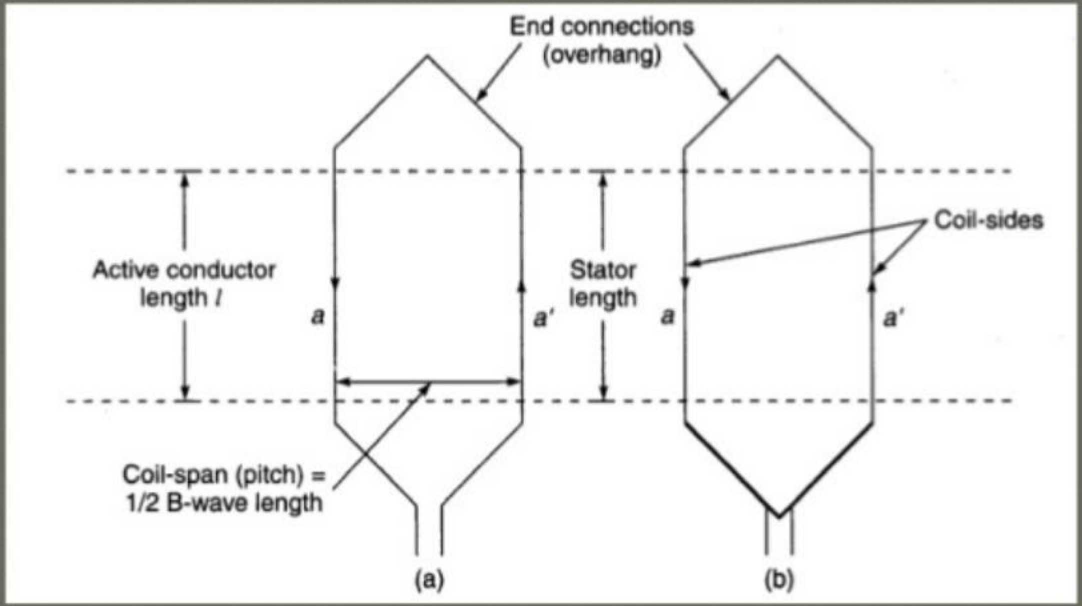
Motores eléctricos

- De corrente contínua (DC)
- De corrente alternada

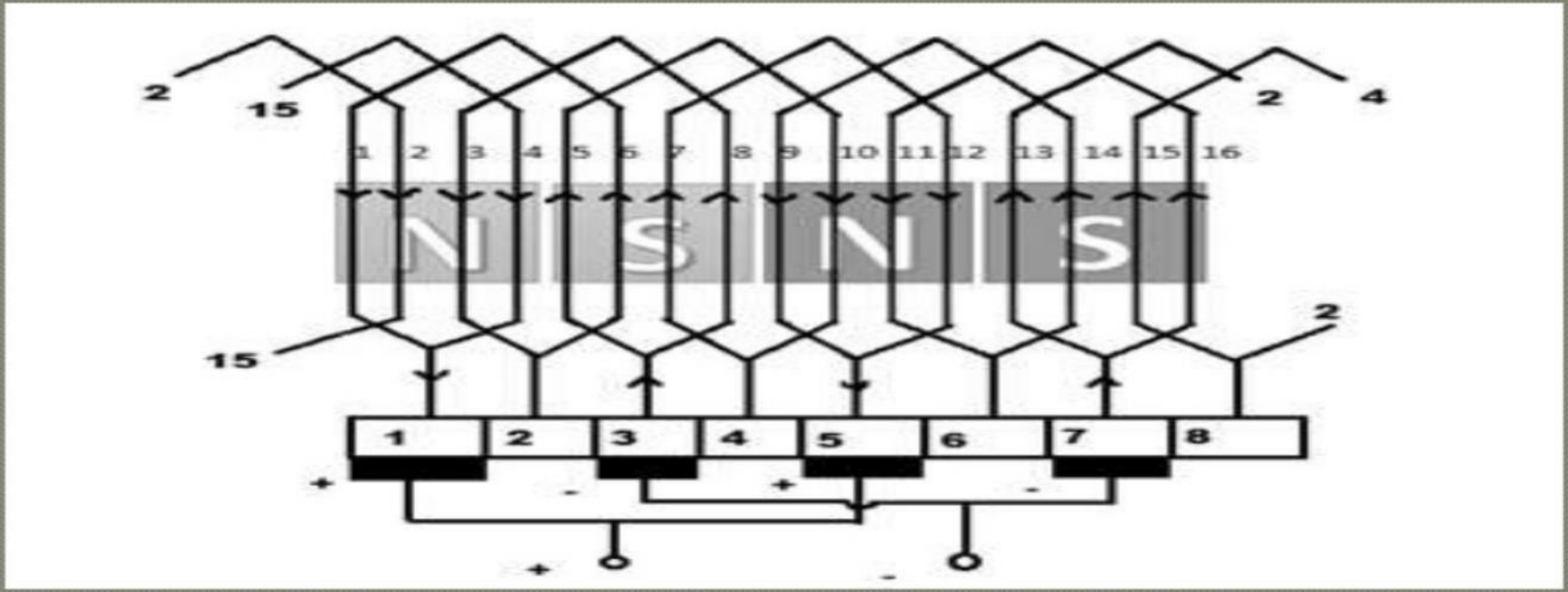
TYPES OF WINDINGS



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.

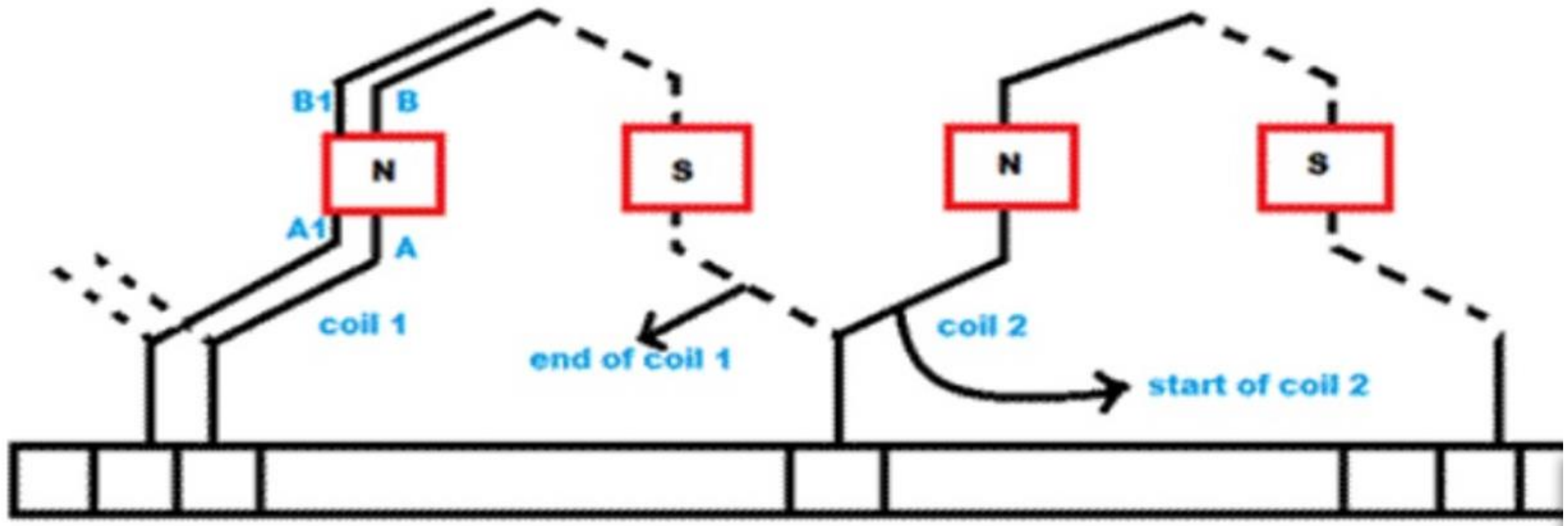
LAP winding

- No. of parallel paths = No. of poles = No. of brushes
- No need of dummy coils
- High current low voltage
- No. of commutator segments =No. of armature slots

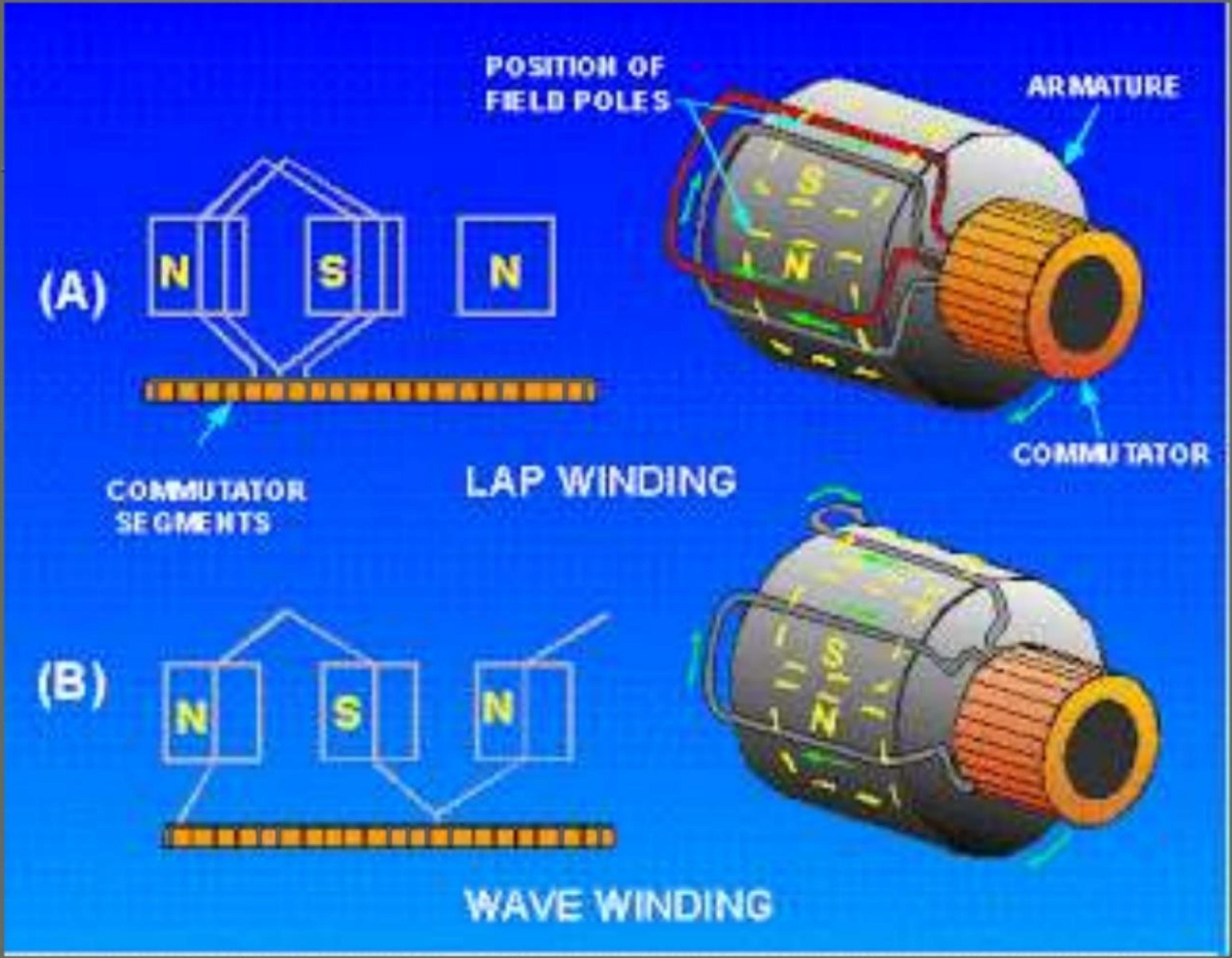


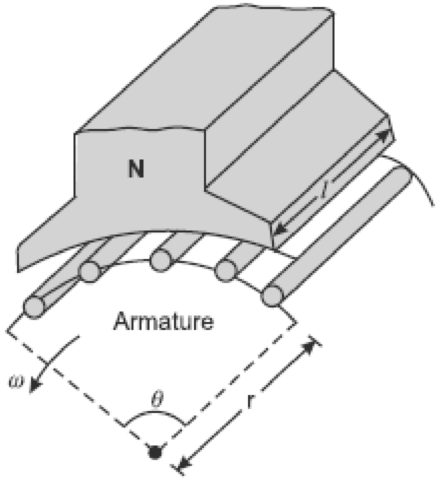
Wave winding

- No. of parallel paths = 2 = No. of brushes
- Dummy coils are required (Mech balance)
- High voltage low current
- No. of commutator segments = No. of



wave winding


POSITION OF FIELD POLES
ARMATURE
(A)
N
S
N
COMMUTATOR
COMMUTATOR SEGMENTS
LAP WINDING
(B)
N
S
N
WAVE WINDING



P = Number of poles of the machine.
ϕ = Flux per pole in Wb
Z = Total number of armature conductors.
N = Speed of armature in *rpm*
A = Number of parallel paths in the armature winding.

Numa revolução o fluxo apanhado por um condutor é

$$= P\phi \text{ Wb}$$

$$e = \frac{P\phi}{t} = \frac{P\phi}{60 / N} = \frac{P\phi N}{60} \text{ volt}$$

$$E = \frac{p\phi N}{60} \times \frac{Z}{A} = \frac{PZ\phi N}{60A} \text{ volt}$$

$$E = \frac{PZ\phi n}{A} \text{ where } n \text{ in speed in } r.p.s.$$

Tempo de uma revolução →

$$n = \frac{N}{60}$$

Para uma dada máquina o nº de polos e nº de condutores por caminho paralelo é constante

$E = K\,\phi\,n$ where $K = \dfrac{PZ}{A}$ is a constant or $E \propto \phi\,n$

$E = K_1\,\phi\,N$ where $K_1 = \dfrac{PZ}{60A}$ is another constant or $E \propto \phi\,N$

$E \propto \phi\,\omega$ where $\omega = \dfrac{2\pi N}{60}$ is the angular velocity in radian/second

Conclui-se que a força electromotriz induzida é proporcional ao fluxo por polo e à velocidade de rotação

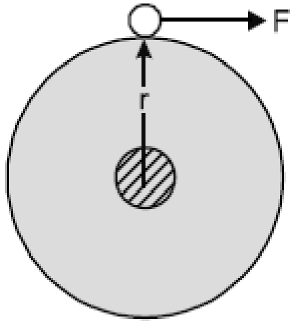
Se a máquina trabalha como gerador

$$E_g = \frac{PZ\phi N}{60A} \text{ volt.}$$

Se a máquina trabalha como motor

$$E_b = \frac{PZ\phi N}{60A} \text{ volt.}$$

Binário



Average force on each conductor, $F = Bil$ newton

Torque due to one conductor $= F \times r$ newton metre

Total torque developed in the armature,

$$T = ZFr \text{ newton metre}$$

or $$T = ZB\,i\,l\,r$$

$$E_g = \frac{PZ\phi N}{60A} \text{ volt.}$$

$$EI_a = \omega T \quad \text{or} \quad EI_a = \frac{2\pi N}{60} \times T$$

or $$\frac{\phi ZNP}{60A} \times I_a = \frac{2\pi N}{60} \times T \quad \text{or} \quad T = \frac{PZ\phi N}{2\pi A} \text{Nm}$$

P = No. of poles.
ϕ = Flux per pole in Wb.
r = Average radius of armature in metre.
l = Effective length of each conductor in metre.
Z = Total armature conductors.
I_a = Total armature current.
A = No. of parallel paths.

An eight pole lap wound DC generator has 960 conductors, a flux of 40 m Wb per pole and is driven at 400 rpm. Find OC emf.

Solution:

$$\text{Open circuit emf, } E_g = \frac{\phi ZNP}{60A}$$

where, $\phi = 40$ m Wb $= 40 \times 10^{-3}$ Wb; $Z = 960$; $N = 400$ rpm; $P = 8$

$$A = P = 8 \text{ (lap winding)}$$

$$\therefore \quad E_g = \frac{40 \times 10^{-3} \times 960 \times 400 \times 8}{60 \times 8} = \mathbf{256\ V}\ (\textit{Ans.})$$

The induced emf in a DC machine is 220 volts at a speed of 1500 rpm. Calculate the electromagnetic torque developed at an armature current of 20 A.

Solution:

Here $E = 220$ V; $N = 1500$ rpm; $I_a = 20$ A

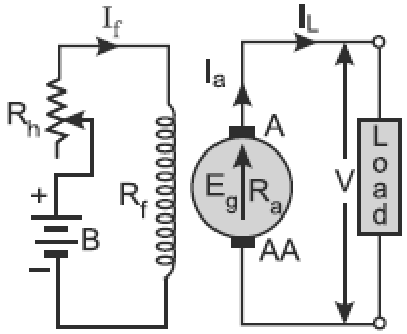
Power developed in the armature

$$\omega T_e = E_b I_a$$

or $$T_e = \frac{E_b I_a}{\omega} = \frac{E_b I_a}{2\pi N / 60} = \frac{220 \times 20 \times 60}{2\pi \times 1500} = \mathbf{23.87\ Nm}\ (Ans.)$$

1. Separately excited DC generators
2. Self excited DC generators – these are further classified as:
    (*i*) Shunt wound DC generators
    (*ii*) Series wound DC generators
    (*iii*) Compound wound DC generators.
        (*a*) Long shunt compound wound generators
        (*b*) Short shunt compound wound generators.

Excitação separada



$$I_a = I_L.$$

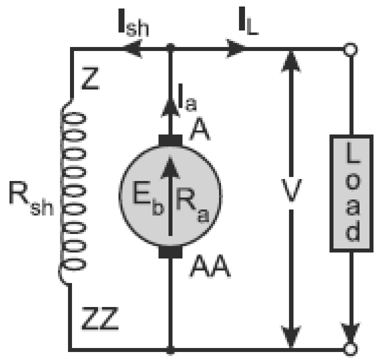
Terminal voltage, $V = E_g - I_a R_a$

If contact brush drop per brush (υ_b) is known,

$$V = E_g - I_a R_a - 2\,\upsilon_b.$$

Power developed $= E_g I_a$;

Power output $= VI_L = VI_a$



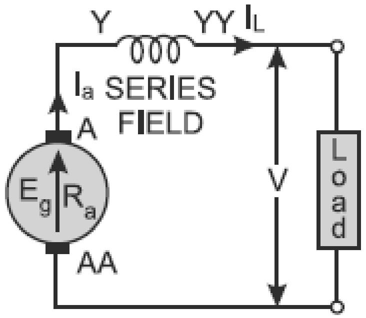
$I_{sh} = V/R_{sh}$

Armature current, $I_a = I_L + I_{sh}$

Terminal voltage, $V = E_g - I_a R_a$

Including brush contact drop, $V = E_g - I_a R_a - 2\upsilon_b$

Power developed $= E_g I_a$; Power output $= VI_L$



Series field current, $I_{se} = I_L = I_a$ ...(4.21)

Series field winding resistance = R_{se}

Terminal voltage, $V = E_g - I_a R_a - I_{se} R_{se} = E_g - I_a (R_a + R_{se})$

Including brush contact drop, $V = E_g - I_a (R_a + R_{se}) - 2\upsilon_b$

Power developed = $E_g I_a$; Power output = $VI_L = VI_a$

Regulação de tensão num gerador shunt

Generated voltage or voltage at the terminals at no-load

$$E_g = E_0 \frac{P\phi ZN}{60A}$$

At full load, the terminal voltage is

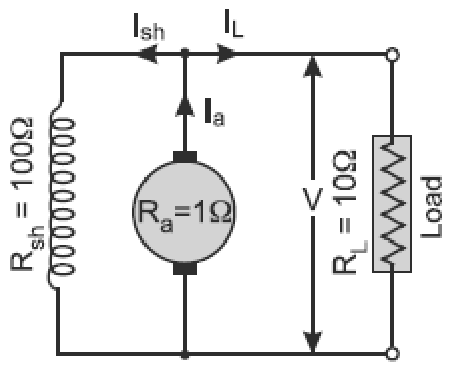
$$V = E_g - I_{a(fl)} R_a - V_b$$

Where, $I_{a(fl)}$ = Full-load armature current

R_a = Armature resistance

V_b = Total voltage drop at the brushes

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



The armature of a four-pole DC shunt generator has 378 wave connected conductors. The armature and shunt winding resistance of the generator is 1 ohm and 100 ohm respectively. The flux per pole is 0.02 Wb. If a load resistance of 10 ohm is connected across the armature terminals and the generator is driven at 1000 rpm, calculate the power absorbed by the load.

$$\text{Generated emf, } E_g = \frac{PZ\phi N}{60\,A} = \frac{4 \times 378 \times 0 \cdot 02 \times 1000}{60 \times 2} = 252\text{ V}$$

$$\text{Line current, } I_L = \frac{V}{R_L} = \frac{V}{10} \text{ (where } V \text{ is terminal voltage)}$$

$$\text{Shunt field current, } \quad I_{sh} = \frac{V}{R_{sh}} = \frac{V}{100}$$

$$\text{Armature current, } \quad I_a = I_L + I_{sh} = \frac{V}{10} + \frac{V}{100} = (0 \cdot 11\,V)$$

$$\text{Using the relation, } \quad E_g = V + I_a R_a;$$

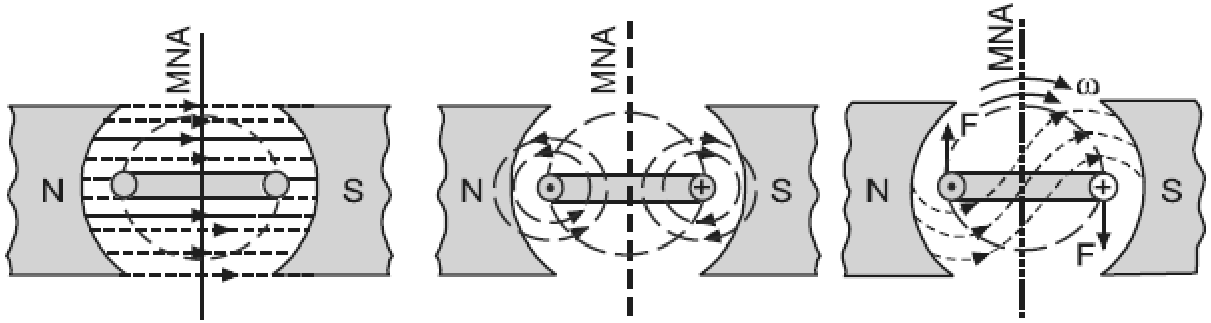
$$252 = V + 0{\cdot}11\,V \times 1{\cdot}0$$

$$\therefore \quad \text{Terminal voltage, } \quad V = 227 \text{ volt}$$

$$\therefore \quad \text{Load current, } I_L = \frac{V}{R_L} = \frac{227}{10} = \mathbf{22{\cdot}7\ A}$$

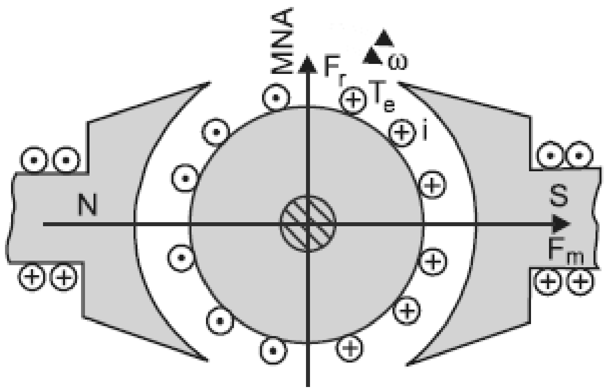
Power absorbed by the load, $P = VI_L = 227 \times 22{\cdot}7 =$ **5·153 kW** (*Ans.*)

Motores DC

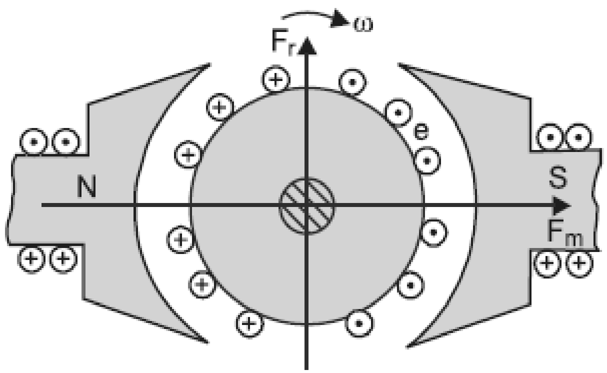


(a) Main field (b) Field due to current carrying coil (c) Resultant field

O comutador

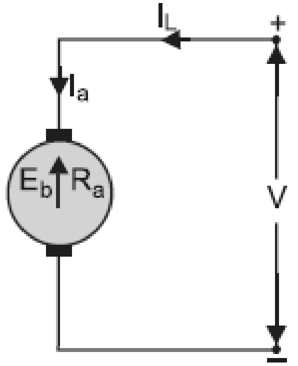


(a) Torque development due to alignment of rotor field with main field



(b) Production of E_b

$$E_b = \frac{PZ\phi N}{60\,A} \qquad \Longrightarrow \qquad E_b \propto \phi N$$



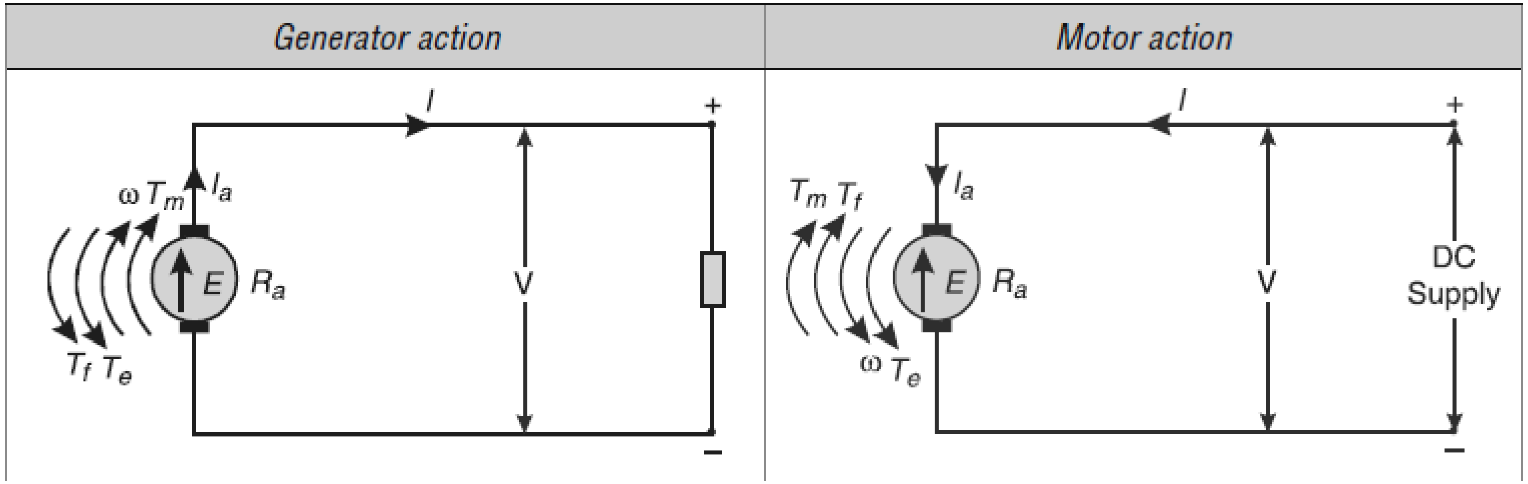
$$E_b = V - I_a R_a.$$

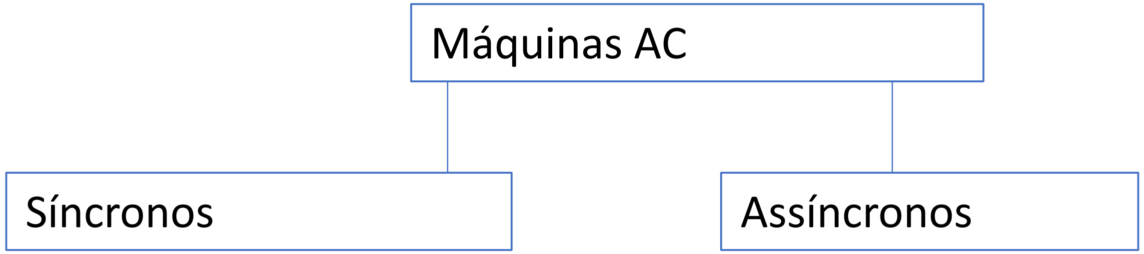
$$I_a = \frac{V - E_b}{R_a}$$

Se o motor for sujeito a um esforço com uma carga, a velocidade diminui, o que faz reduzir a força contra-electromotriz, pelo que a corrente fornecida ao motor aumenta binário

$$EI_a = \omega T_e \qquad \text{or} \qquad EI_a = \frac{2\pi N}{60} \times T_e$$

$$\text{or} \qquad \frac{\phi\ ZNP}{60A} \times I_a = \frac{2\pi N}{60} \times T_e \qquad \text{or} \qquad T_e = \frac{PZ\phi N}{2\pi A}\,\text{Nm}$$




Máquinas AC
Síncronos
Assíncronos

$$N_S = \frac{120f}{P} \quad \text{or} \quad f = \frac{PN_S}{120}$$

where N_S is the synchronous speed in *rpm;* f is the supply frequency and P is the number of poles of the machine.

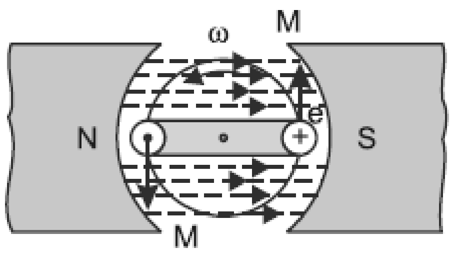


Fig. 6.1 Generator principle

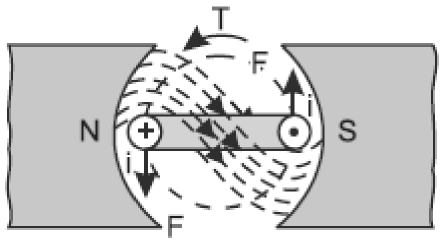
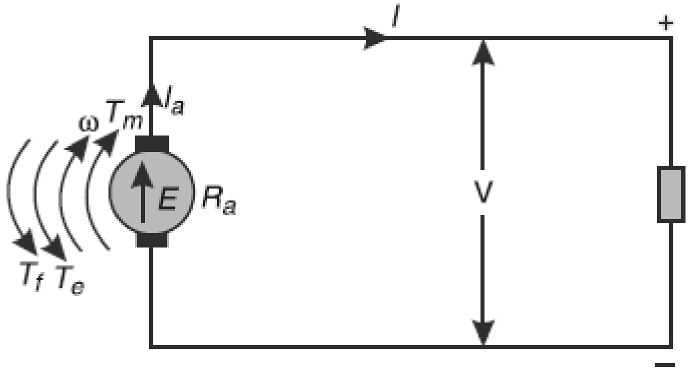
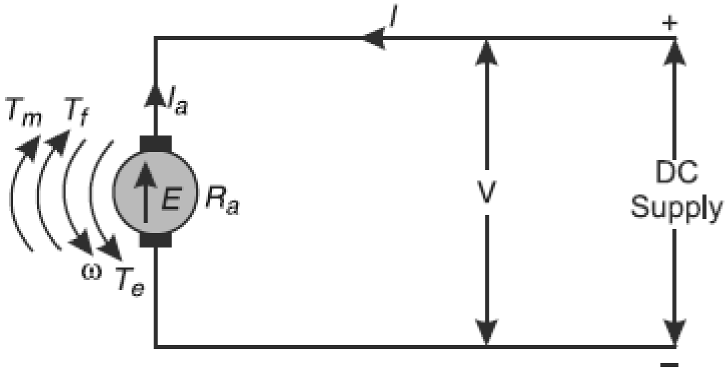
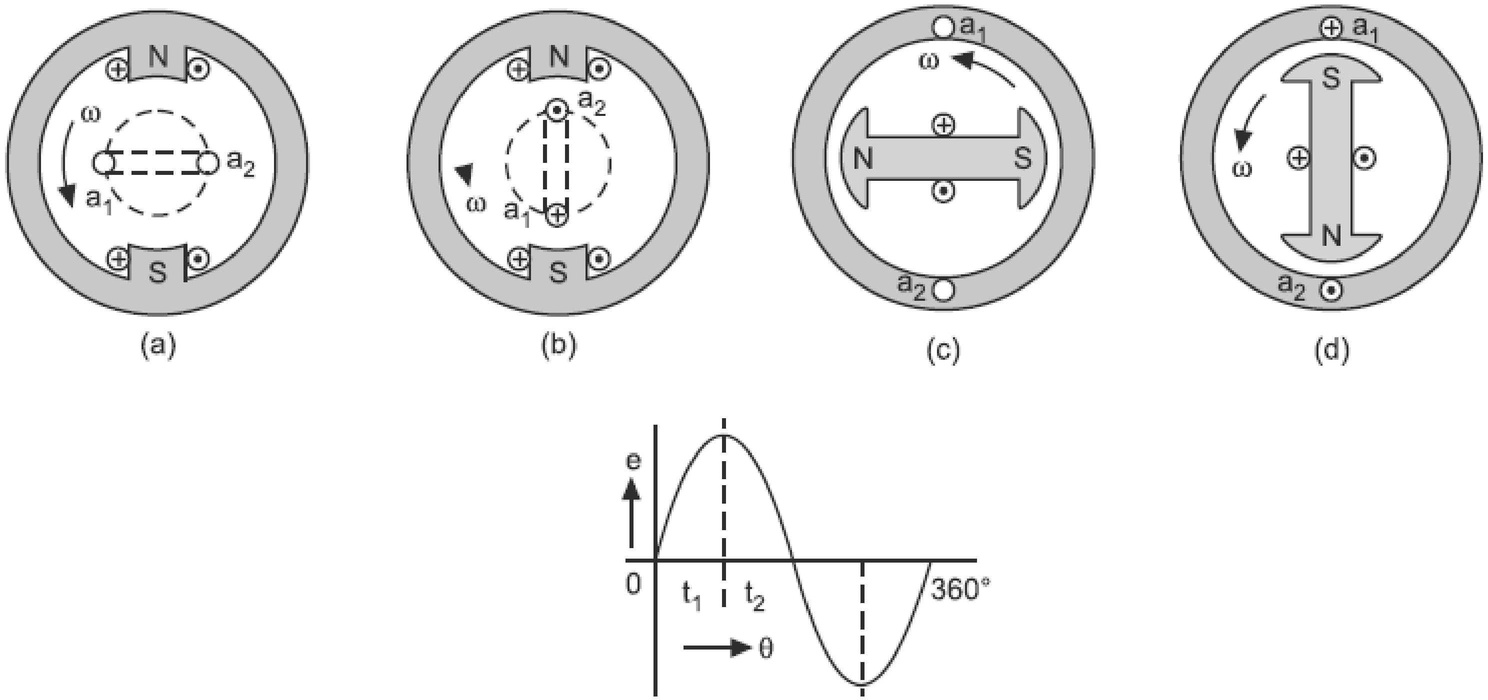


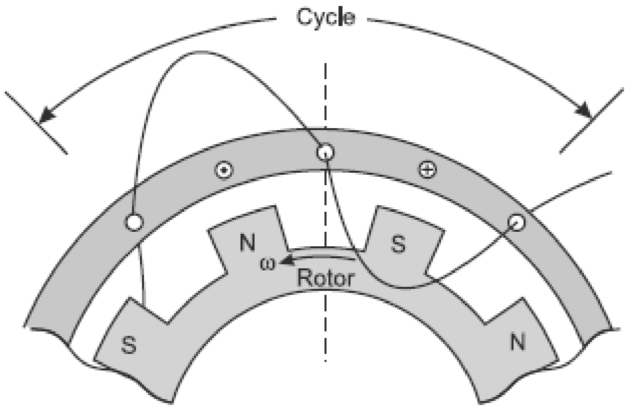
Fig. 6.2 Motor principle

Generator action	*Motor action*
 **Fig. 6.3** Generator action	 **Fig. 6.4** Motor action
1. In generator action, the rotation is due to mechanical torque, therefore, T_m and ω are in the same direction.	**1.** In motoring action, the rotation is due to electromagnetic torque, therefore, T_e and ω are in the same direction.
2. The frictional torque T_f acts in opposite direction to rotation ω.	**2.** The frictional torque T_f acts in opposite direction to rotation ω.
3. Electromagnetic torque T_e acts in opposite direction to mechanical torque T_m so that $\omega T_m = \omega T_e + \omega T_f$.	**3.** Mechanical torque T_m acts in opposite direction to electromagnetic torque T_e so that $\omega T_e = \omega T_m + \omega T_f$.
4. In generator action, an emf is induced in the armature conductors which circulates current in the armature when load is connected to it. Hence, *e* and *i* both are in the same direction.	**4.** In motoring action, current is impressed to the armature against the induced emf (*e*), therefore current flows in opposite direction to that of induced emf.
5. In generator action, $E > V$	**5.** In motor action, $E < V$
6. In generator action, the torque angle θ is leading.	**6.** In motoring action, the torque angle θ is lagging.
7. In generator action, mechanical energy is converted into electrical energy.	**7.** In motoring action, electrical energy is converted into mechanical energy.

Coo se gera uma tensão induzida variável (sinusoidal)



Relação entre frequência, velocidade de rotação e número de polos



$\therefore$ No. of cycle made per revolution $= \frac{P}{2}$

No. of revolutions made per second $= \frac{N_s}{60}$

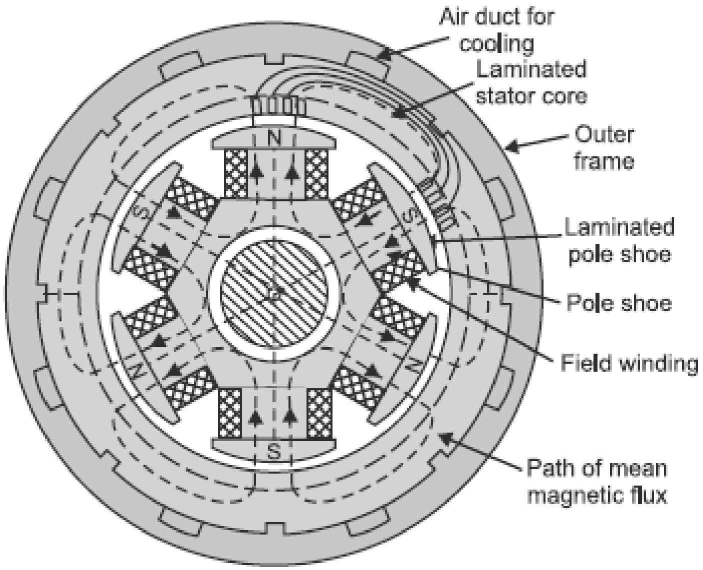
$\therefore$ No. of cycles made per second = No. of cycles/revolution × No. of revolutions/s

$$f = \frac{P}{2} \times \frac{N_s}{60} = \frac{PN_s}{120} \text{ cycles/s or Hz}$$

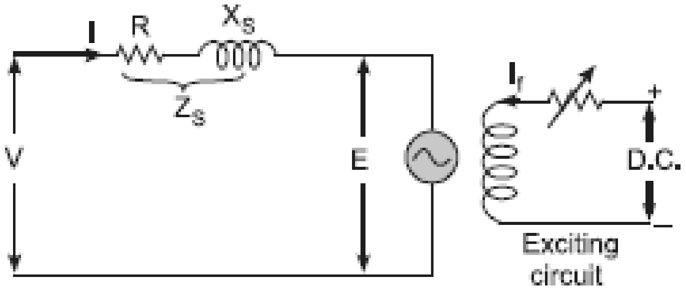
Rotor e estator

O campo magnético na máquina pode estar tanto no estator como no rotor

Nas máquinas síncronas o campo de excitação está normalmente no rotor e não no estator



Circuito equivalente de um motor síncrono



V = Voltage applied to the armature (phase value)

I = armature current (phase value)

R = effective armature resistance in ohm per phase

X_S = synchronous reactance per phase

E = excitation voltage (phase value)

Z_S = synchronous impedance per phase

I_f = exciting or field current

where, $\overline{Z}_S = R + jX_S = \sqrt{R^2 + X_S^2} \angle \tan^{-1} \dfrac{X_S}{R}$ ohm

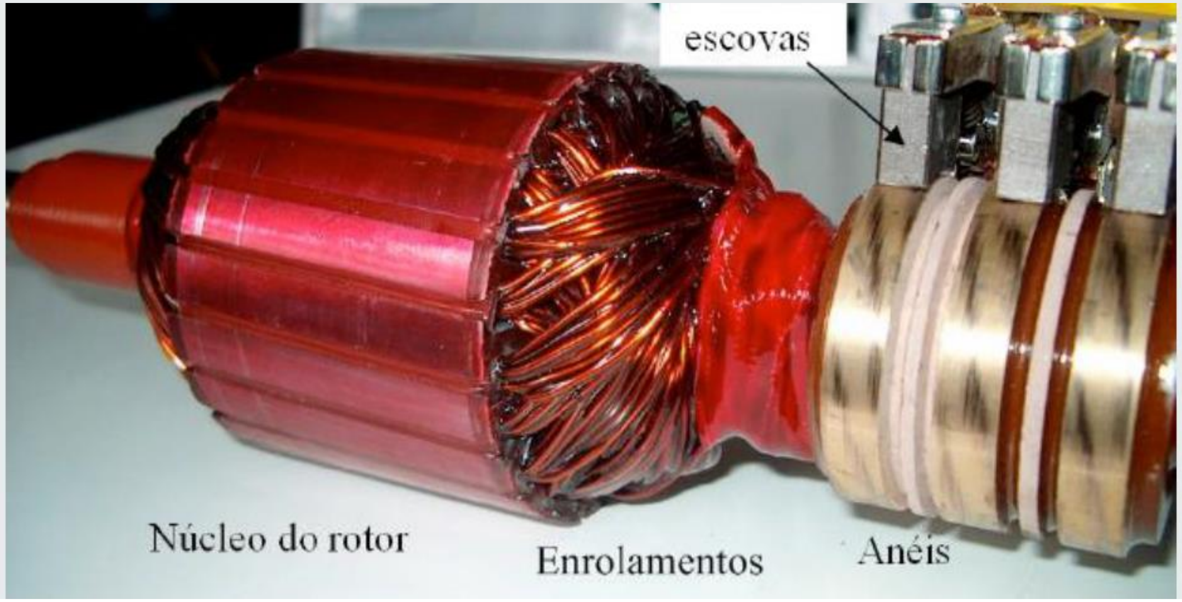
$$\overline{V} = \overline{E} + \overline{I}\overline{Z}_s = \overline{E} + \overline{I}(R + jX_S) = \overline{E} + \overline{I}R + j\overline{I}X_S$$

$$\overline{E} = \overline{V} - \overline{I}\overline{Z}_s = \overline{V} - \overline{I}(R + jX_S) = \overline{V} - \overline{I}R - j\overline{I}X_S$$

Máquinas assíncronas

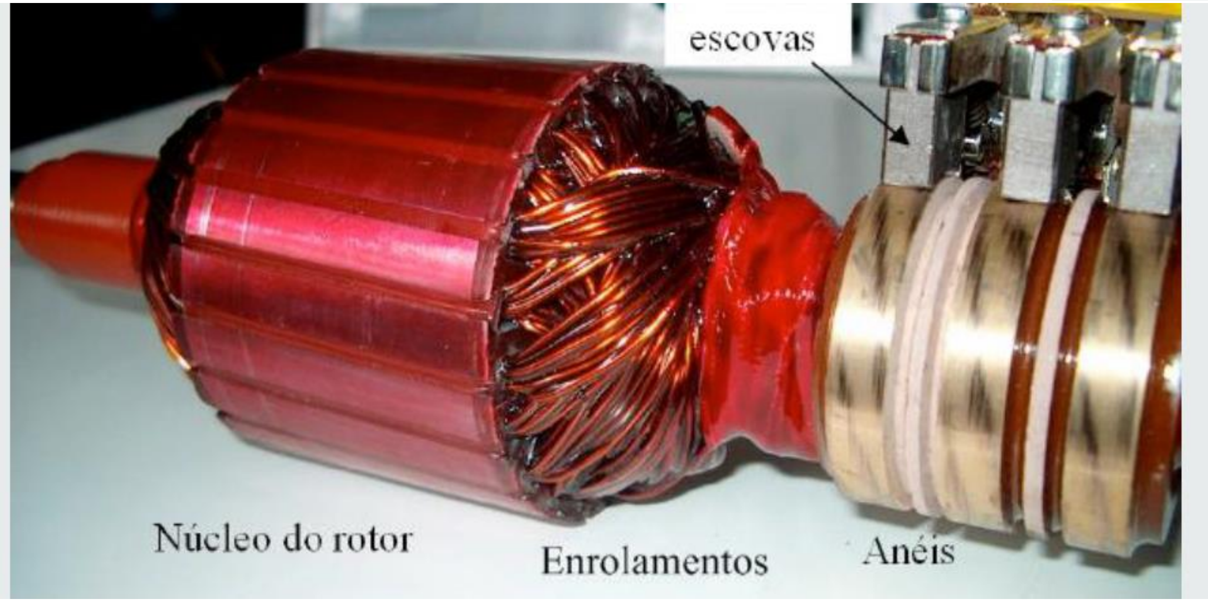
O estator é alimentado com corrente trifásica

Máquinas Assíncronas
- Rotor em gaiola
  - simples
  - dupla
  - de barras profundas
- Rotor bobinado



Normalmente o rotor é trifásico encontrando-se os seus enrolamentos ligados em **estrela ou em triângulo**.

A ligação ao exterior é obtida através de 3 escovas que fazem contacto com cada um destes anéis.



Tal como no caso do transformador, as grandezas do rotor podem ser reduzidas ao estator e vice-versa.

Classification of electrical machines