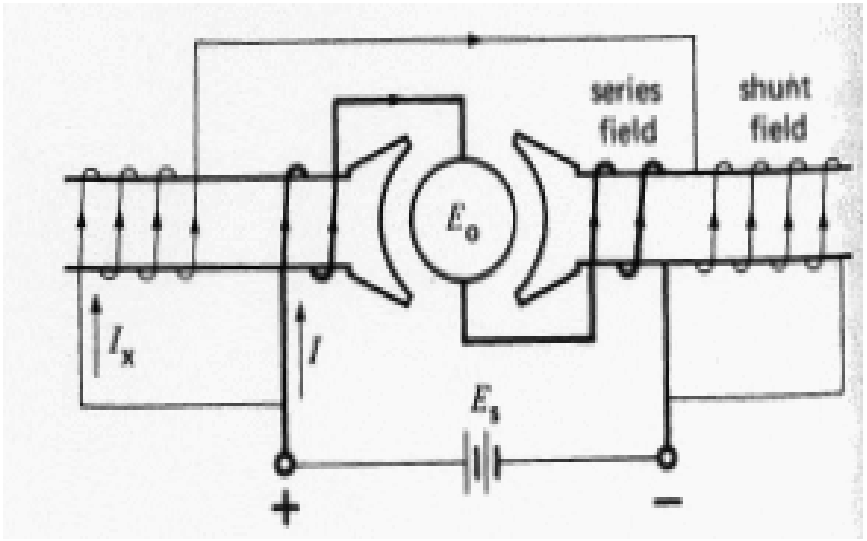




DC Motors

Compound





DC Motors

Speed Control

In many industrial applications, the speed and torque must be controlled.

The speed can be increased by:

1. Increasing armature current (up to base speed)
2. Decreasing field current (above base speed)

DC Motors

Reversal of rotation

In many industrial and commercial applications, the speed must be reversed at a particular instant or stage.

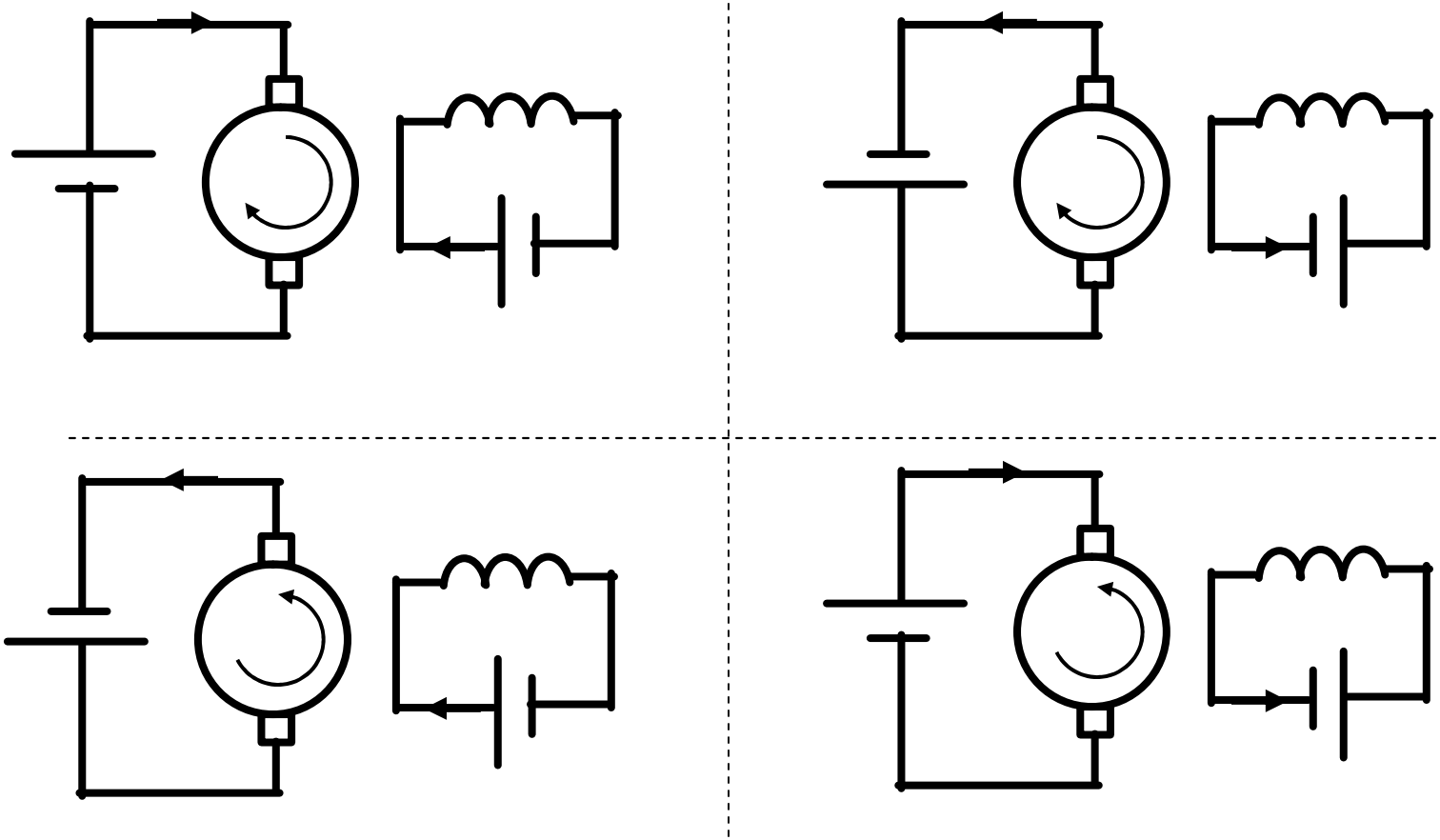
The direction of rotation of a DC motor can be reversed by either *reversing the polarity* of the voltage across *either* the *field* or *armature*.

When both the field and armature connections are reversed, the rotation will not be reversed.

DC Motors

Reversal of rotation

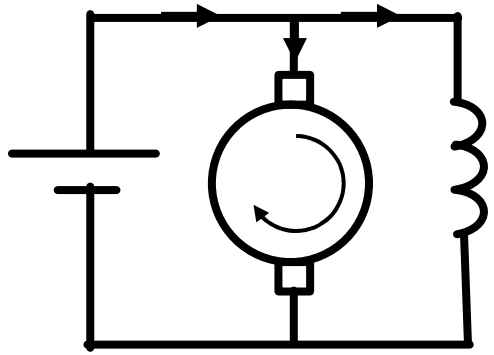
Separately-excited

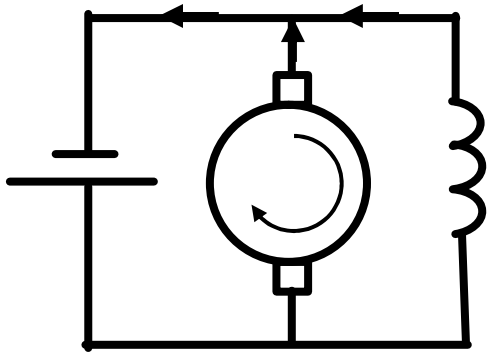


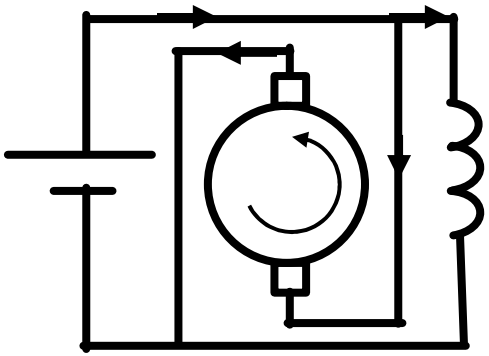
DC Motors

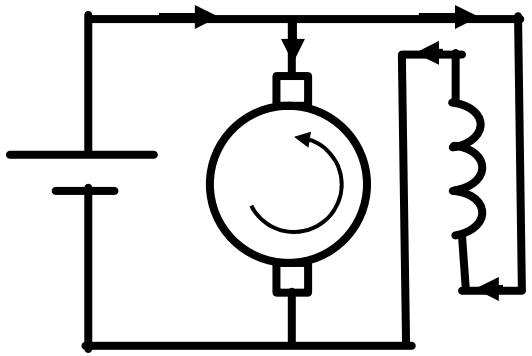
Reversal of rotation

Shunt



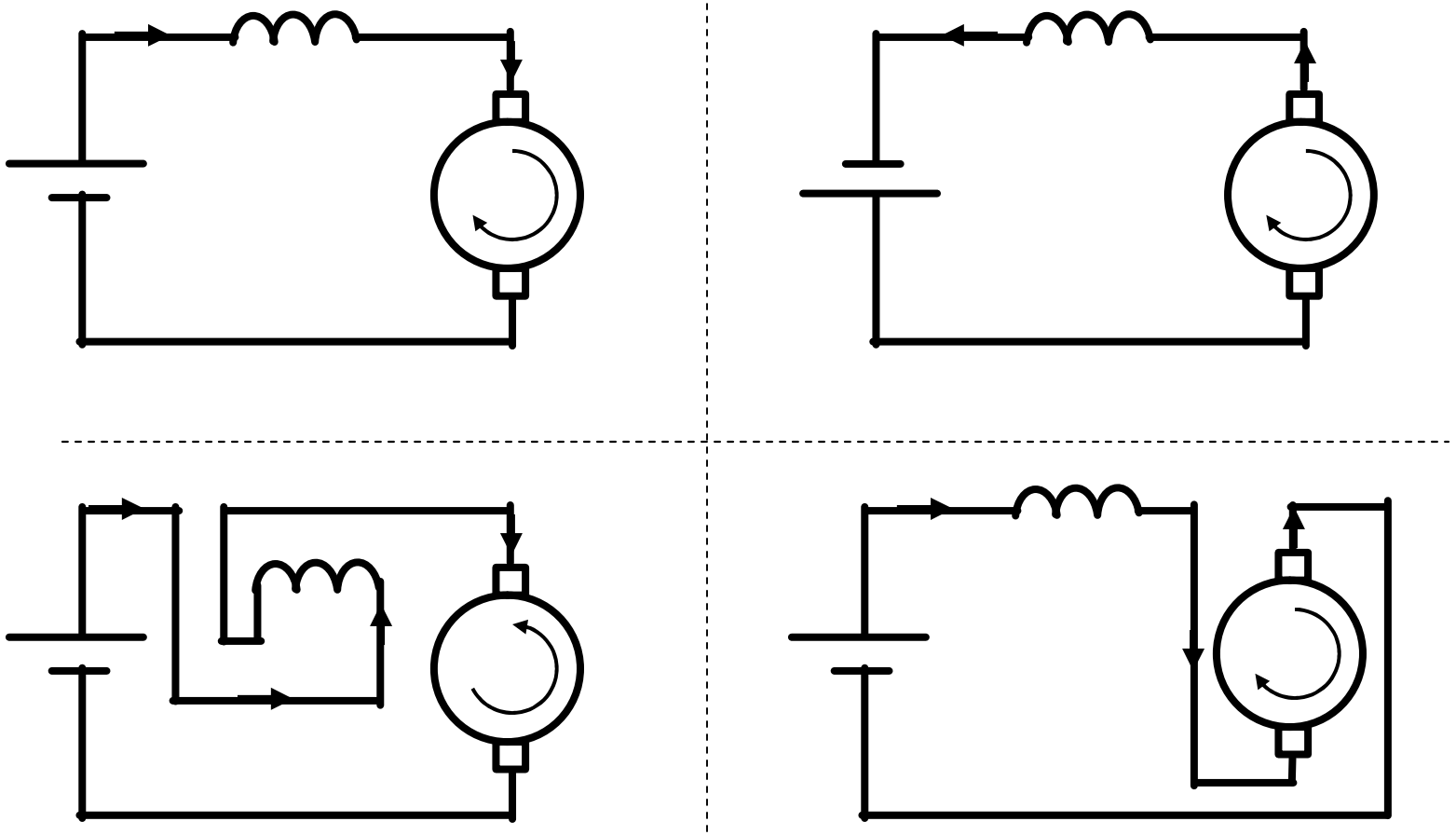






DC Motors

Reversal of rotation **Series**



THREE-PHASE INDUCTION MOTORS

Three-Phase Induction Motors

Introduction

Types

1. Squirrel-cage (90% of industrial applications)
2. Wound-rotor or slip-ring

Applications

- Pumps, compressors, fans, conveyors, escalators, lifts, hoists, etc.

Merits compared to DC motor

- Robust, long life
- Less maintenance requirements (squirrel-cage type)
- Higher power per unit volume

Three-Phase Induction Motors

Construction

Stator

Three identical windings made up of copper wires inserted in slots of laminated steel core.

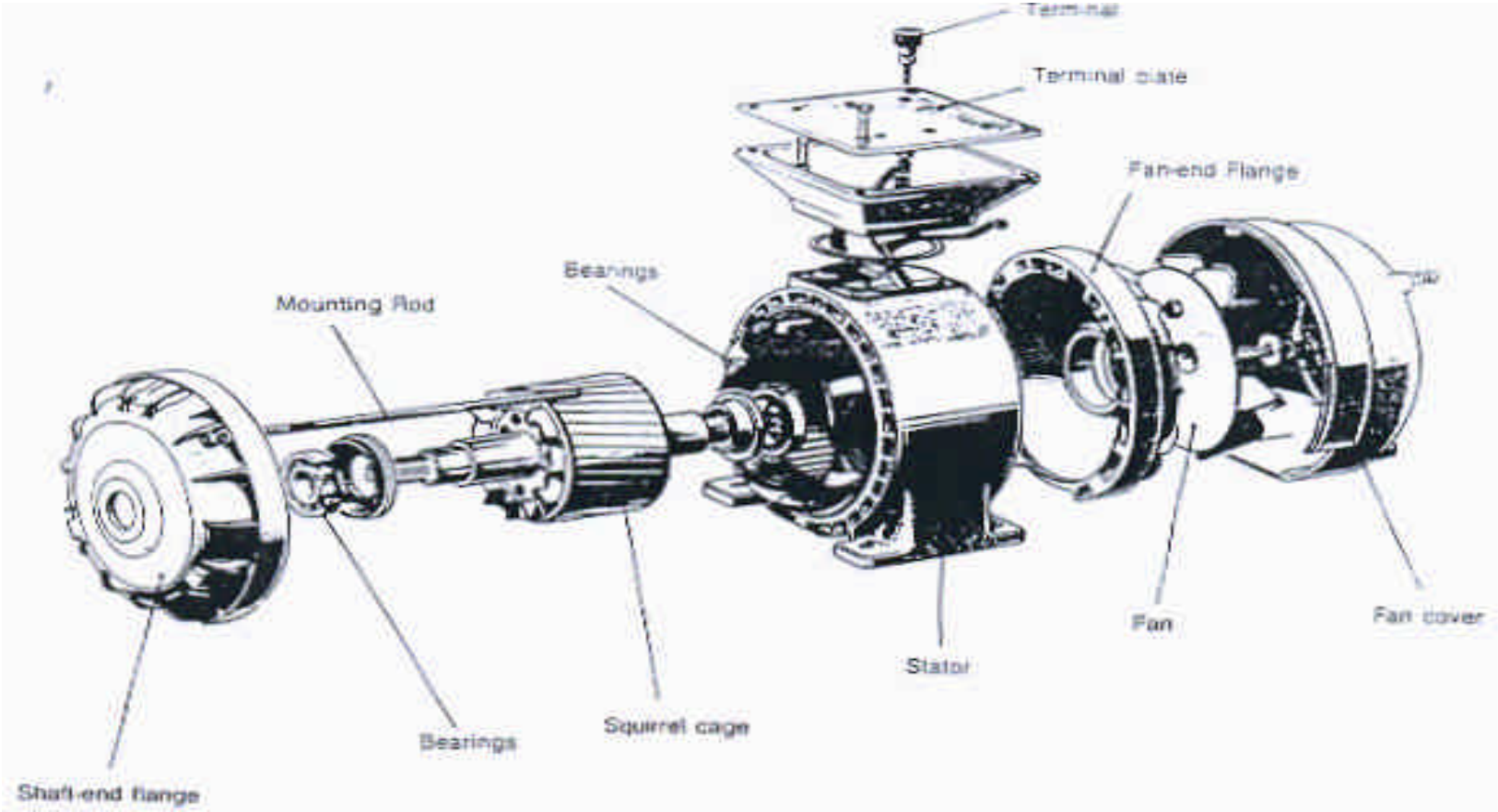
Rotor

- Squirrel-cage: Three identical windings made up of cast aluminum and shorted by two aluminum rings
- Wound-rotor: Three identical windings made up of copper wires connected to three slip rings. The slip rings can be connected to external resistors via carbon brushes

Three-Phase Induction Motors

Construction

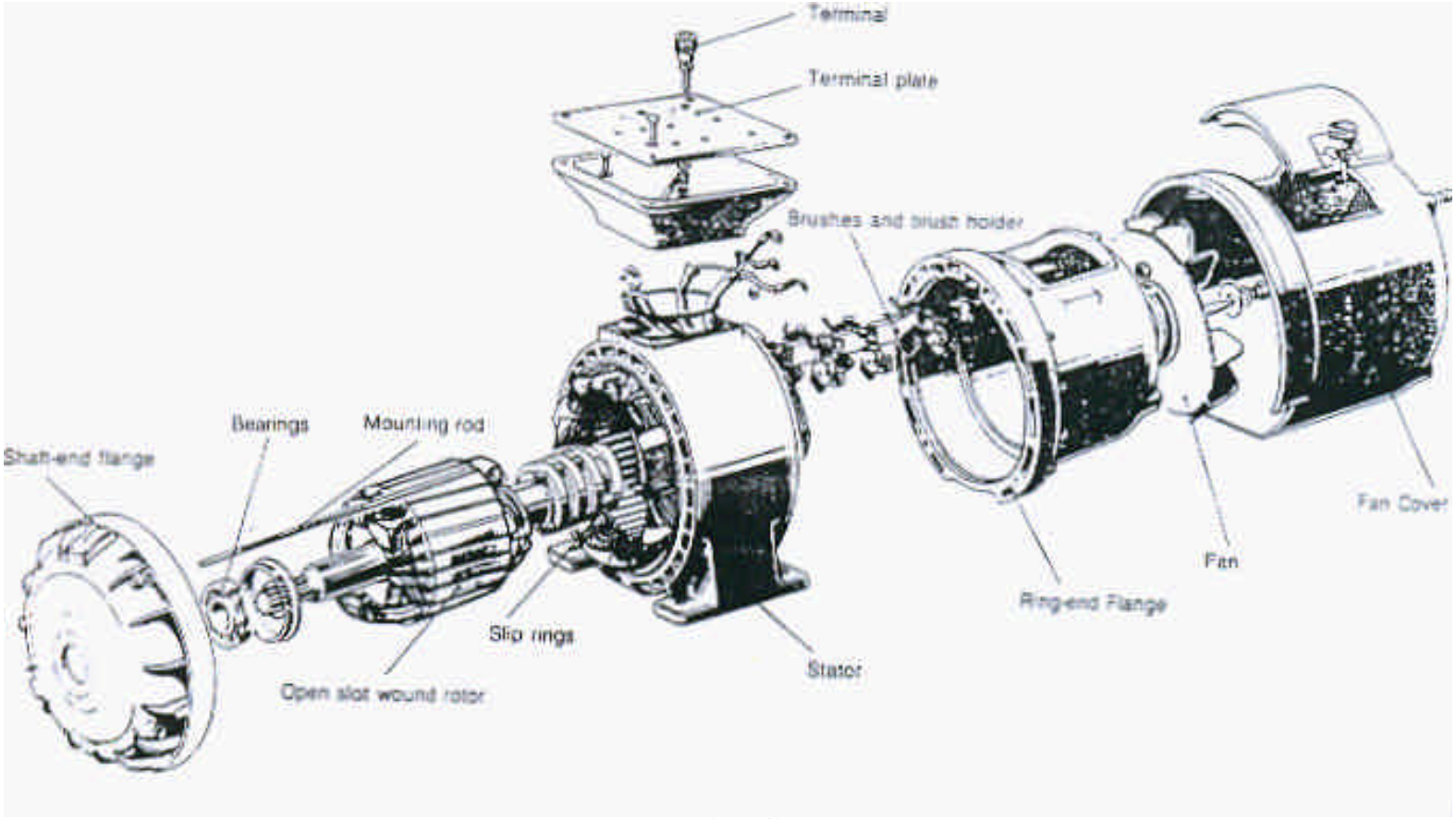
Squirrel-cage motor



Three-Phase Induction Motors

Construction

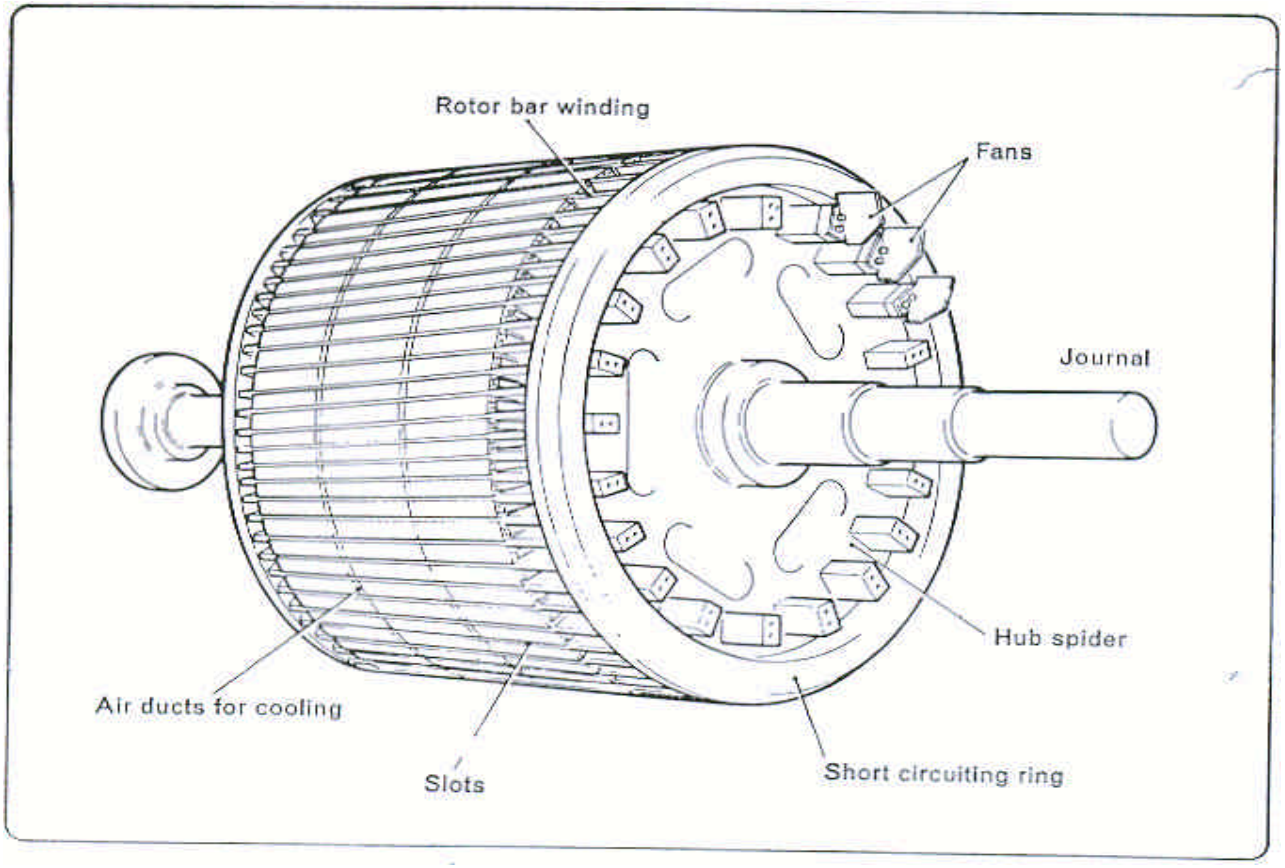
Wound-rotor motor



Three-Phase Induction Motors

Construction

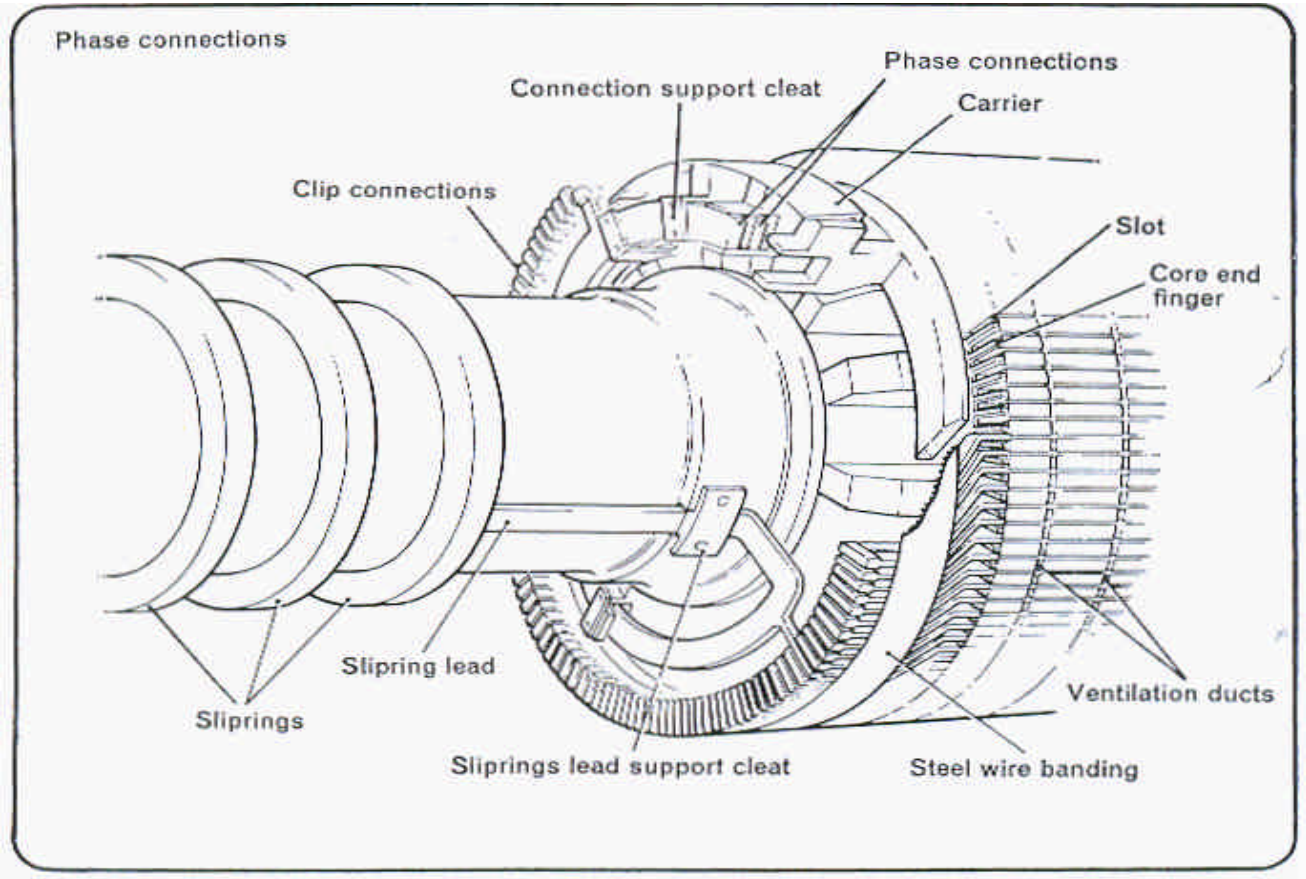
Squirrel-cage rotor



Three-Phase Induction Motors

Construction

Close up view of wound-rotor



Three-Phase Induction Motors

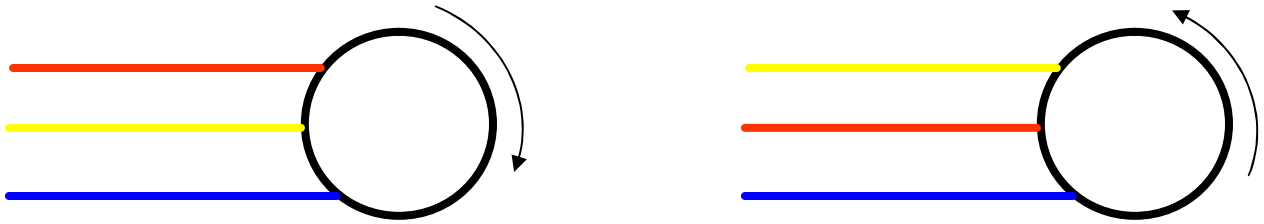
Principle of Operation

When 3-phase ac power is applied to the stator windings, a revolving field is established in the stator core. According to Faraday's Law, this changing field induces currents in the rotor windings which also create another magnetic field which is slower than the stator field.

Three-Phase Induction Motors

Principle of Operation

The interaction between the two fields produces a torque which turns the rotor. The direction of rotation depends on the phase sequence of the stator voltages. Interchanging any two phases reverses the direction.



Three-Phase Induction Motors

Basic Connections

There are two basic connections for the stator windings:

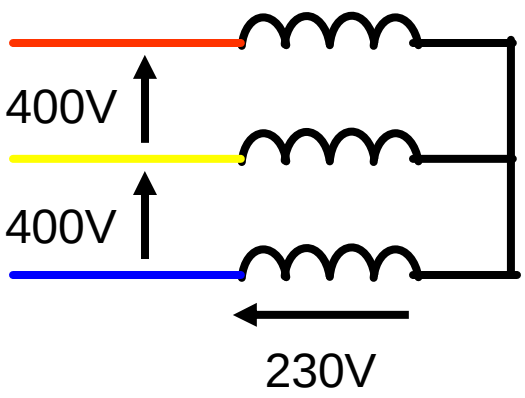
1. Star (Y):58% of line-line voltage appears across each stator winding. So in a 3-phase, 4-wire, 400V, 50 Hz system, around 230V appears across each winding.

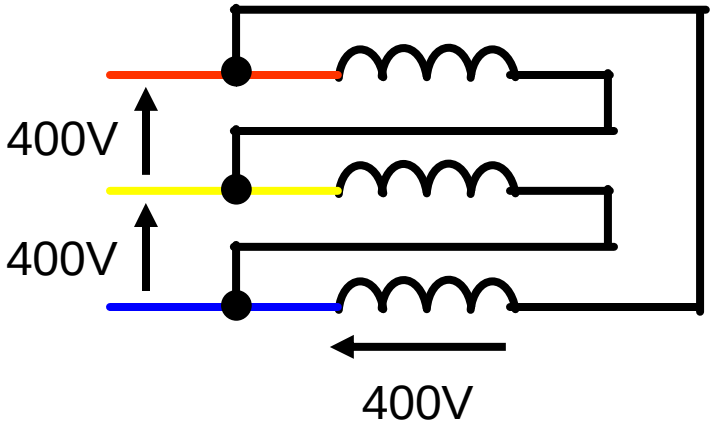
   In a squirrel-cage motor, the rotor windings are not connected as Y or Δ but rather shorted at both ends. The rotor windings of a wound rotor motor are Y-connected.

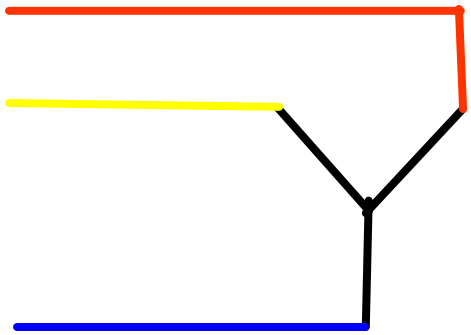
2. Delta (Δ): Full line-line voltage appears across each winding. So 400V would appear across each phase.

Three-Phase Induction Motors

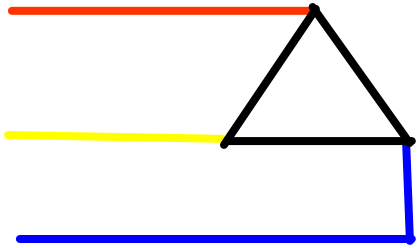
Basic Connections







Y-connection



D-connection

SINGLE-PHASE INDUCTION MOTORS

Single-Phase Motors

Introduction

Types

The types are classified on how the motor is started and on the rotor design.

Single-phase induction motors

1. Split-phase 2. Capacitor-run 3. Capacitor-start

4. Capacitor-start, capacitor-run 5. Shaded-pole

Commutator motors

6. Universal motor 7. Repulsion motor (becoming extinct)

Applications

- Pumps, compressors, fans, washing machines, drills, vacuum cleaners, timers, etc

Single-Phase Induction Motors

1 Split-phase motor

Applications

- Small fans, blowers, any moderate starting torque loads

Construction

1. Stator: two copper windings known as *main* and *auxiliary* windings. They are set electrically 90^{o} around the stator core.
2. Rotor: squirrel-cage and centrifugal switch

Principle of operation

When 1ϕ supply across stator windings, each winding Sets up a magnetic field. The two stator magnetic fields are out phase by less than 90^{o}. The net magnetic field induces another magnetic field in the rotor and hence a torque is produced.

Single-Phase Induction Motors

1 Split-phase motor

Principle of operation

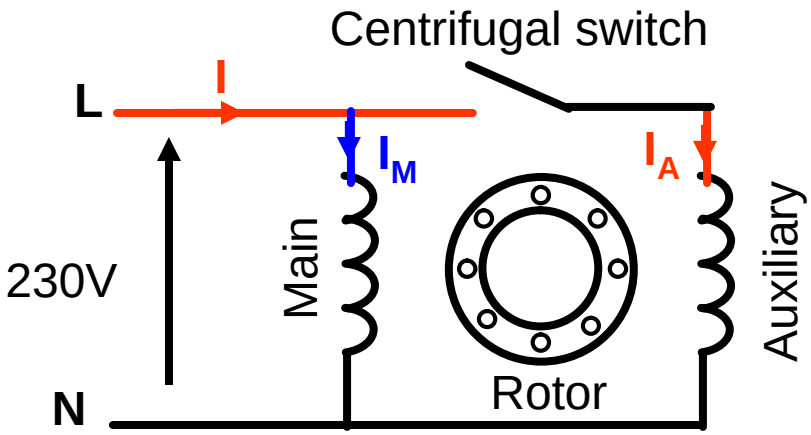
When only one stator winding is used, the motor does not rotate but rather vibrates. This is because its magnetic field is not enough to turn the rotor. At startup, both windings are employed. When the rotor reaches 75% of its final speed, the *auxiliary* winding is disconnected (or split) from the circuit and only the *main* winding remains connected to the supply. This is achieved by the centrifugal switch.

The auxiliary windings has smaller size of wire than the main winding. Hence, the auxiliary resistance is higher.

Single-Phase Induction Motors

1 Split-phase motor

Equivalent Circuit

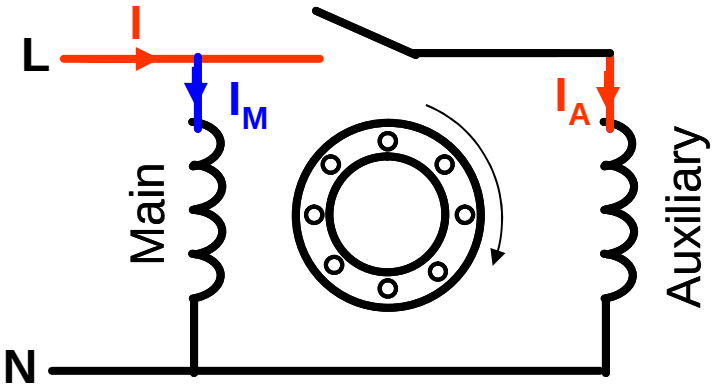


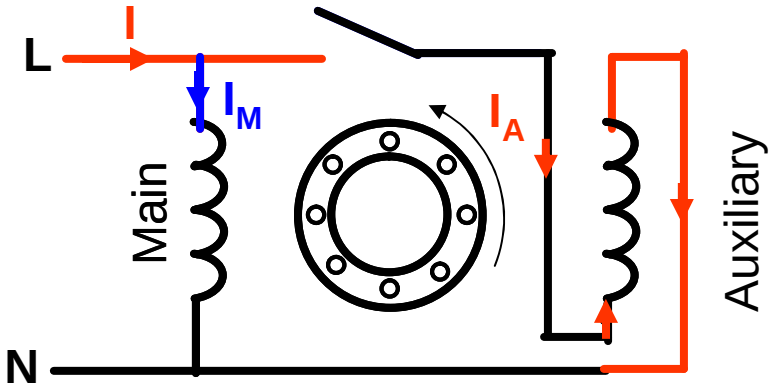
$$I = \sqrt{(I_M)^2 + (I_A)^2}$$

Single-Phase Induction Motors

1 Split-phase motor

Reversal of direction





Single-Phase Induction Motors

2 Capacitor-start motor

Applications

- Compressors, pumps, any high starting torque loads

Construction

1. Stator: two copper windings known as *running* and *starting* windings, and a capacitor.
2. Rotor: squirrel-cage and centrifugal switch

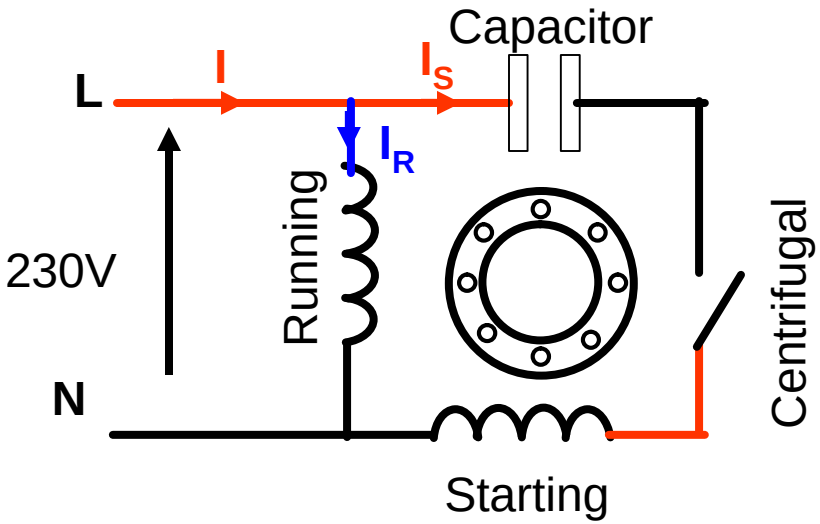
Principle of operation

The same as the split phase but the inclusion of the capacitor produces higher torque. When 75% of rotor speed is reached, the capacitor and staring winding are disconnected.

Single-Phase Induction Motors

2 Capacitor-start motor

Equivalent Circuit

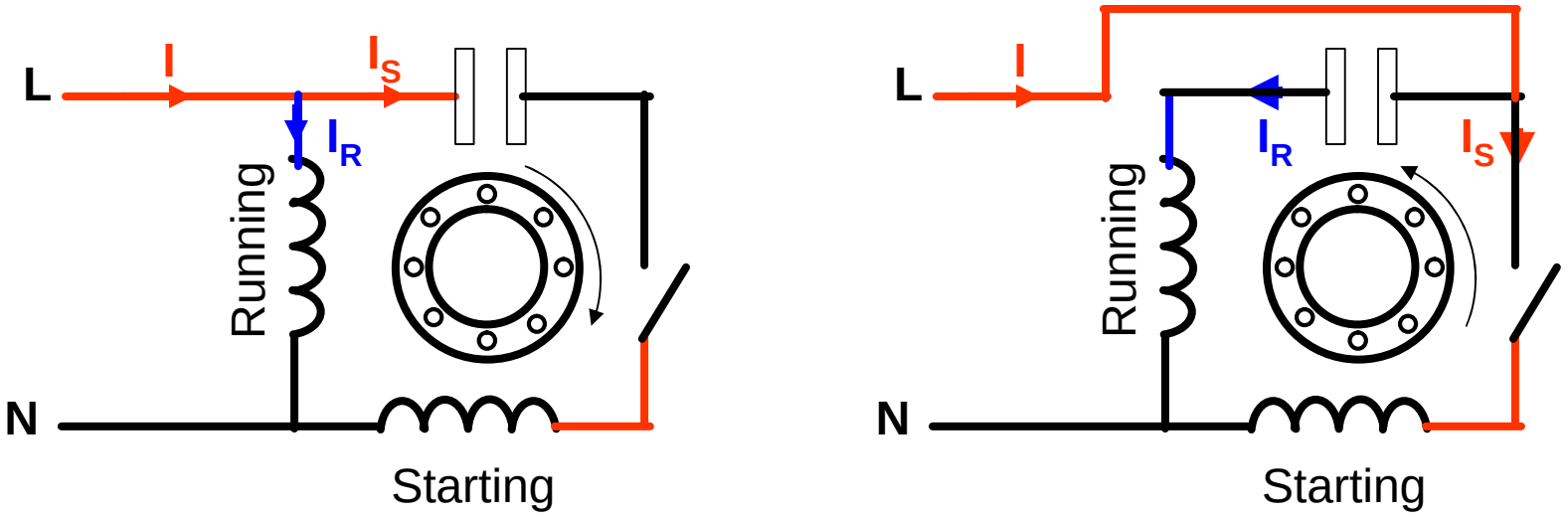


$$I = \sqrt{(I_R)^2 + (I_S)^2}$$

Single-Phase Induction Motors

2 Capacitor-start motor

Reversal of direction



Single-Phase Induction Motors

3 Capacitor-run motor

Applications

- Compressors, pumps, any low starting torque loads

Construction

1. Stator: two copper windings known as *running* and *starting* windings, and a capacitor.
2. Rotor: squirrel-cage

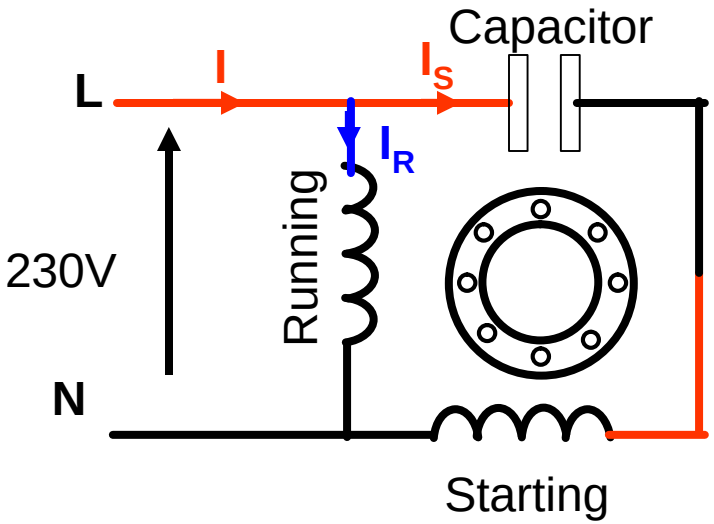
Principle of operation

The starting torque is lower than capacitor-start motor but higher than split-phase motor.

Single-Phase Induction Motors

3 Capacitor-run motor

Equivalent Circuit



$$I = \sqrt{(I_R)^2 + (I_S)^2}$$

Single-Phase Induction Motors

4 Capacitor-start, capacitor-run motor

Applications

- Compressors, pumps
- **Construction**

1. Stator: two copper windings known as *running* and *starting* windings, and two capacitors.
2. Rotor: squirrel-cage, centrifugal switch

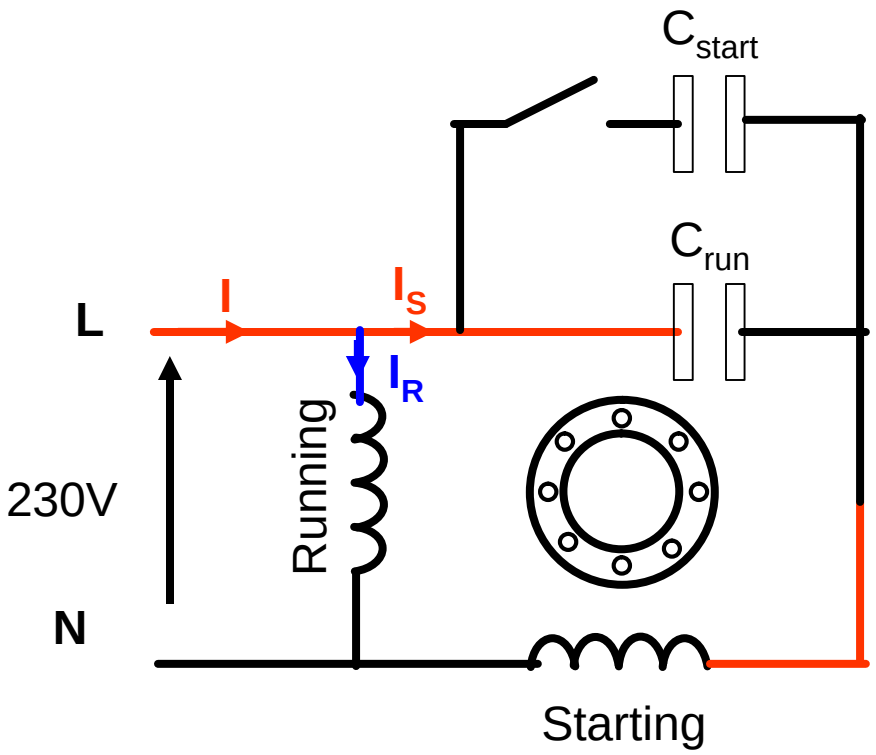
Principle of operation

At starting, two capacitors are incorporated with the starting winding. When the speed reaches 75% of its ultimate value, the centrifugal switch disconnects one of the capacitors and the motor continues to run as a capacitor-run motor.

Single-Phase Induction Motors

4 Capacitor-start, capacitor-run motor

Equivalent Circuit



Single-Phase Induction Motors

4 Shaded-pole motor

Applications

- Very small fans, exhaust fans, timers, very low torque loads

Construction

1. Stator: *main* and *auxiliary* windings. Auxiliary winding is two shading rings made of copper
2. Rotor: squirrel-cage

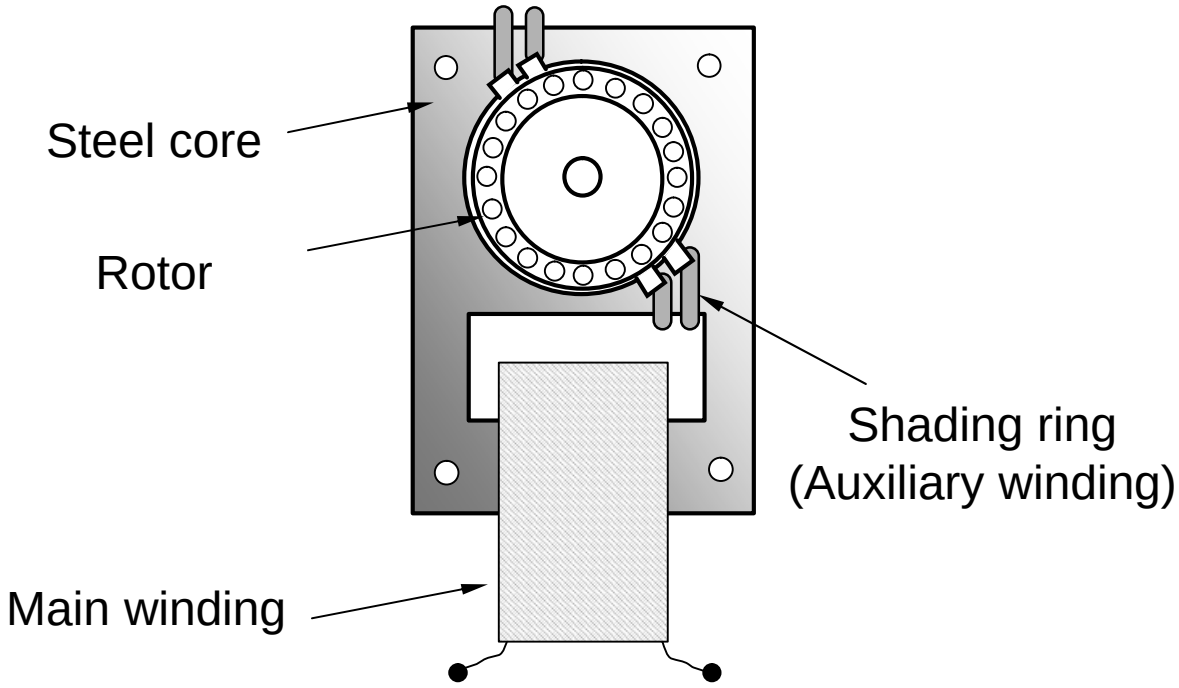
Principle of operation

The out-of-phase stator magnetic fields induce currents in the rotor and so a torque is produced.

Single-Phase Induction Motors

4 Shaded-pole motor

Construction



Single-Phase Motors

5 Universal motor

Applications

- Power tools e.g. drills, jack hammers, grinders
- Vacuum cleaners, blenders

Construction

Similar to DC series motor

Principle of operation

It works on AC and DC voltage. When connected to an AC source, ac current flows in the armature and field. The field flux reacts with the armature current to produce a torque.

At no load, the motor reaches as high as 30, 000 rpm. This motor is characterized by very high starting torque.