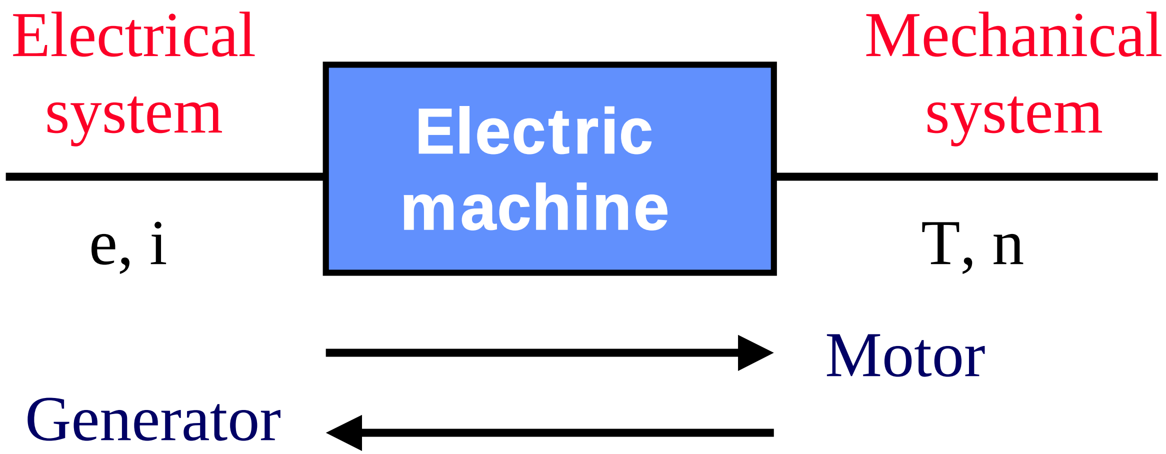
Electrical Machines 1

Hour 1

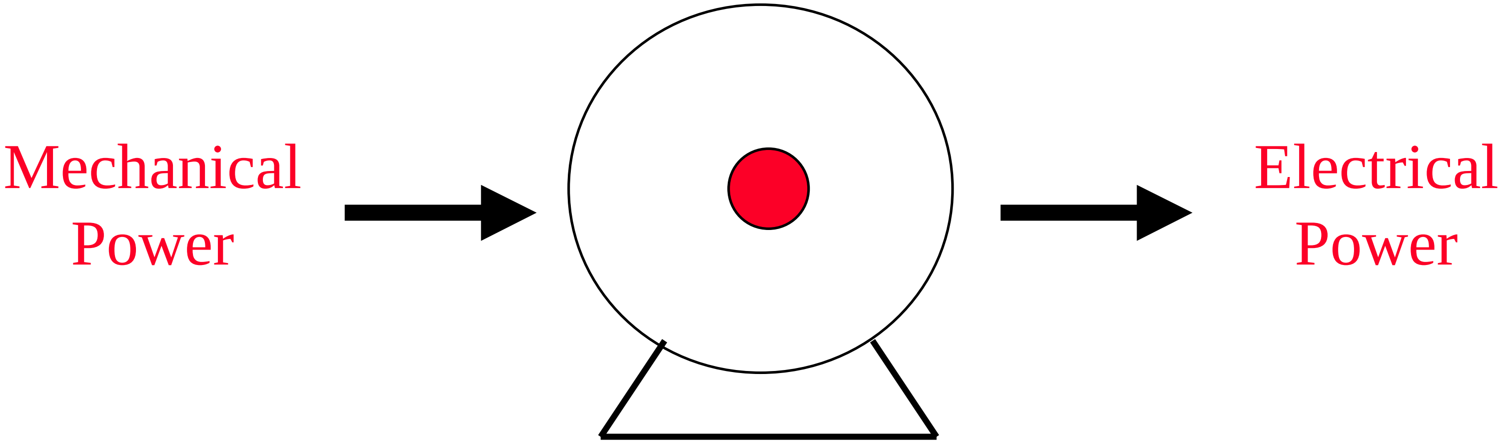
Electrical Machines

- An electromechanical converter which is used to continuously translate electrical input to mechanical output, or vice versa.
- The process of translation is known as Electromechanical Energy Conversion.



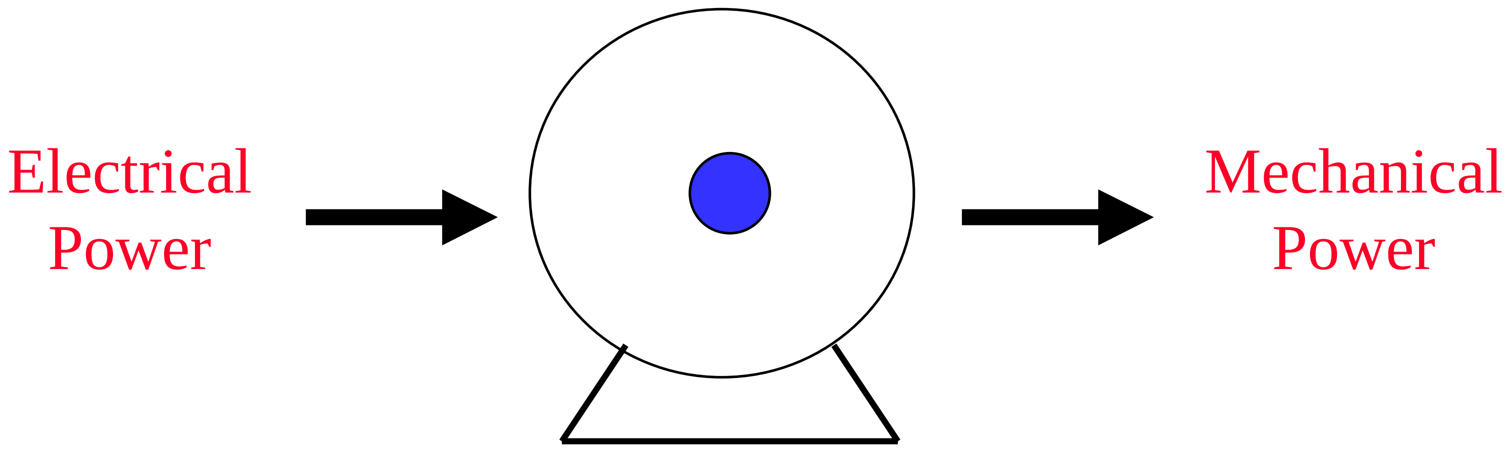
Generator

- The electromechanical energy conversion is from mechanical to electrical



Motor

- The electromechanical energy conversion is from electrical to mechanical



Electromagnetic Conversion
(P.121 – P.123)

1 When a conductor moves in a magnetic field, voltage is induced in the conductor

$$\boxed{e = Bl v}$$

2. When a current-carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.

$$\boxed{F = BI l}$$

Basic Structure of Electrical Machines (P.123 - P.125)

Stator

- This part of the machine does not move and normally is the outer frame of the machine.

Rotor

- This part of the machine is free to move and normally is the inner part of the machine.

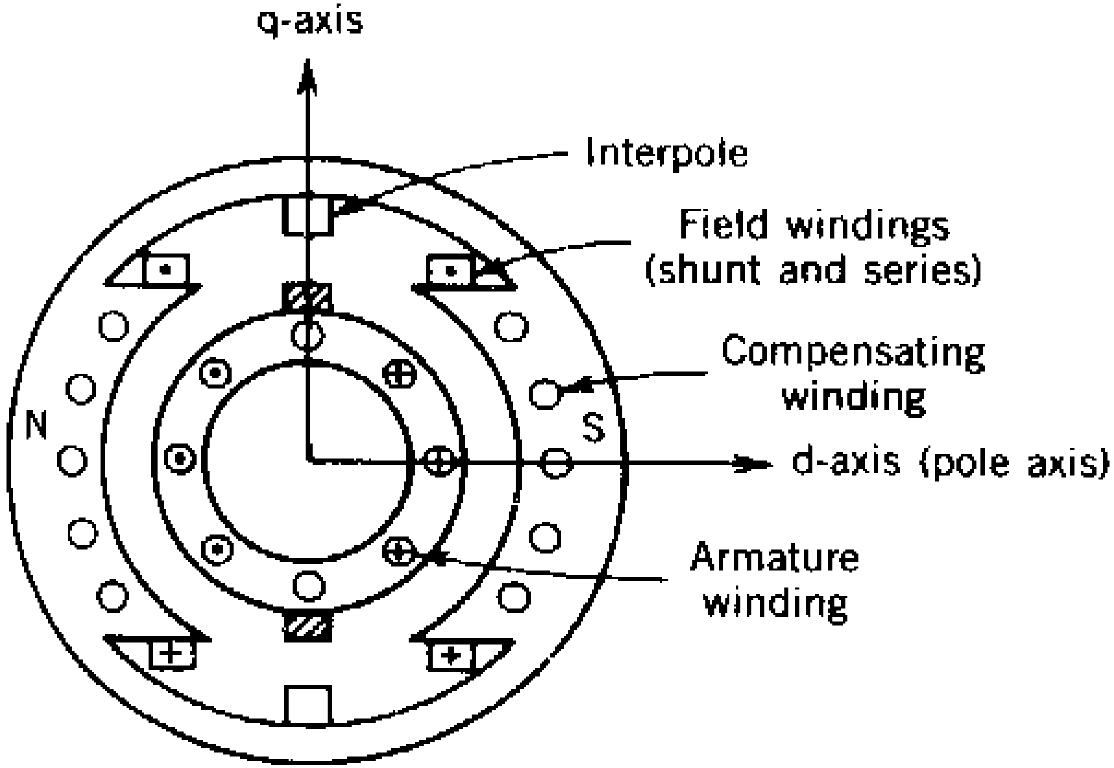
DC Machines

DC machines are versatile and extensively used in industry. A wide variety of volt-ampere or torque-speed characteristics can be obtained from various connections of the field windings.

DC Machine Construction (sect.4.2.1)

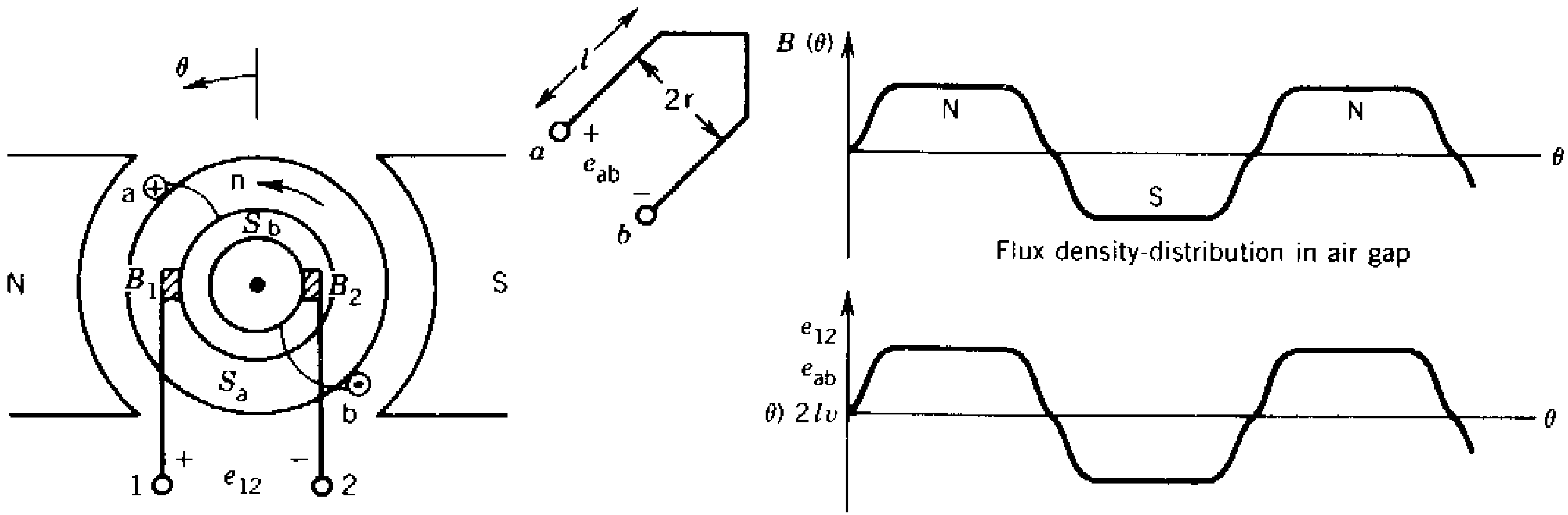
Stator has salient poles that are excited by one or two field windings:

- shunt field winding
- series field winding



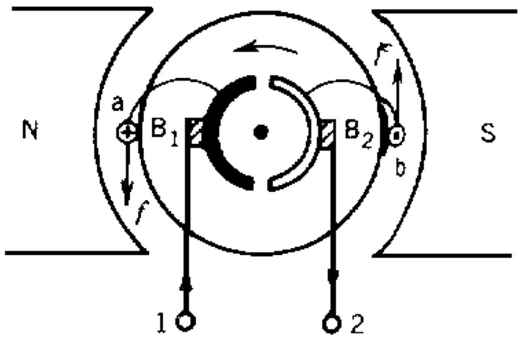
DC Machine Construction (cont)

- Armature winding is placed on the rotor
- Voltage induced in armature winding is alternating (Fig.4.12)

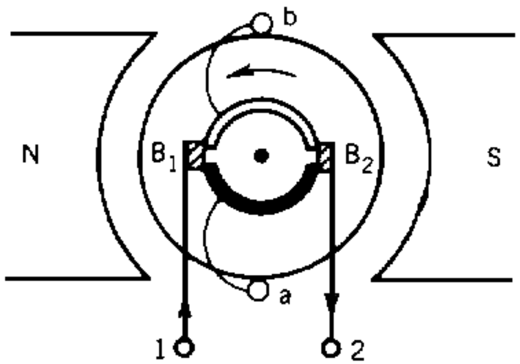


DC Machine Construction (cont)

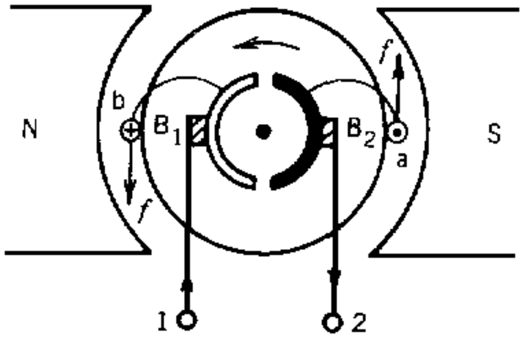
- Commutator-brush combination is used as a mechanical rectifier to make the armature terminal voltage unidirectional and also to make the mmf wave due to armature current fixed in space



(a)

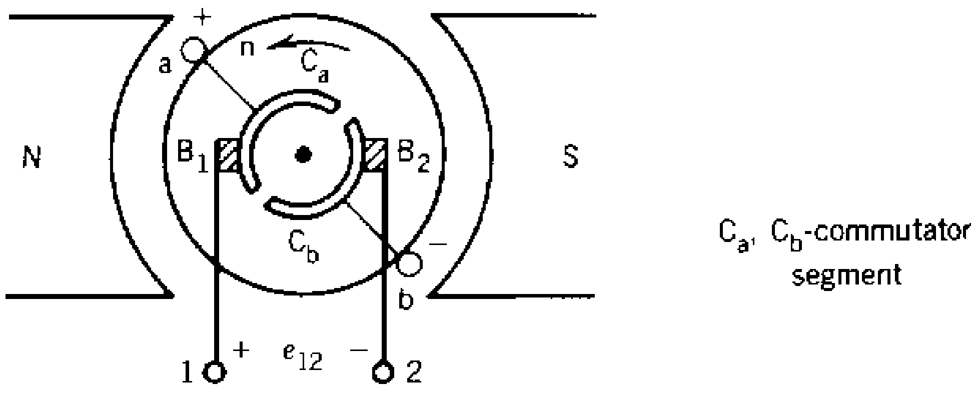


(b)

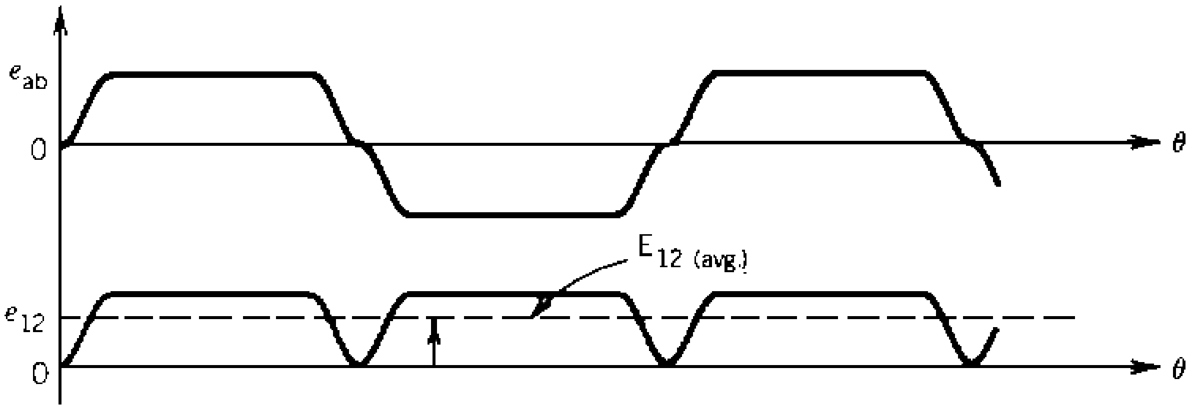


(c)

Voltage Rectification by Commutators (sect. 4.2.2)



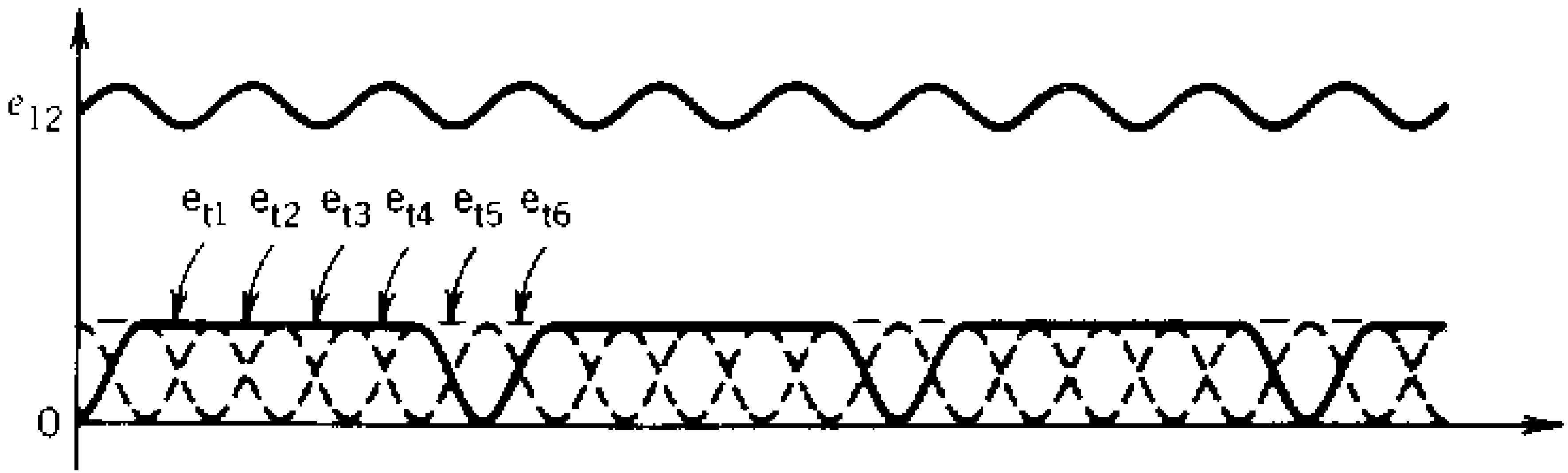
(a)



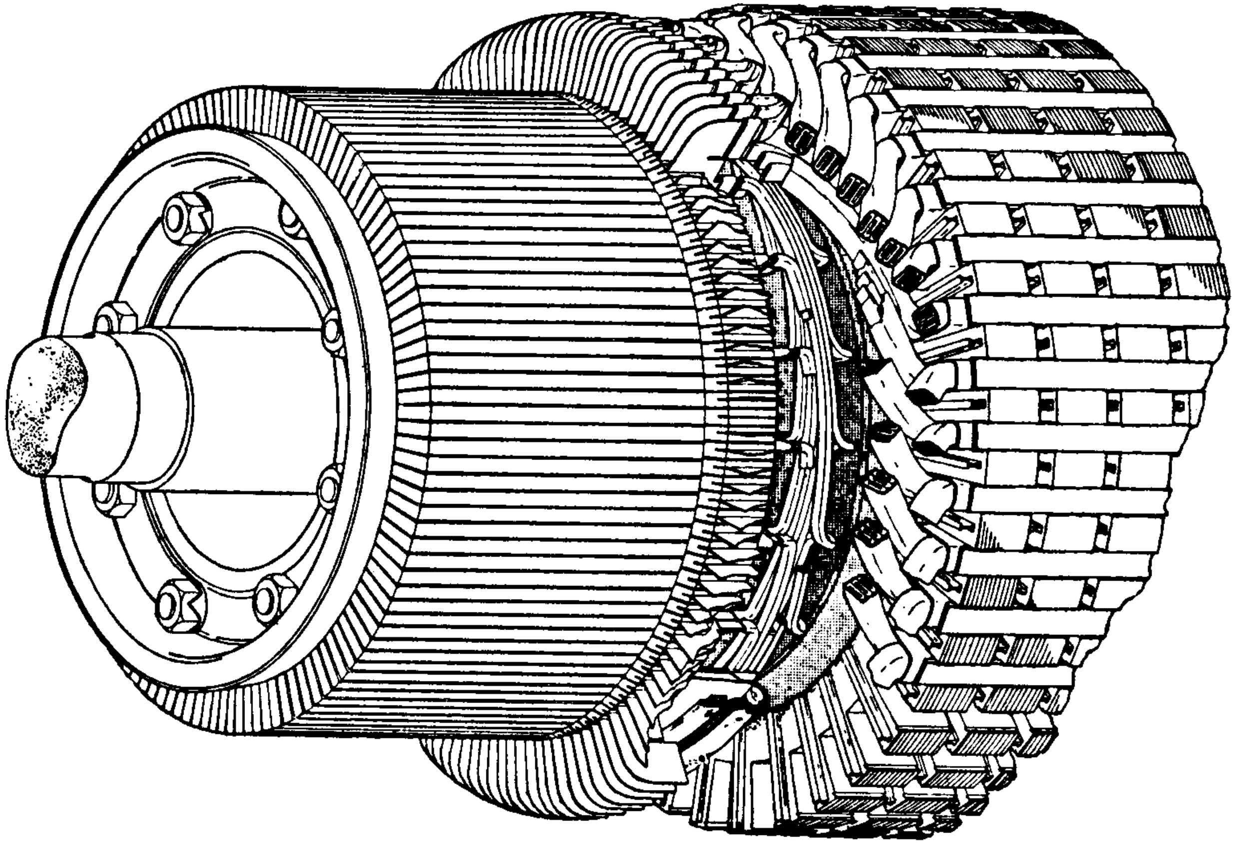
(b)

Multi-turn Machine

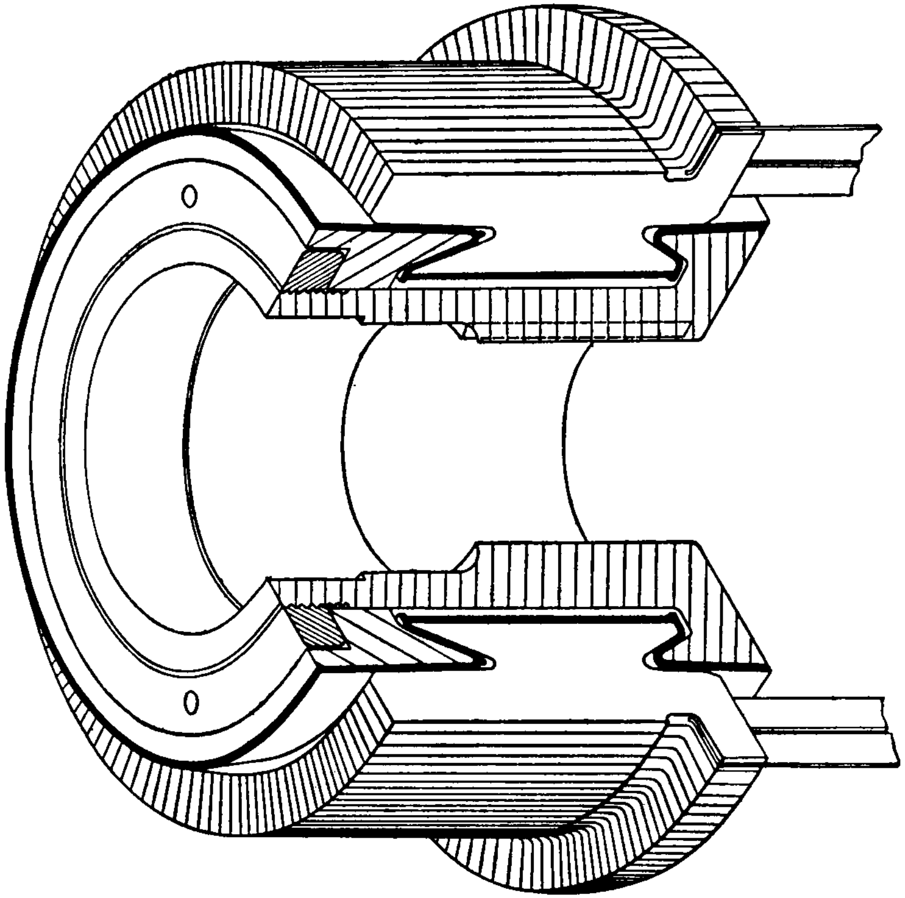
In an actual machine a large number of turns are placed in several slots around the periphery of the rotor to reduce the ripple.



Close-up of Commutator (1/2)



Close-up of Commutator (2/2)



Electrical Machines 1

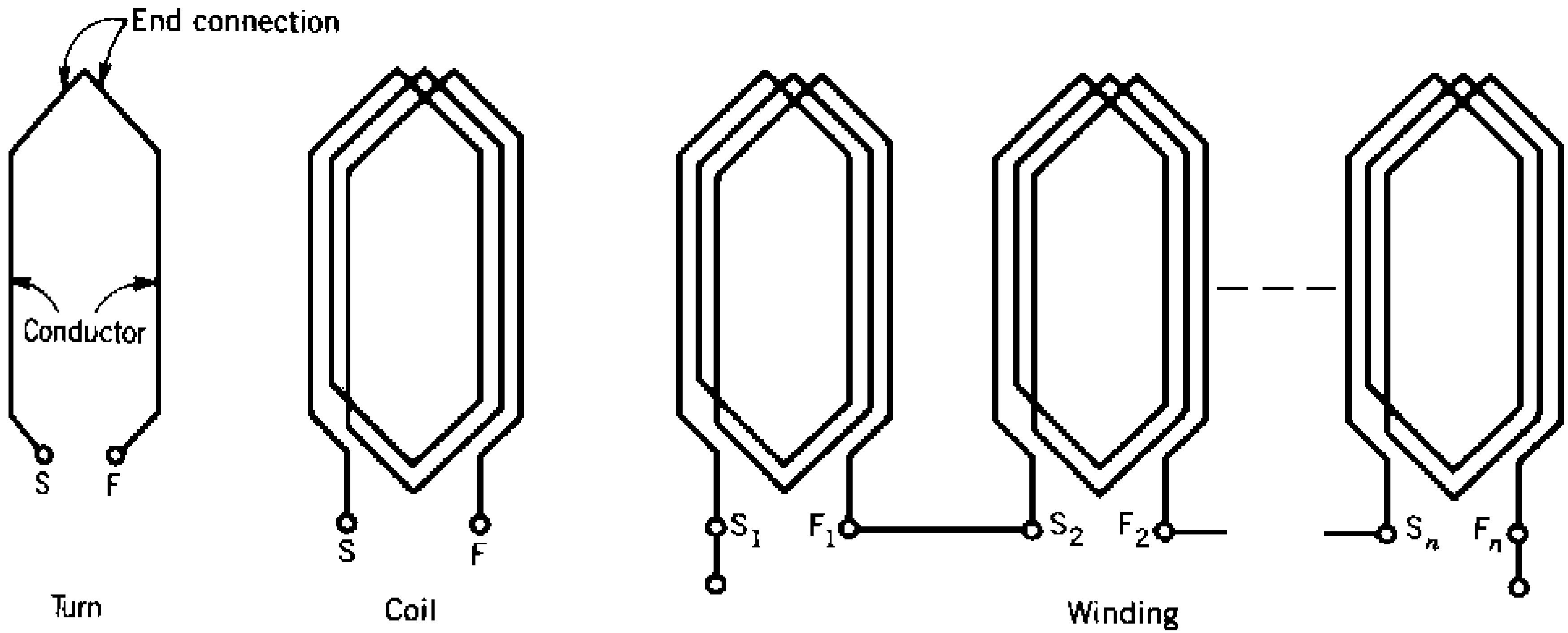
Hour 2

Armature Windings (Sect.4.2.3)

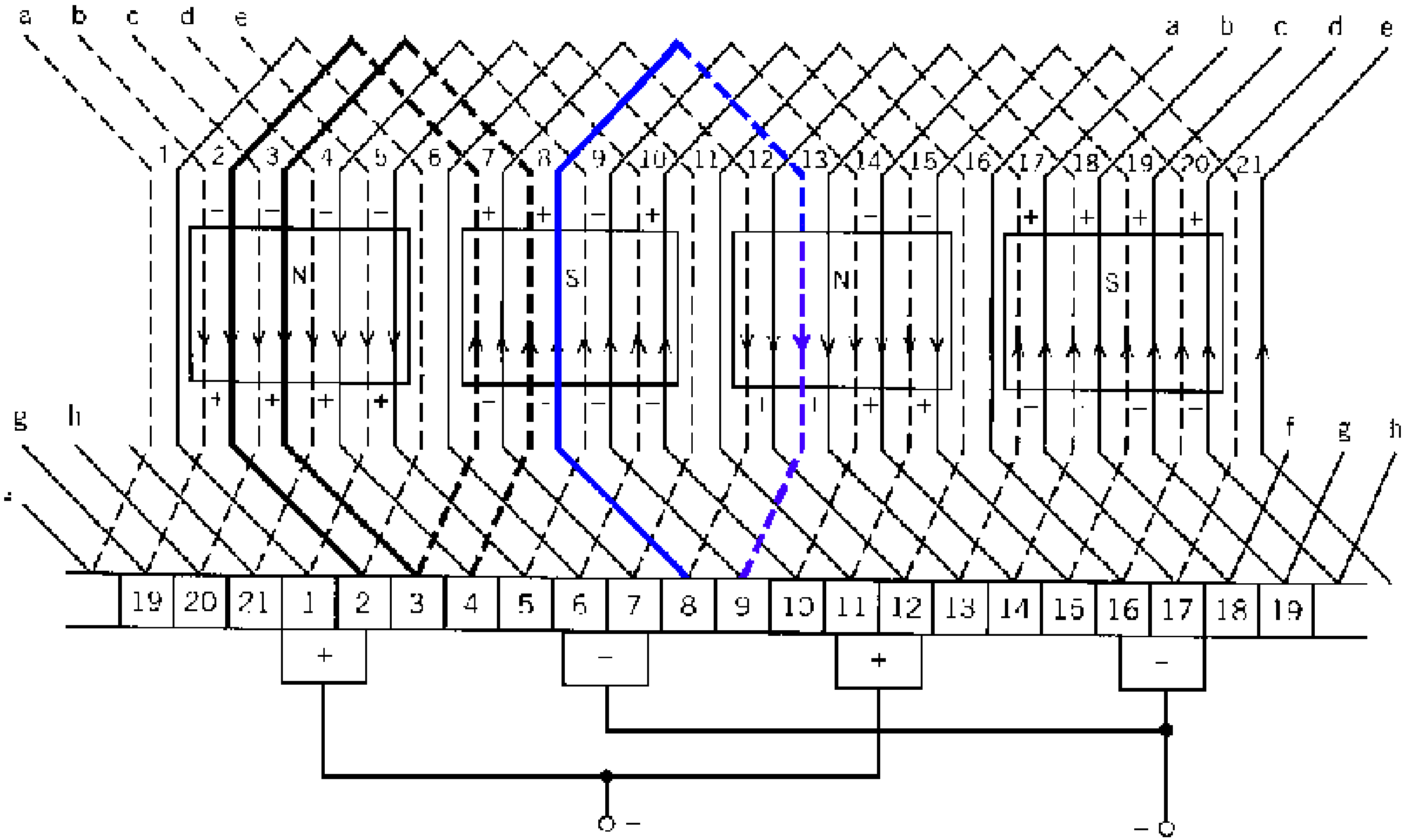
Terms:

- A turn consists of 2 conductors connected to one end by an end connector.
- A coil is formed by connecting several turns in series
- A winding is formed by connecting several coils in series
- See. Figure 4.15

Turn, Coil and Winding



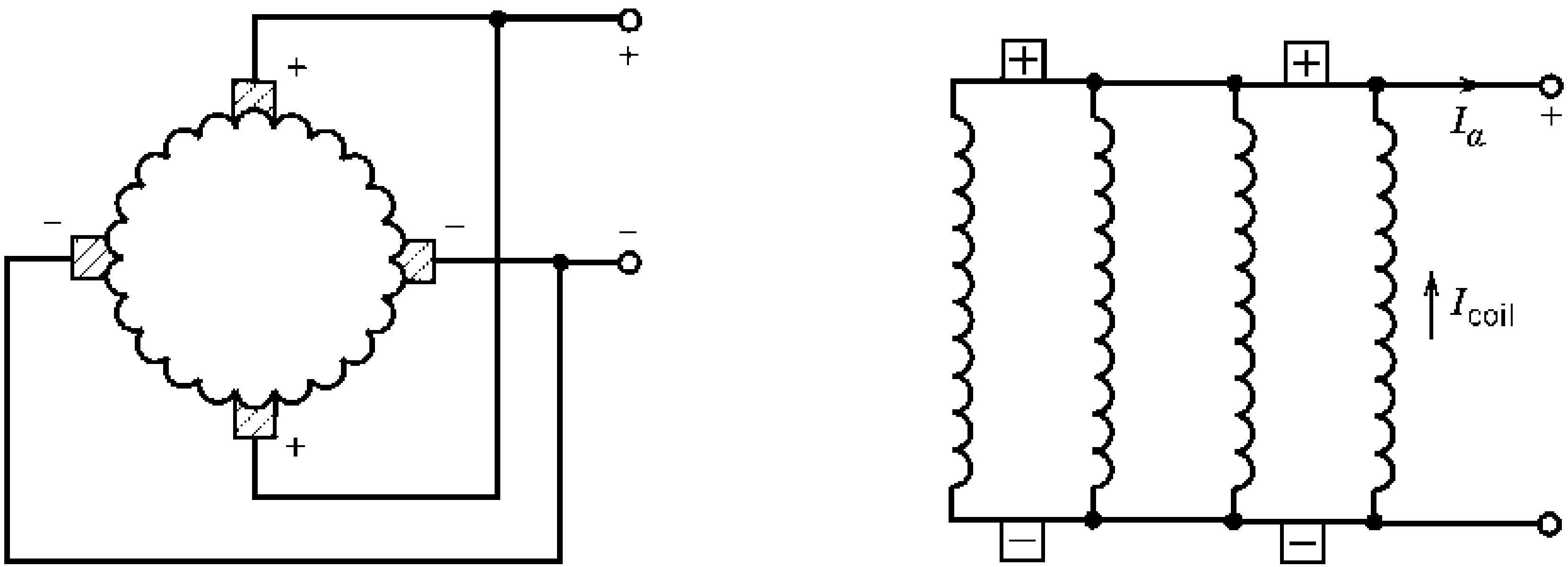
Lap Winding (Fig. 4.17)



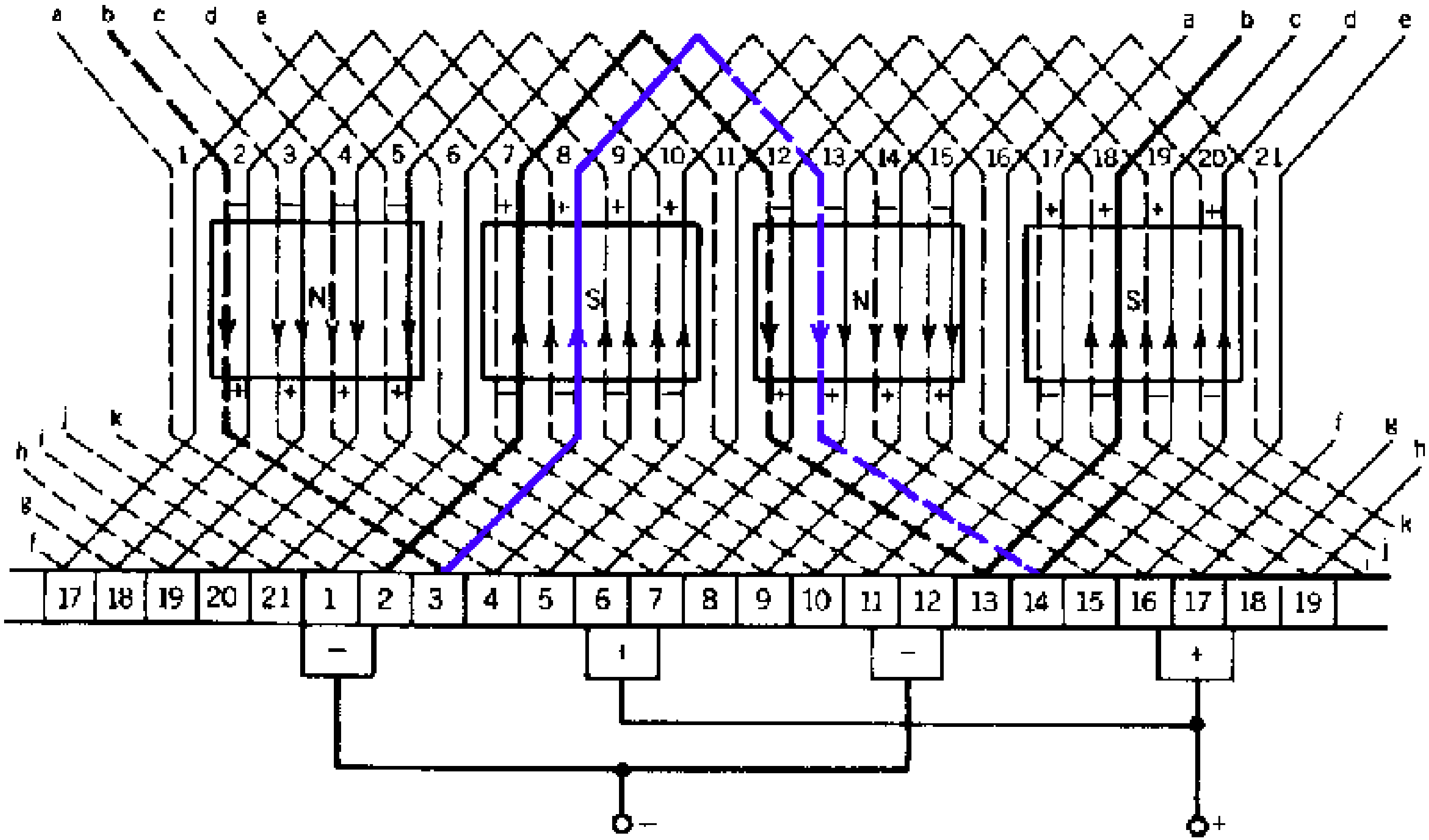
Lap Winding (Fig. 4.17)

- The 2 ends of a coil are connected to adjacent commutator segments.
- The number of brushes is equals to the number of poles.
- The number of parallel paths is equals to the number of poles.
- Each path takes 1/p times the load current (p = no. of poles)

Lap Winding (Fig. 4.17)



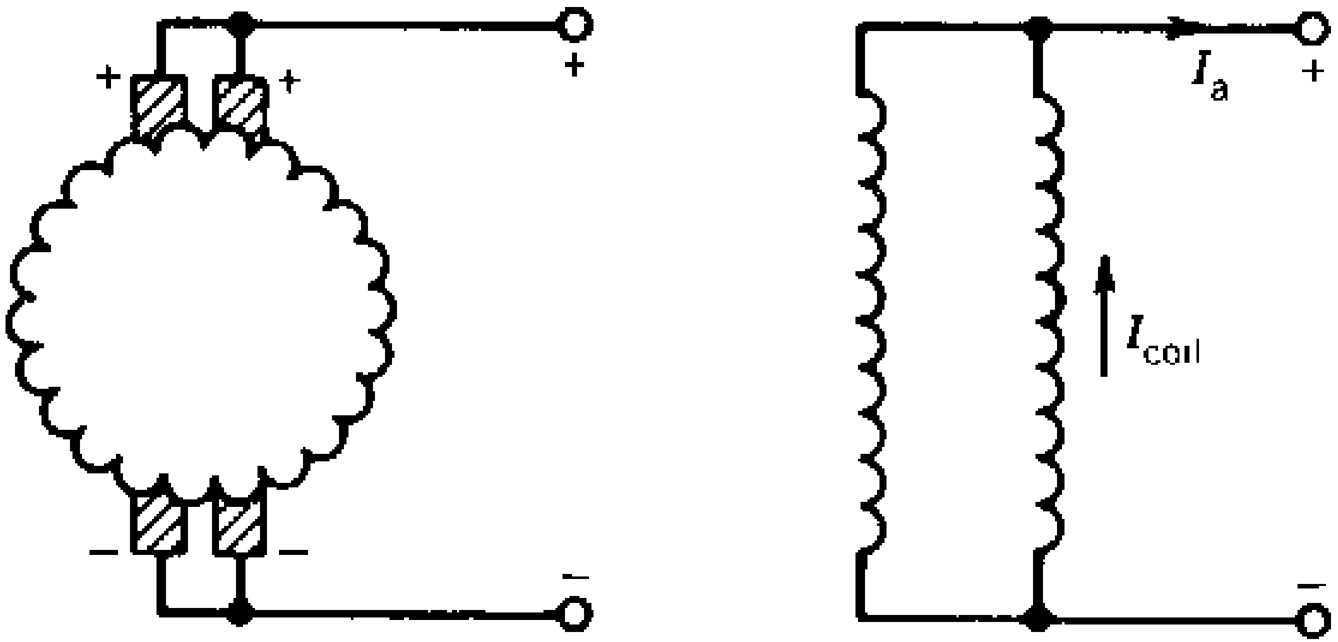
Wave Winding (Fig. 4.18)



Wave Winding (Fig. 4.18)

- The 2 ends of a coil are connected to commutator segments which separated by twice the pole-pitch.
- Only 2 brushes are necessary, irrespective of the number of poles, but 4 or more may be used.
- The number of parallel paths is always 2.
- Each path takes 1/2 of the load current.

Wave Winding (Fig. 4.18)



Example

A 6-pole armature is wound with 498 conductors. The flux and the speed are such that the average emf generated in each conductor is 2V. The current in each conductor is 120A. Find the total current and the generated emf of the armature if the winding is connected (a) wave, (b) lap. Also find the total power generated in each case.

240A, 498V; 720A, 166V; 119.5kW

Armature Induced Voltage

Emf Equation

Let Φ = Total flux per pole in Webers

n = Speed of the armature in rev/sec

p = number of pairs of poles (pole-pair)

Z = Total number of conductors on armature

a = Number of parallel paths through armature

(wave winding, a = 2, lap winding, a = 2p)

Emf Equation

Total number of poles = $2p$

A particular conductor pass $2pn$ poles/sec

Time taken tp pass one pole = $1/2pn$ sec

Emf induced per conductor = $d\Phi/dt$

= $\Phi/1/2pn$

= $2pn\Phi$ volts

On the armature, there are Z/a conductors in series

$\therefore$ Total induced emf, $\boxed{E_a = 2pn\Phi Z/a}$ volts

Armature Voltage (Sect. 4.2.4)

As the armature rotates in the magnetic field produced by the stator poles, voltage is induced in the armature winding:

$E_a = K_a \Phi \omega_m$ (Eq.4.9 P.138)

(where $K_a = Np/\pi a$ or $K_a = Zp/2\pi a$)

N=No.of turns, and

p= No. of poles K_a

E_a= generated voltage (Generator)

E_a= back emf (Motor)

Armature Voltage Ex 1

The wave wound armature of a 6-pole DC generator has 30 slots and in each slot there are 8 conductors. The flux per pole is 0.0174Wb. Calculate the value of the emf generated when the speed of the armature is 1200 rev/min.

(Ans: 250.56V)

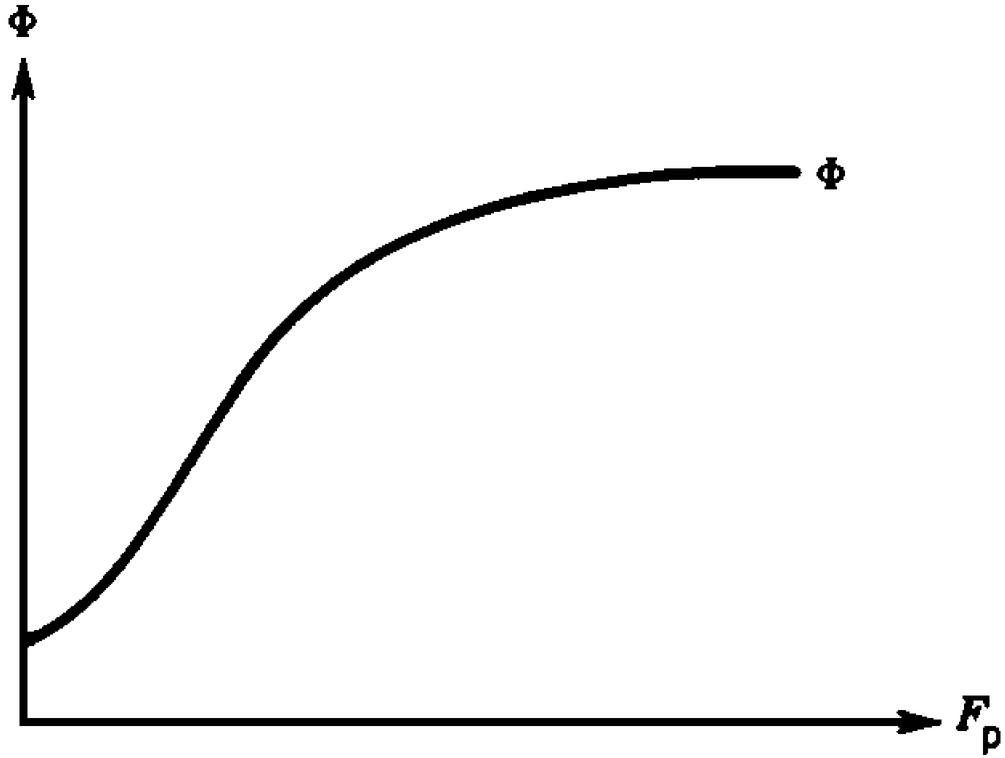
Armature Voltage Ex 2

A lap wound DC generator is to have an output voltage of 500V at 26 rev/s. The armature has 28 slots each containing 12 conductors. Calculate the required value of flux per pole.

(Ans: 0.057Wb)

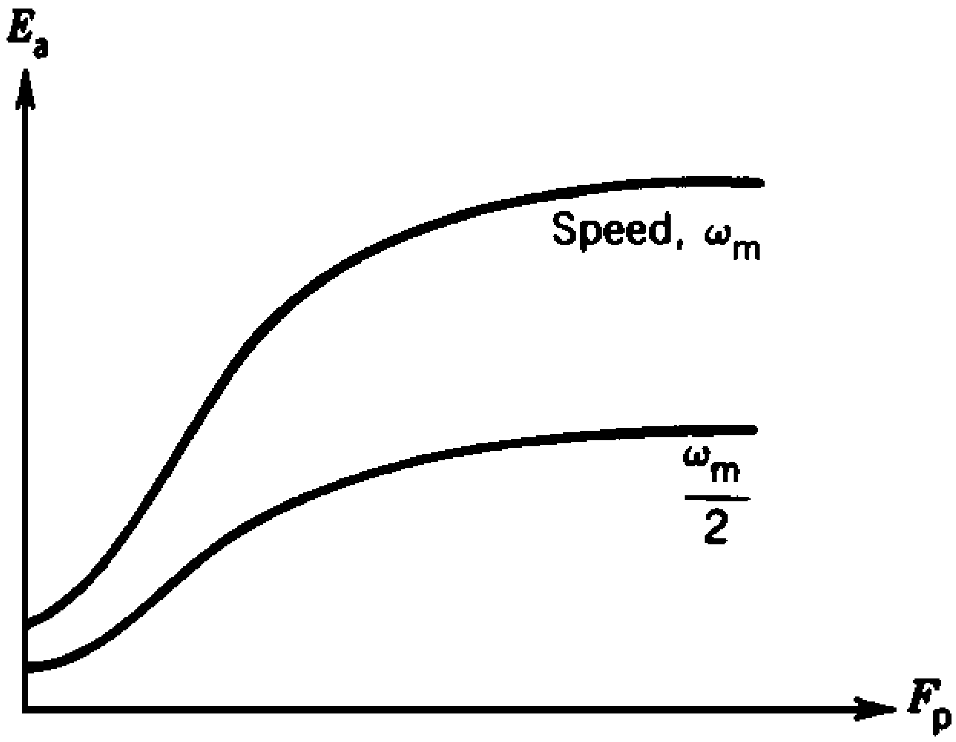
Magnetization Curve (Sect. 4.2.6)

- Flux-mmf relation (Fig. 4.22)



∝ Field Current

Magnetization Curve (Fig.4.23)



Also known as:

- Saturation Curve
- Open-Circuit Characteristic

the magnitude of induced emf is depending on the rotor speed

Electrical Machines 1

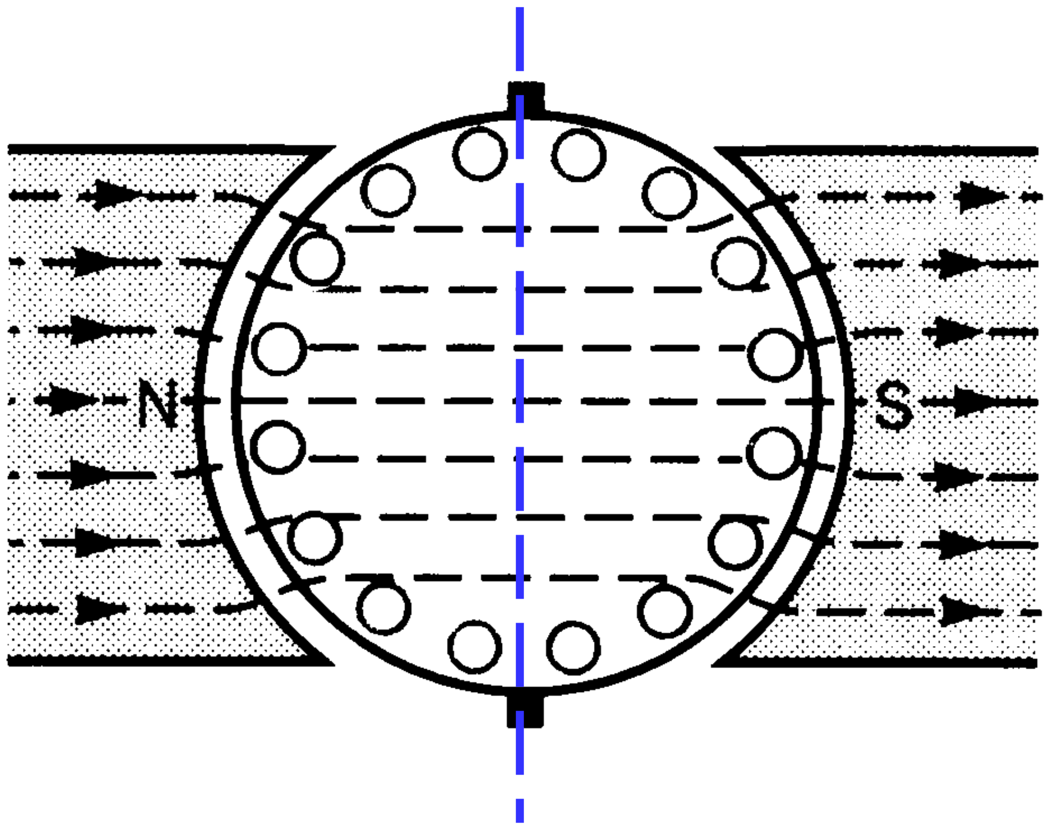
Hour 3

Armature Reaction (P.147 to P.150)

- With no current flowing in the armature, the flux in the machine is established by the mmf produced by the field current.
- However, if the current flows in the armature circuit it produces its own mmf (hence flux) acting along the q-axis.
- Therefore, the original flux distribution in the machine due to the field current is disturbed.

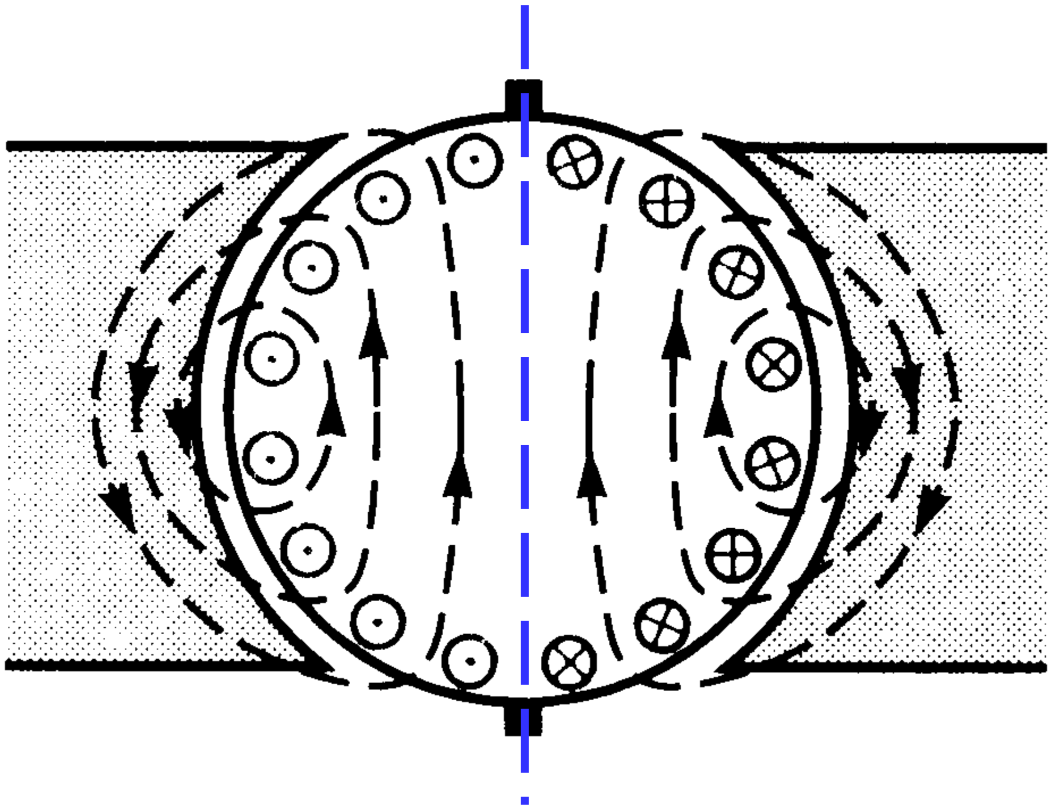
Armature Reaction

1. Evenly distributed flux due to Field Current alone



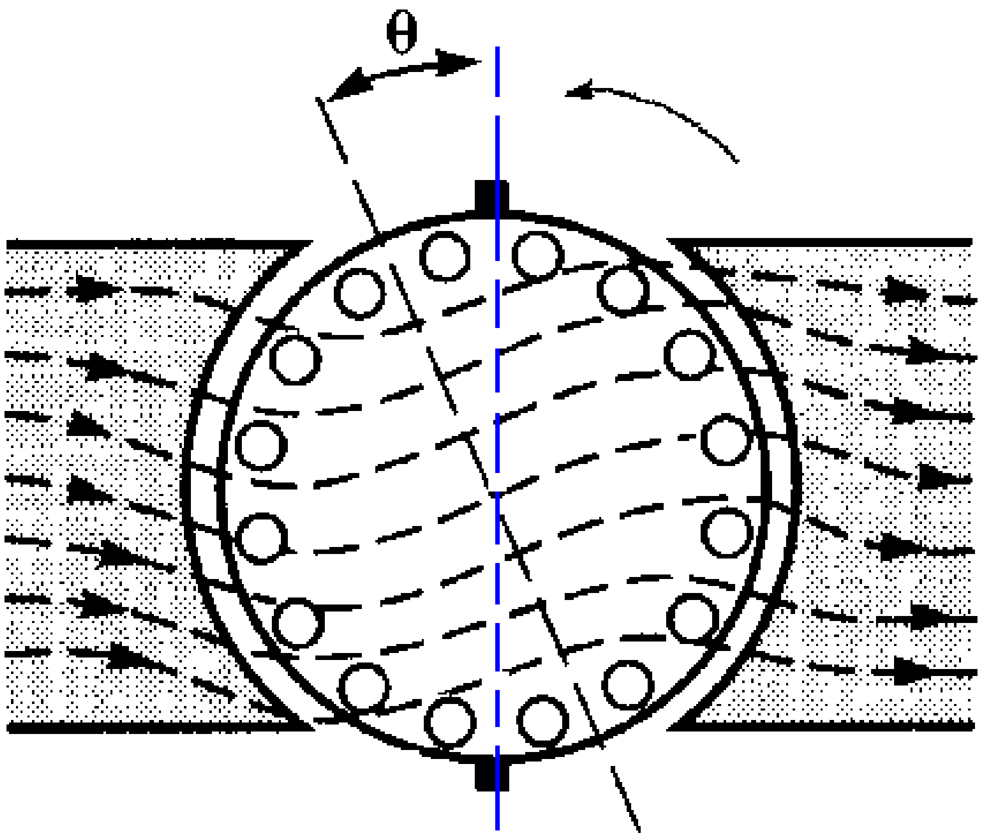
Armature Reaction

2. Flux Distribution due to Armature Current alone



Armature Reaction

3. Overall Flux Distribution (M.N.A. Shifted)



Effects of Armature Reaction

- Distort the air-gap flux pattern of the machine.
- In DC generator, the magnetic neutral axis is being shifted by some angle θ in the direction of rotation.
- The distorted flux density weakening one pole tip and strengthening the other.
- Uneven flux density distribution which will result in a reduction in the total flux (due to magnetic saturation).
- Due to the field is distorted, there is an emf between the commutator segments at the instant when both touch the same brush. This emf generates a brief, high current that causes excessive sparking and arcing as the commutator rotates

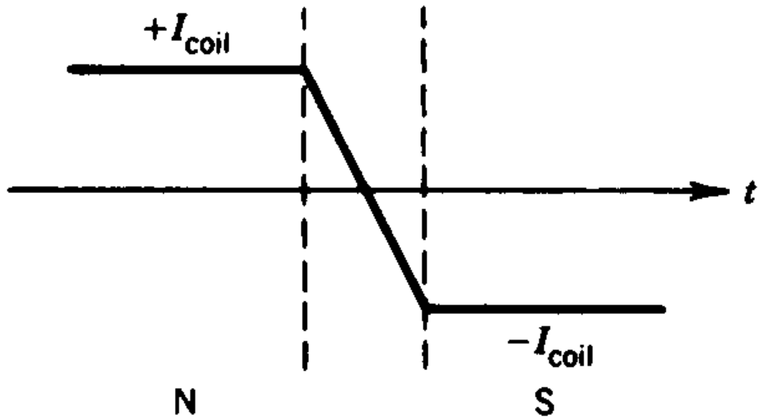
Summary of AR

	Leading Pole-tip	Trailing Pole-tip	Magnetic Neutral Axis
Generator	Weakened	Strengthened	Shifted Forward
Motor	Strengthened	Weakened	Shifed Backward

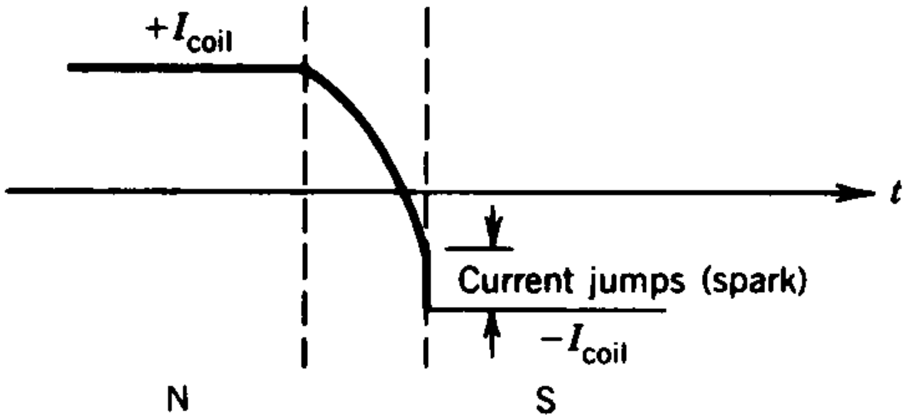
Commutation (Sect 4.3.5)

- Ideal commutation curve [Fig. 4.46(c)].
- 2 reasons for non-ideal commutation:
  - Coil inductance
  - Reactance voltage
- Causes sparking [Fig. 4.46(d)].

Commutation Curve (Fig.4.46c)



Ideal



Actual

Methods of Reducing Sparking

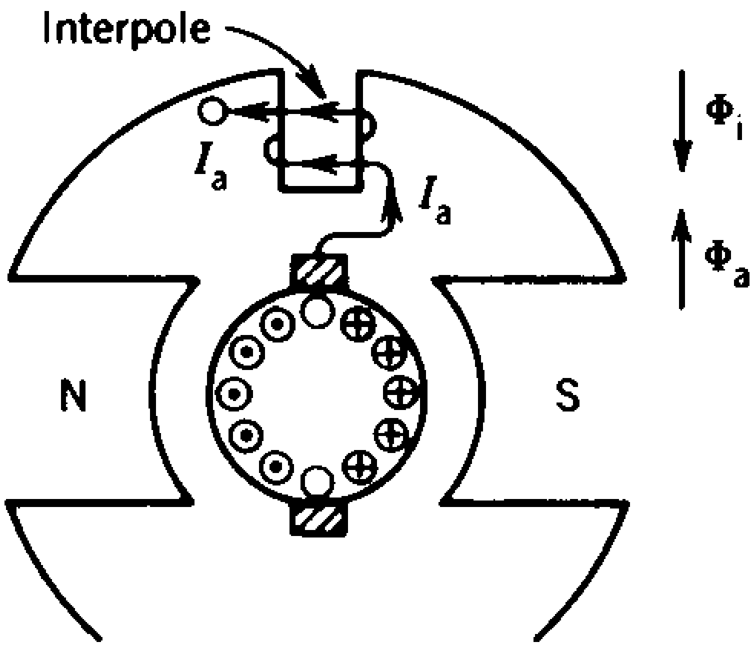
(Remedies for Armature Reaction)

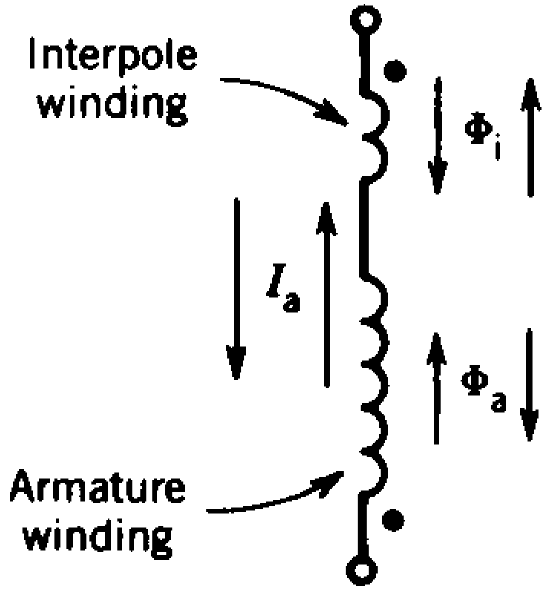
- Use of high-resistance brushes
- Brush Shifting
- Interpoles
- Compensating Winding

Interpoles (Sect 4.3.5)

- Commutation pole.
- Small poles which are situated between the main poles.
- Its winding carries the armature current in such a direction that its flux opposes the q-axis flux produced by the armature current flowing in the armature winding [see Fig. 4.46(e)].
- The net flux in the interpole region is almost zero.

Interpoles (Sect 4.3.5)





Compensating Winding (P.150 to P.151)

- Winding which is fitted in slots cut on the main pole faces.
- They are arranged that the mmf produced by currents flowing in these windings opposes the armature mmf [see Fig. 4.33(a)].
- Compensating winding is connected in series with the armature winding so that its mmf is proportional to the armature mmf [see Fig. 4.33(b)].

Compensating Winding (Fig.4.33)