# Three-phase asynchronous motor

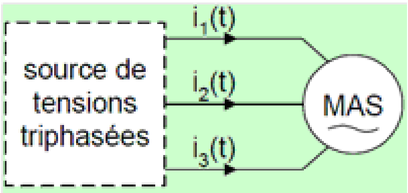
The term **asynchronous** comes from the fact that the speed of these machines **is not necessarily proportional** to the frequency of the currents flowing through them.
**Originally it was a machine used as an engine only, which is what we are studying here.**

**Constitution**

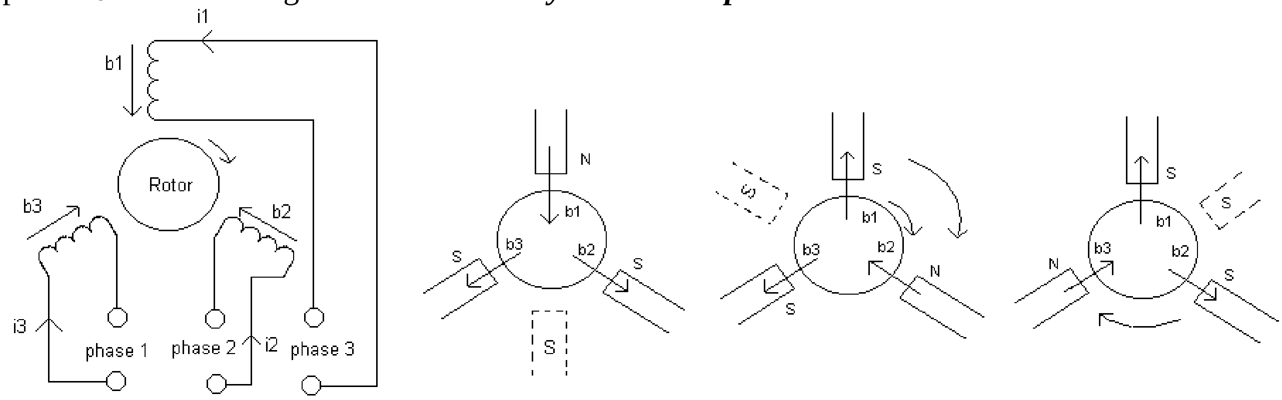
The inductor is located at the stator, the armature at the rotor. **There is no connection between the stator and the rotor** .
- The stator , identical to that of the synchronous machine, is connected to the network or to a speed variator .
- The rotor is made up of short-circuited conductors.

There are two types of rotors:
- "Squirrel cage" rotor (robust and inexpensive): made up of identical metal bars, parallel to the axis of rotation. On each side, the ends of these bars are joined together by low-resistance metal rings. The assembly therefore forms a cage called: "squirrel cage"
- Wound rotor

**Fonctionnement**




To obtain a rotating magnetic field, the three coils fixed in the stator, geometrically offset by 120°, are traversed by alternating currents of pulsation ω also phase-shifted by 120°.
The currents being alternating, we will have periodically for each coil the north and south poles of the magnetic field which will reverse:
Note: To change the direction of rotation, simply swap 2 phases.
The rotation frequency of this field is imposed by the frequency f ( $\omega = 2\pi f$) of the stator currents, that is, its rotation speed is proportional to the frequency of the power supply.
The speed $n_s$ of this rotating field is called ***the synchronous speed***




The rotor winding is therefore subjected to flux variations (of the rotating stator magnetic field). An induced electromotive force appears which creates rotor currents. These induced currents are responsible for the appearance of a torque which tends to set the rotor in motion in order to oppose the flux variation: **Lenz's law** .
The rotor therefore begins to turn in an attempt to follow the stator field.
Each stator coil has two magnetic poles = 1 dipole; therefore the number of dipoles p = 1
But we can build coils with 2 pairs of poles (p = 2) or more…
$\Omega s$ being the rotational pulsation of the magnetic field = synchronism pulsation = $2\pi . n_s$
So generally speaking $\omega = p\,\Omega s = 2.\pi.f = p.\,2\pi.n_s$ from which $n_s (tr/s) = f (Hz) / p$
If we call $\Omega$ the rotor rotation speed in rd/s = $2\pi.n$ with n = rotor rotation speed in rpm

**Note: no-load $\Omega = \Omega s$ ; Load $\Omega < \Omega s$ the machine operates as a motor**

**Slide**

The g slip measures the relative deviation between the machine rotation speed and the synchronous speed:

$g = (n_s - n)/n_s = (\Omega_s - \Omega)/\Omega_s$ from which $n = n_s.(1-g)$

• Example: Consider a three-phase network ( f = 50 Hz) supplying a motor with three pairs of poles (p = 3) 6 poles:

$n_s = f/p$ 50/3 = 16.7 rpm = 1000 rpm

At rated load, this engine runs at 950 rpm: $g_N$ = (1000 - 950)/1000 = 0.05 = **5%**

No load (no load), n ≈ 1000 rpm: g no load ≈ **0%**

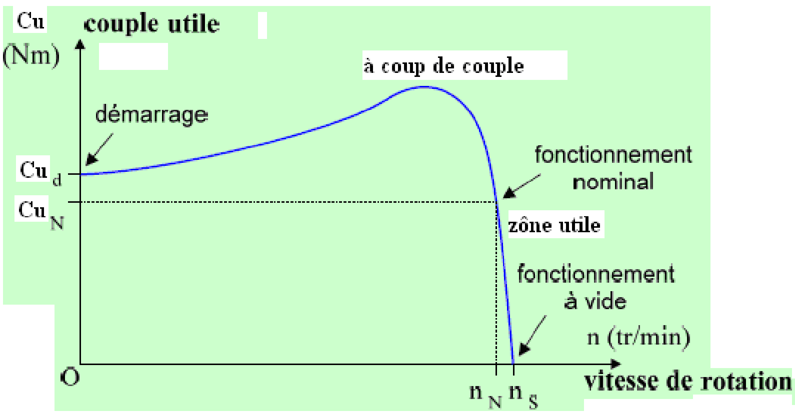
At startup ( n = 0): g = 1 (100%)

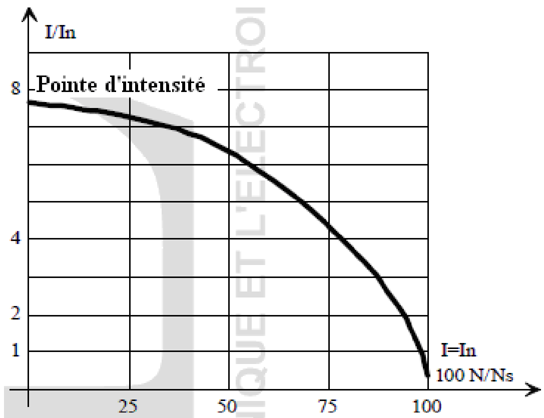
• Notes In normal operation, slip does not exceed a few percent.

When no-load, an asynchronous motor runs at almost synchronous speed.

### Mechanical characteristic Cu(n)

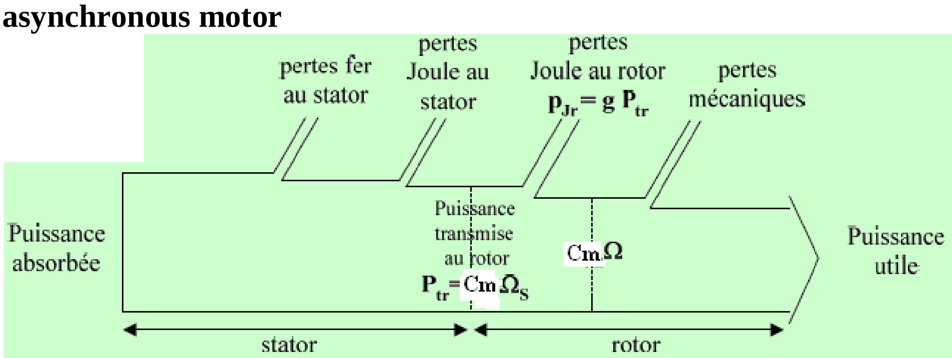
The **characteristic** of the torque that this machine provides shows a maximum called **torque jerk** at start-up (annoying for the driven mechanics) which corresponds to a **peak intensity** of 5 to 10 times In harmful to the power supply network. It will therefore be necessary to reduce it. To do this, a **starting system is used** which will adapt the voltages applied to the machine in order to limit this current.




Example: starting under reduced voltage, or by autotransformer, or star-delta…..

### Power balance of asynchronous motor




$P_1$ = Input electrical power (absorbed): = $\mathbf{P_a = UI\sqrt{3}\cos\varphi}$

U: phase-to-phase voltage in volts; I: intensity in a line wire, in amperes

$P_{tr}$ = electromagnetic power transmitted from the stator to the rotor = $P_a$ – stator losses = $C_m \Omega_s$

$C_m$ : electromagnetic torque, $\Omega_s$ = synchronous speed of the magnetic field in radians per second

$P_2$ = Mechanical power output = $P_u = C_u . \Omega = C_u 2\pi n$ = mechanical power in Watt

Cu: useful engine torque in newton meters

Ω: rotor speed in radians per second.

• Joule losses at the rotor: $P_{Jr} = P_{tr} - C_m . \Omega = C_m (\Omega_S - \Omega) = g C_m \Omega_S$ ; $\mathbf{P_{Jr} = g P_{tr}}$

• iron losses are mainly located in the stator (they are negligible in the rotor).

$P_2 = \mathbf{P_u = C_u \Omega = P_a}$ **- Losses**

$$\text{Rendement} \quad \eta = \frac{P_u}{P_a} = \frac{\sqrt{3}UI\cos\varphi - \text{Pertes}}{\sqrt{3}UI\cos\varphi} = \frac{Cu\ \Omega}{Cu\ \Omega + \text{Pertes}} = \frac{Cu\ \Omega}{\sqrt{3}UI\cos\varphi}$$

**Losses = Pferstator + PJstator + PJrotor + Pmechanics**

The only disadvantage of the **asynchronous motor** is the reactive energy, always consumed to magnetize the air gap.

## Exercises on the asynchronous motor

**Exercise 1**
An asynchronous motor runs at 965 rpm with a slip of 3.5%.
Determine the number of poles of the motor knowing that the network frequency is f = 50 Hz.

**Correction 1**

$g = (n_s - n)/n_s =$ hence $n = n_s.(1-g)$ $n_s = n/1-g = 965/(1-0.035) = 1000$

Number of pole pairs: $p = f / n_s = 50 / (1000 / 60) = 3$ 6 poles

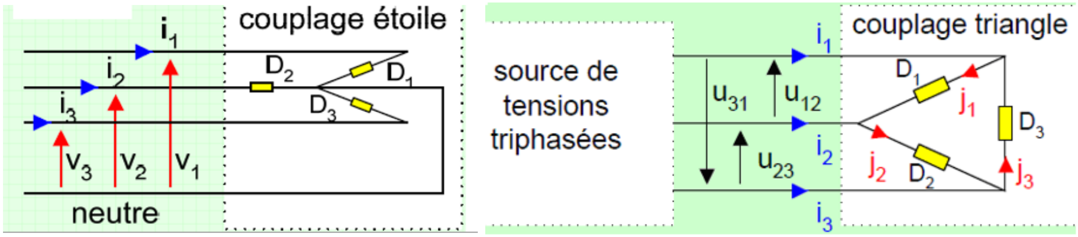
**Exercise 2**
The windings of a three-phase asynchronous motor are connected in delta.
The resistance of a winding is R = 0.5 Ω , the line current is I = 10 A.
Calculate the Joule losses in the stator.

**Correction 2**

Joule losses in the stator $3RJ^2 = RI^2 = 0.5 \times 10^2 = 50$ W

**Exercise 3**
The voltages indicated on the nameplate of a three-phase motor are: 400 V / 690 V 50 Hz
(this means that the nominal voltage across a winding is 400 V).
**1-** What should be the motor coupling on a 230 V / 400 V three-phase network?
**2-** And on a three-phase 400 V / 690 V network?

**Correction** 3




400V/690V (This means that the rated voltage across one winding is 400V and the rated voltage across two windings is 690V both voltages are three phase)

**1-**
**230/400 V network 230 single voltage 400 compound voltage**

Triangle coupling

2-
**400/690 V network 400 single voltage 690 compound voltage**

Star coupling

**Exercise 4**
The nameplate of the asynchronous motor of a milling machine bears the following indications: 3 ~ 50 Hz
Δ 220 V 11 AY 380 V 6,4 A1455 rpm cos φ = 0.80
1- The motor is powered by a three-phase 50 Hz network, 380 V between phases.
What should be the coupling of its windings for it to operate normally?
2- What is the number of poles of the stator? (we give synchronism speed: 1500 rpm)
3- Calculate the nominal slip (in %).
4- A no-load test under nominal voltage gives:
- absorbed power: Pa = 260 W - line current intensity: I =3,2 A
Mechanical losses are estimated at 130 W.
Hot measurement of the resistance of a stator winding gives Rs = 0.65 Ω .
Deduct the iron losses.
5- For nominal operation, calculate:
- Joule effect losses at the stator - Joule effect losses at the rotor
- the yield - the useful torque Cu

**Correction** 4

1- The motor is powered by a three-phase 50 Hz network , 380 V between phases.

Compound voltage then Star coupling because the Star voltage is 380 V.

$p = f / n_s$ $n_s$ =1500 p= 50 / (1500 / 60) = 2 4 poles

4 poles

3- the nominal slip $\frac{1500-1455}{1500} = 3\%$

4- Power balance:

Joule effect losses at the stator: 3 × 0.65 × 3.2² = 20 W $3R_sI^2$ I no-load

Losses due to Joule effect at the rotor: negligible when empty

Iron losses: 260 – (130 + 20 + 0) = 110 W

5- - Joule effect losses at the stator $3R_sI^2$ = 3 × 0.65 × 6.4² = 80 W

- Joule effect losses at the rotor

Power consumption: **$P_a = UI\sqrt{3}\cos\varphi =$** $\sqrt{3}$ × 380 × 6.4 × 0.80 = 3370 W

Power transmitted to the rotor **$P_{tr}$** : = $P_a$ – stator losses = 3,370 – (80 + 110) = 3,180 W

Joule losses at the rotor **: $P_{Jr} = g P_{tr}$ =** 3 180 × 0.03 = 95 W

Useful power: **$P_{tr}$ – Losses (** rotor joule losses + mechanical losses **)** = 3180 – (130 + 95) = 2,955 W

or = Useful power = **$P_a$ – total losses = 3,370 – (130 + 95+80 + 110)=** 2,955 W

- the yield

Yield: 2,955 / 3,370 = 87.7%

- the useful couple Cu $\frac{2955}{1455 \times \frac{2\pi}{60}} = 19,4 \text{ Nm}$

**Exercise 5**

A 220 V / 380 V four-pole three-phase asynchronous squirrel-cage motor is supplied by a 220 V network between phases, 50 Hz.

A no-load test at a rotation frequency very close to synchronism gave for the absorbed power and the power factor: Pv = 500 W and cos φ v = 0.157.

A load test gave: - intensity of absorbed current: I = 12,2 A- slip: g = 6% - absorbed power: Pa = 3340 W.

The resistance of a stator winding is Rs = 1.0 Ω .

1-1- Which of the two voltages indicated on the nameplate can a stator winding withstand?

1-2- Deduce the coupling of the stator on the 220 V network.

2- For no-load operation, calculate:

2-1- the rotation frequency nv assumed to be equal to the synchronism frequency

2-2- the intensity of the current in line Iv

2-3- the value of Joule losses in the stator PJs v

2-4- the value of the losses in the stator iron pfs, assumed to be equal to the mechanical losses pm

3- For operation under load, calculate:

3-1- the rotation frequency (in rpm)

3-2- the power transmitted to the rotor Ptr and the moment of the electromagnetic torque Cem

3-3- the useful power Pu and the efficiency η

3-4- the moment of the useful couple Cu

**Correction 5**

1-1- 220 V

1-2- Triangle coupling

2- 2-1- the rotation frequency $n_v$ = 1500 rpm

2-2- the intensity of the current in line $I_V = \frac{P_V}{\sqrt{3} U \cos\varphi_V} = \frac{500}{\sqrt{3} \cdot 220 \cdot 0{,}157} = 8{,}36\ A$

2-3- the value of Joule losses in the stator $p_{Js\,v}$ $3 R J_V^2 = R I_V^2 = 70$ W (couplage triangle)

2-4- Power balance: $P_{fs} + p_m$ = 500 – 70 = 430 W $P_{fs} = p_m$ = 430 W / 2 = 215 W

3- 3-1- the rotation frequency (in rpm) 1500(1- 0.06) = 1410 rpm

3-2- $P_{tr}$ = 3340 – 150 – 215 = 2975 W

$$C_{em} = \frac{P_{tr}}{\Omega_S} = \frac{2975}{1500 \frac{2\pi}{60}} = 18{,}95\ Nm$$

3-3- the useful power $P_u$ and the efficiency η

$P_u$ = 2975 – 2975×0.06 – 215 = 2580 W

η = 2580 / 3340 = 77.3%

3-4- the moment of the useful couple $C_u = \frac{P_u}{\Omega} = \frac{2580}{1410 \frac{2\pi}{60}} = 17{,}5\ Nm$

4- $C_u$ = 0 Nm at n = 1500 rpm From where: $C_u$ = - 0.1944 n + 291.7

At equilibrium: $C_u = C_r$ $8 \cdot 10^{-6} n^2$ = - 0.1944 n + 291.7

Solving this second degree equation gives: n = 1417 rpm

Calculate the useful power of the motor. $C_r = C_u = 8 \cdot 10^{-6} \cdot 1417^2$ = 16.1 Nm $P_u$ = 2385 W