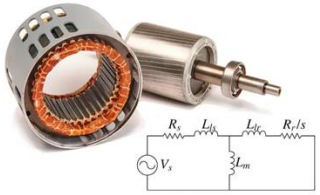
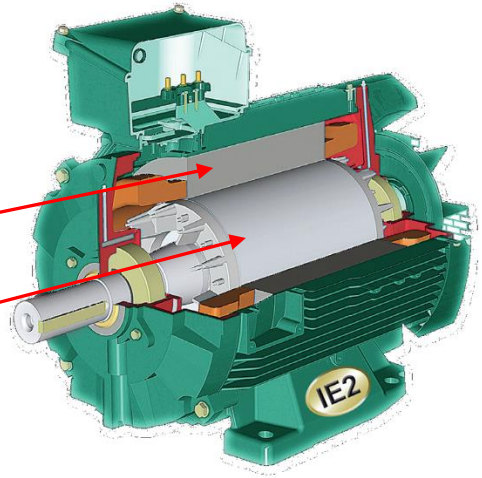


3-phase motors

- Construction:

3-phase
STATOR
+
ROTOR

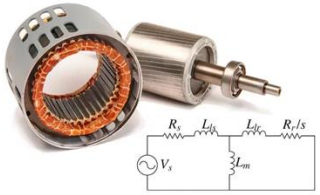


DC rotor

=> Synchronous machine

3-phase rotor

=> Induction/Asynchronous machine



3-phase motors

- The 3-phase stator:

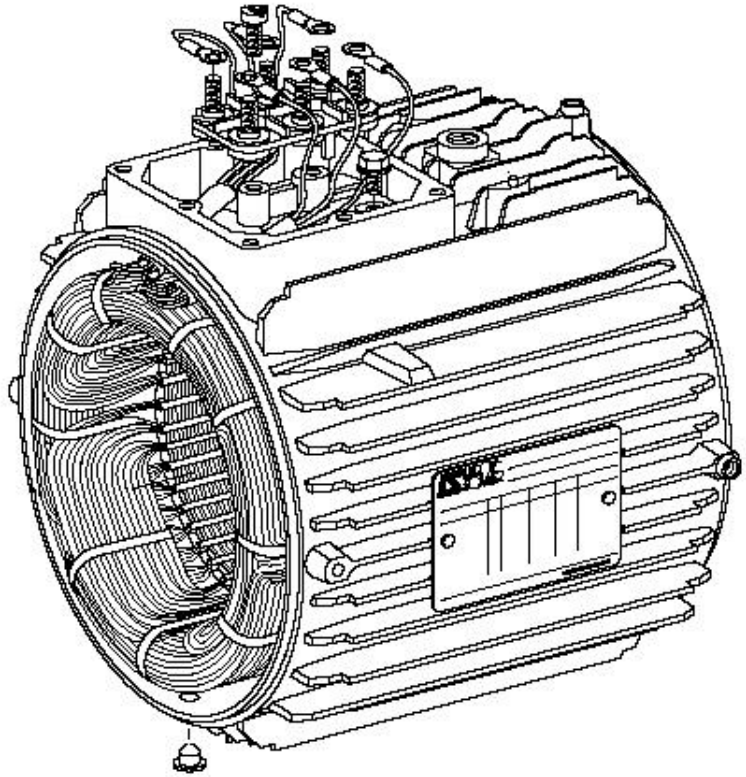
- The stator is the same for both the synchronous and the asynchronous machines

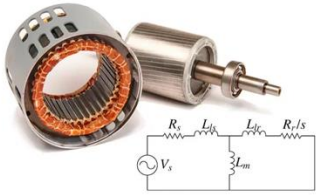
- Consists of an aluminum frame onto which a crown of notched steel sheets is fixed.

- Windings of appropriate cross-sections are distributed in these slots, forming a winding assembly with as many circuits as supply phases (3).

⇒ Spatial distribution of the sinusoidal field

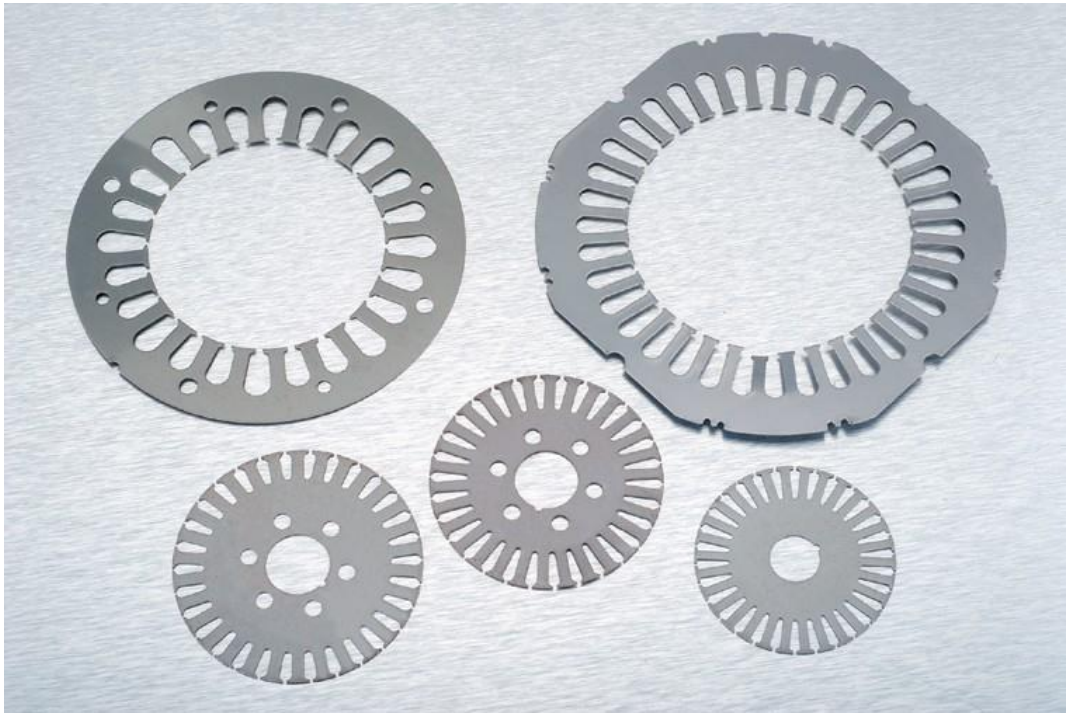
⇒ Creation of a rotating magnetic field

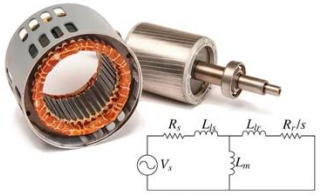




3-phase motors

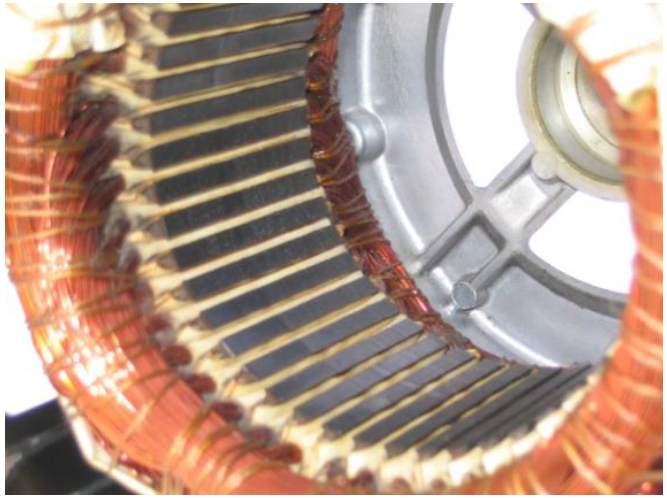
- The 3-phase stator:

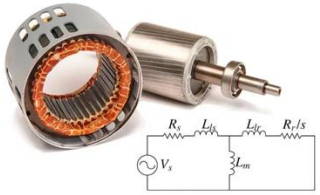




3-phase motors

- The 3-phase stator:





3-phase motors

- Stator: field distribution

- Field created in an air gap by one or several turns

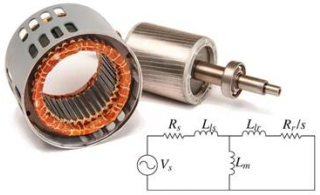
=> N turns winding arranged in slots on the surface of an air gap, without leakage, through which flows a direct current I

=> The iron frame channels the field lines. In the air gap, there is a B field that is assumed to be radial.

=> Conventions: North pole axis = angular abscissa

=> Conventions: Field counted positively when oriented towards the outside of the machine (north pole) and negatively towards the inside (south pole)

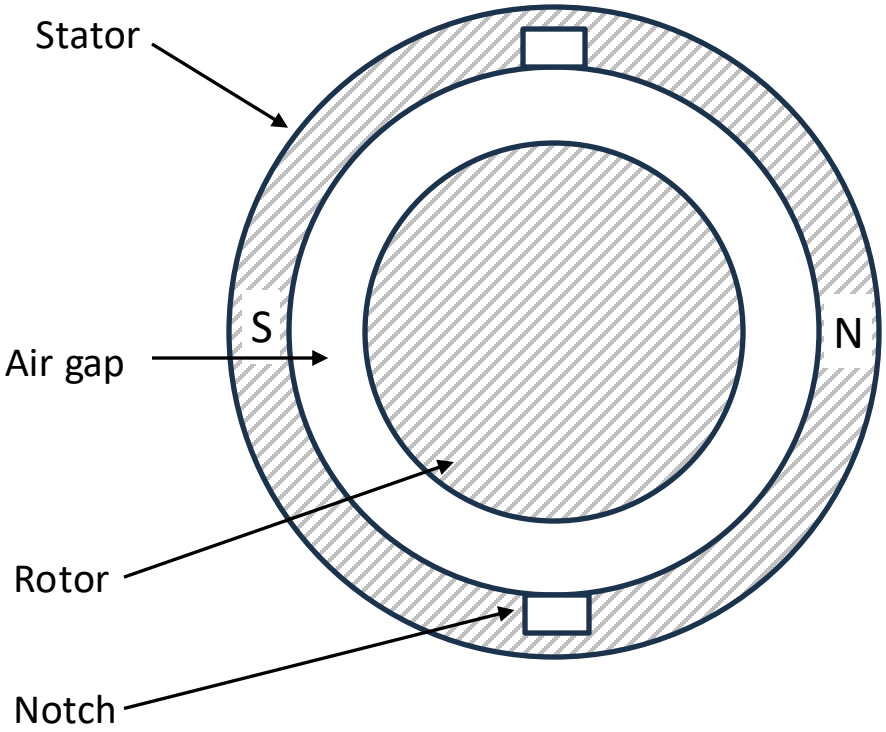
=> Conventions: Unsaturated magnetic material



3-phase motors

- Stator: field distribution

- Field created in an air gap by one or several turns: case of the bipolar stator + 2 notches



- Ampere's theorem:

$$H_{iron} l_{iron} + H_{air} l_{air} = \sum i_{interlaced}$$

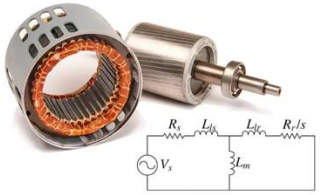
- Assumption of perfect magnetic material

=> $\mu_r \to \infty$ => $H_{iron} \to 0$

- Induction magnetic field in the airgap:

$$B_{air} = \mu_0 \frac{ni}{2e}$$

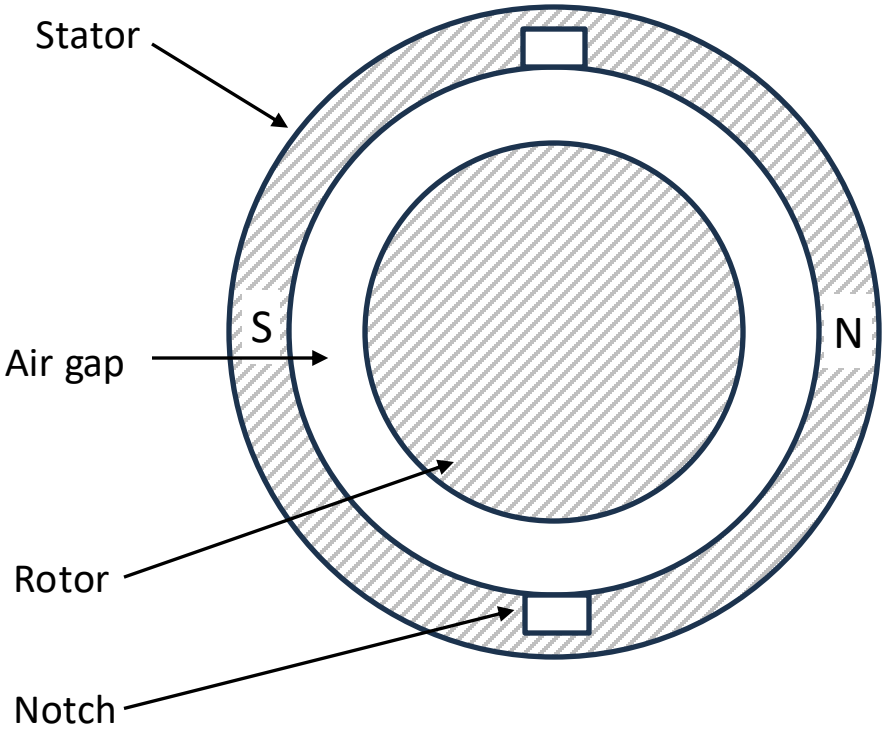
n number of turns, e airgap width

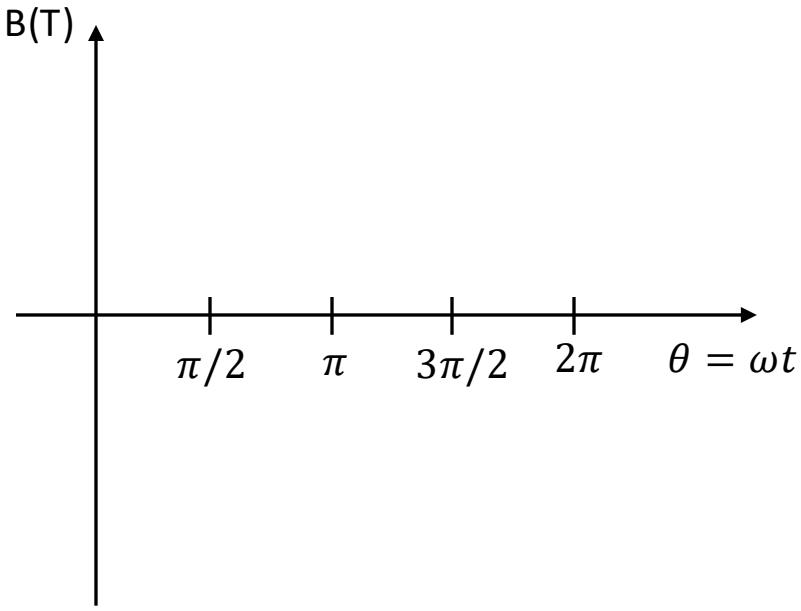


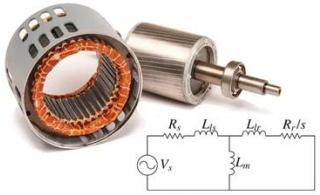
3-phase motors

- Stator: field distribution

- Field created in an air gap by one or several turns: **case of the bipolar stator + 2 notches**



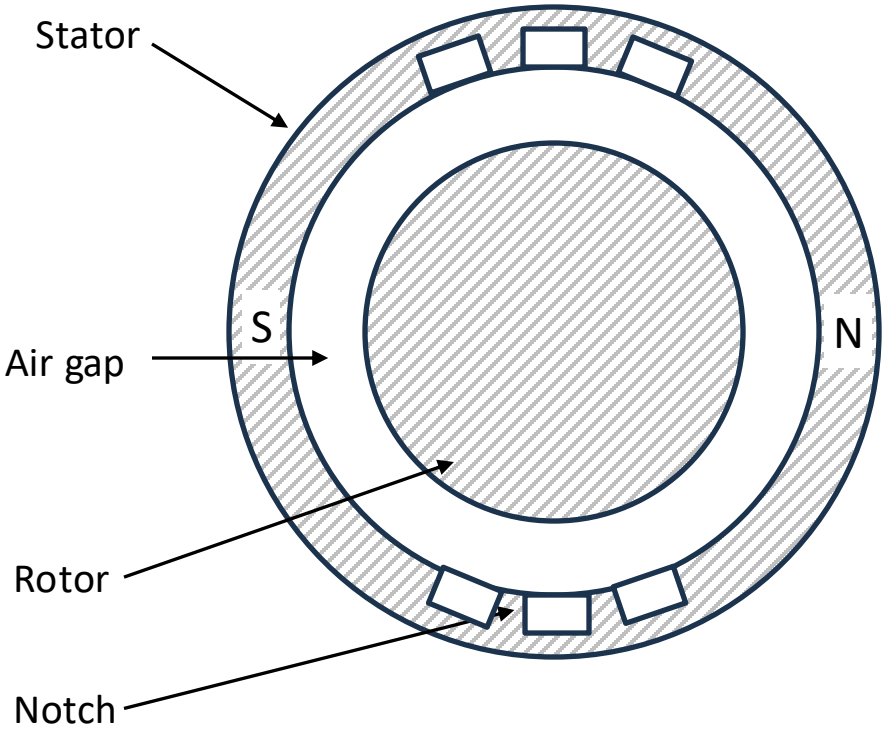




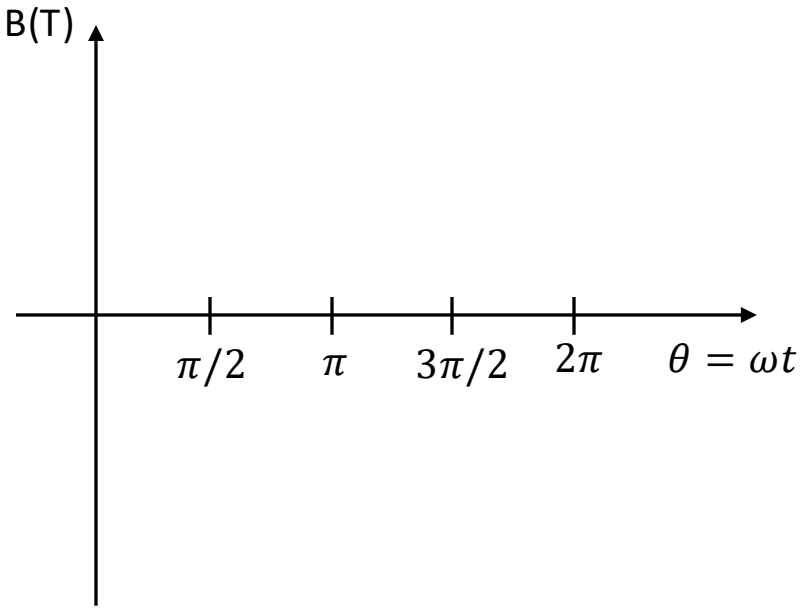
3-phase motors

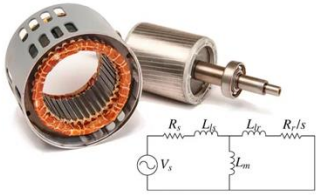
- Stator: field distribution

- Field created in an air gap by one or several turns: **case of the bipolar stator + 3 notches pairs**



$$B_{air\,1} = \mu_0 \frac{ni}{2e} \qquad B_{air\,2} = \mu_0 \frac{ni}{6e}$$

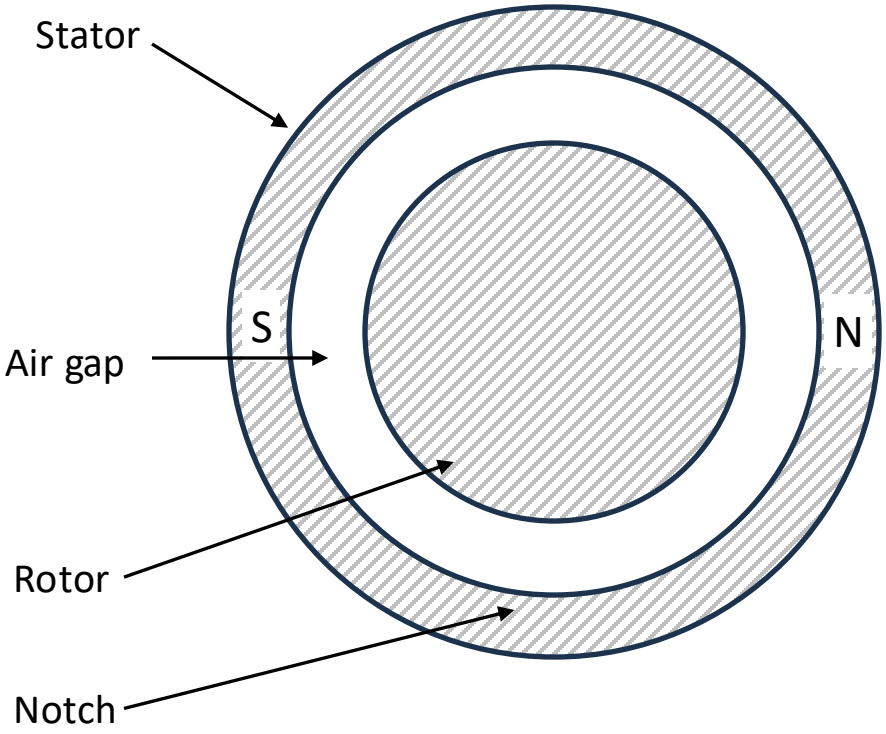


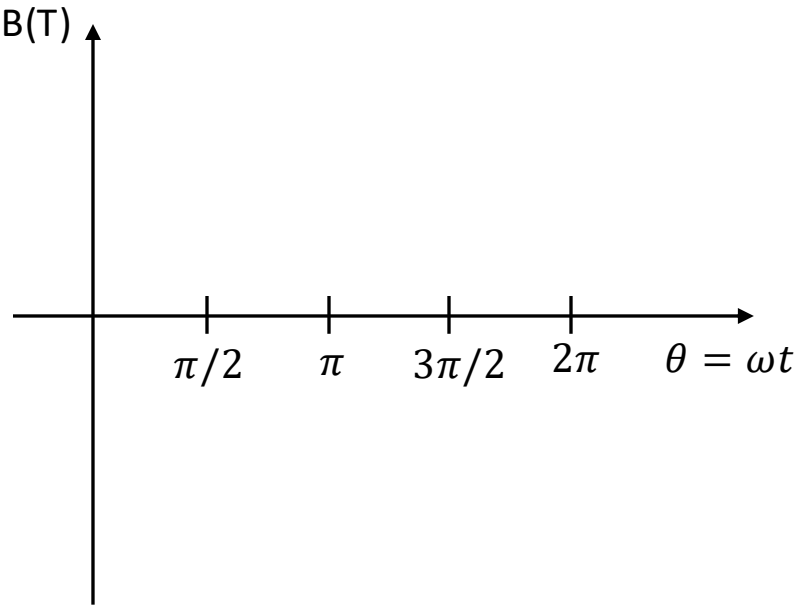


3-phase motors

- Stator: field distribution

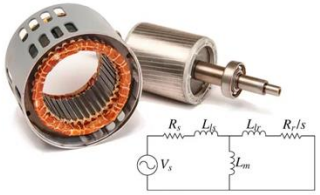
- Field created in an air gap by one or several turns: **bipolar stator** + **notches all around the stator**





=> B field with sinusoidal spatial distribution

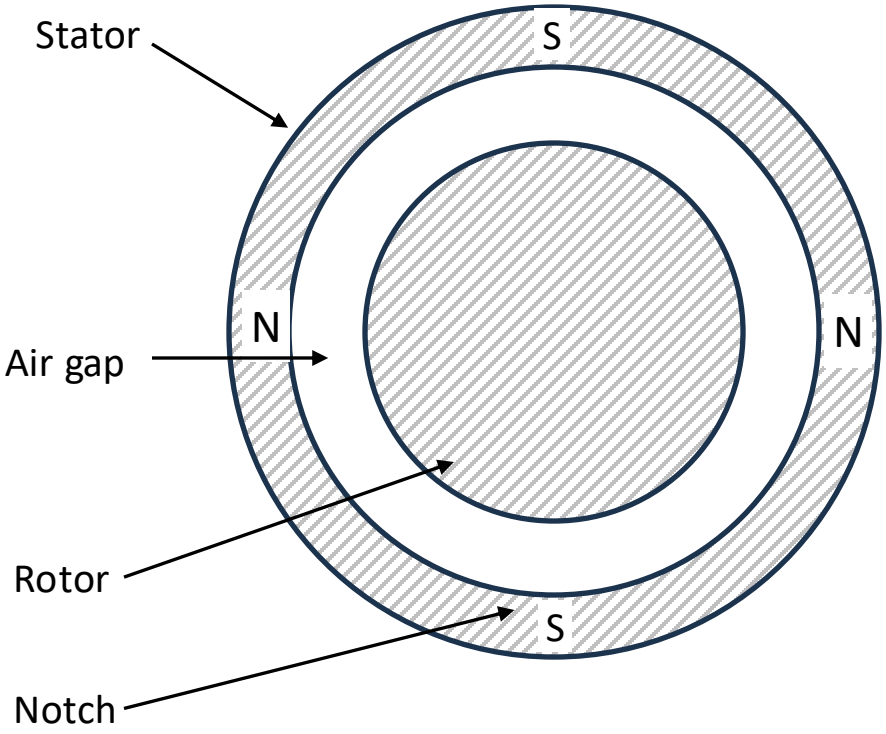
$$B(\theta) = \mu_0 \frac{ni}{2e} cos\theta = \hat{B} cos\theta$$

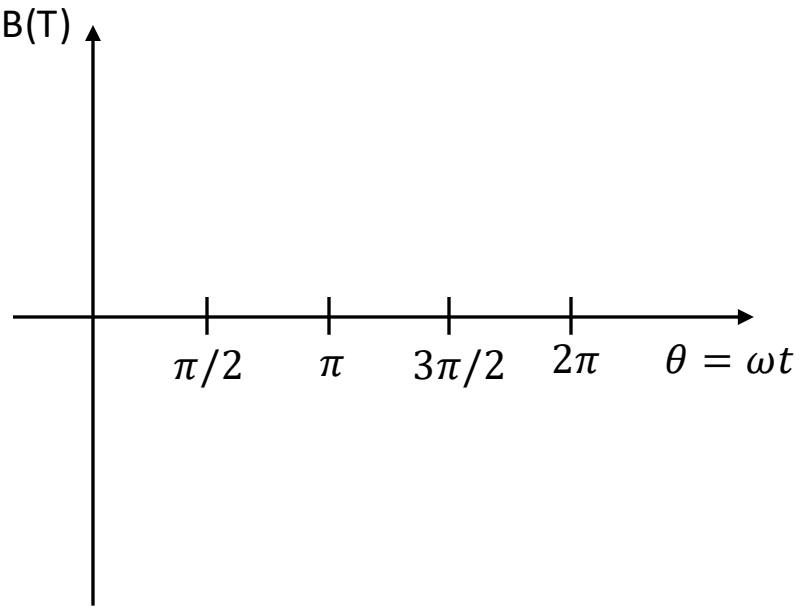


3-phase motors

- Stator: field distribution

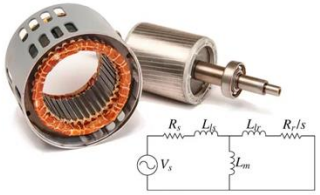
- Field created in an air gap by one or several turns: **multipolar stator (p pole pairs)**





=> Static B field distribution (no rotation)

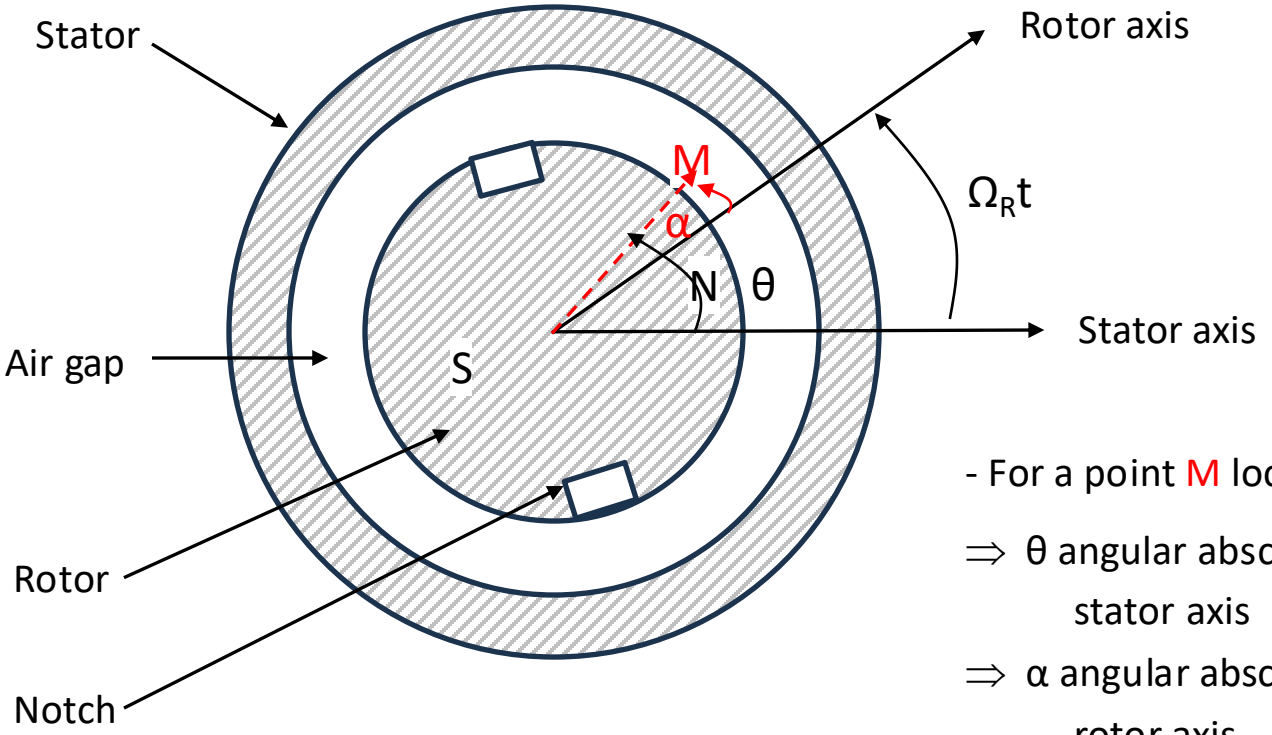
$$B(\theta) = \mu_0 \frac{ni}{2e} cosp\theta = \hat{B} cosp\theta$$



3-phase motors

- Stator: field distribution

- Rotating B field created by a rotor in which a DC current flows: **bipolar rotor**

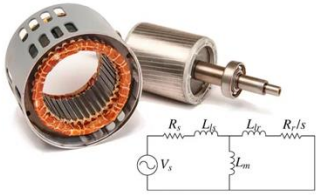


$\Omega_R t$ is the rotor rotation speed

- For a point M located in the air gap:

$\Rightarrow$ θ angular abscissa with respect to the fixed stator axis

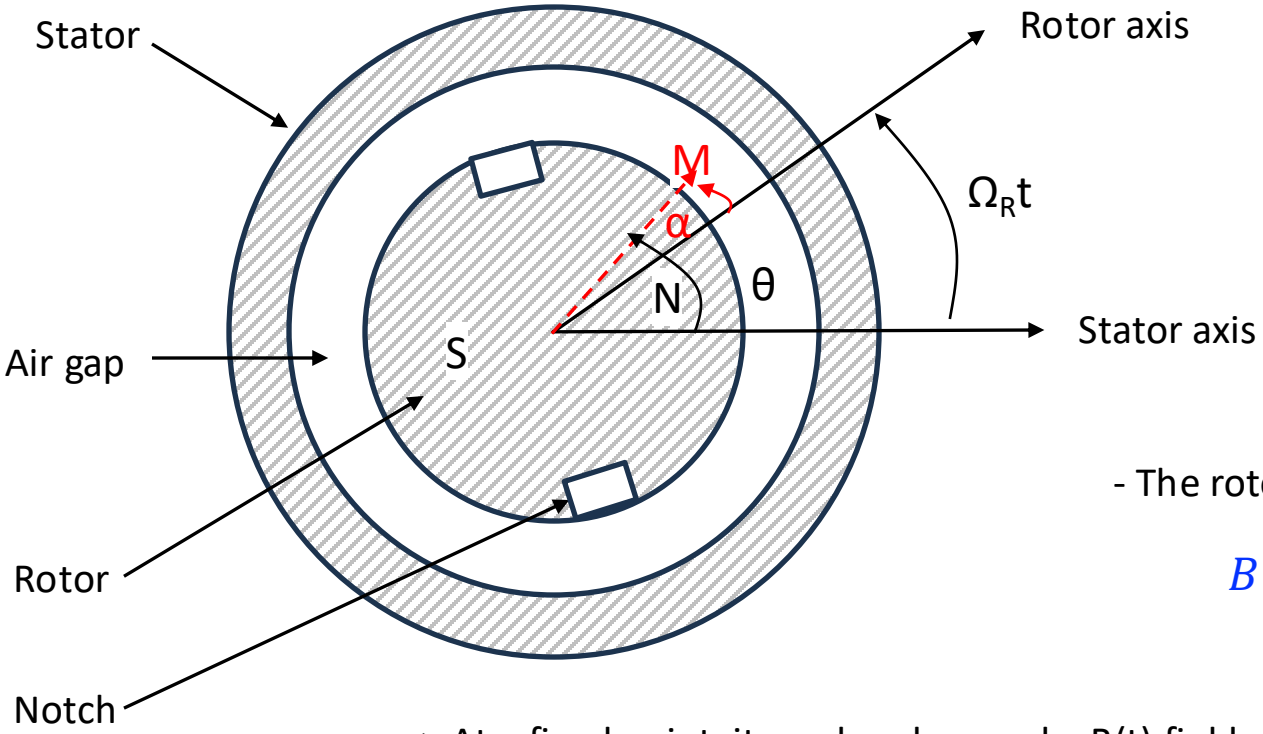
$\Rightarrow$ α angular abscissa with respect to the rotor axis



3-phase motors

- Stator: field distribution

- Rotating B field created by a rotor in which a DC current flows: **bipolar rotor**



M sees the B field rotating at

$\Omega_R=\omega$

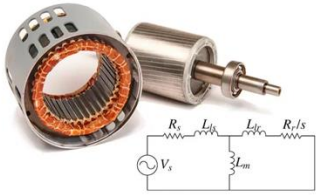
$$\theta = \omega t + \alpha$$

- The rotor winding creates at point M:

$$B(\theta, t) = \hat{B}\cos(\theta - \omega t)$$

=> At a fixed point, it can be observed a B(t) field varying sinusoidally with time

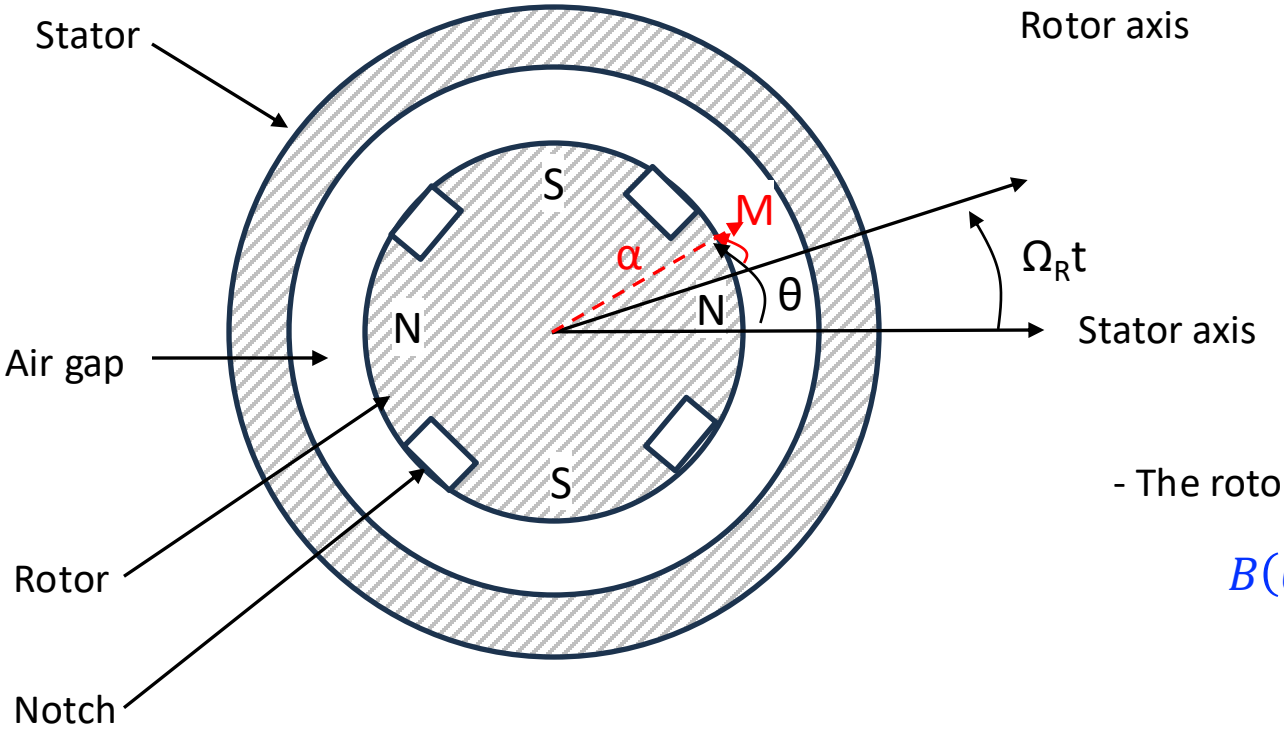
=> At a fixed point and time t, a static B(θ) distribution is observed => rotating distribution field



3-phase motors

- Stator: field distribution

- Rotating B field created by a rotor in which a DC current flows: **multipolar rotor**



M sees the B field rotating at

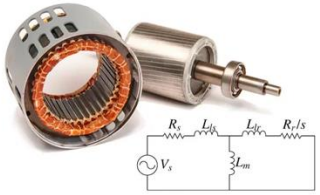
$\Omega_R=\omega/p$

$$\theta = \frac{\omega}{p}t + \alpha$$

- The rotor winding creates at point M:

$$B(\theta, t) = \hat{B}\cos(p\theta - \omega t)$$

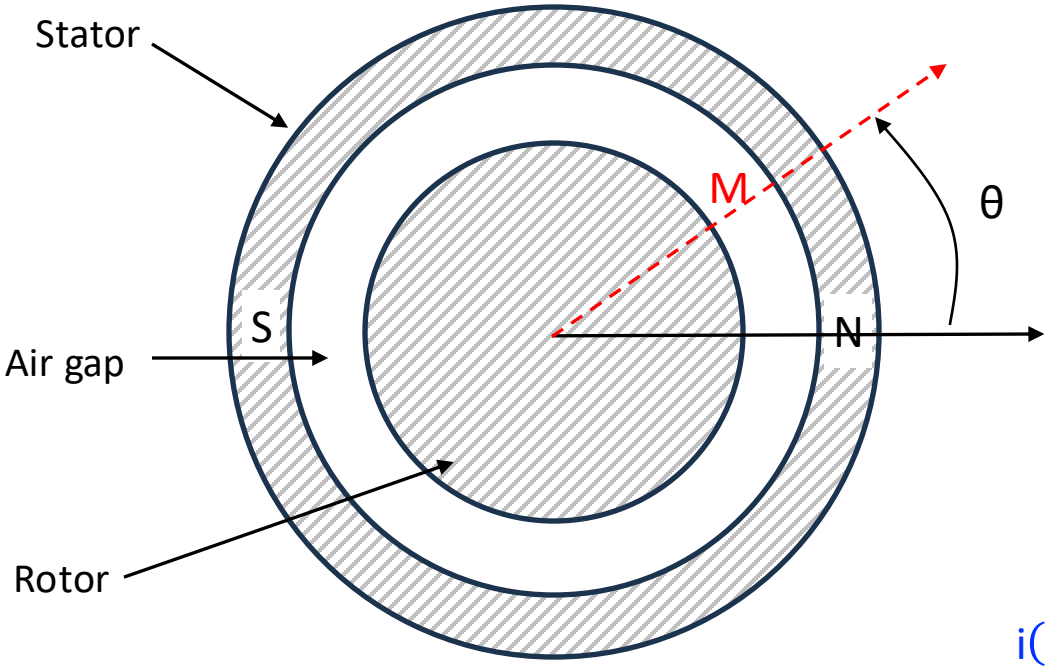
=> Sinusoidal distribution of rotating B field



3-phase motors

- Stator: field distribution

- Rotating B fields created by a **single-phase stator** in which an AC current flows: **bipolar stator**

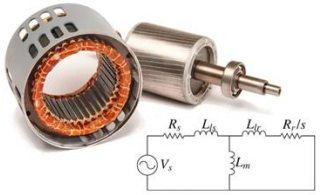


- Let us consider a stator with sinusoidal spatial distribution operating in unsaturated mode regime

- A sinusoidal current flows through the stator winding

$$i(t) = \hat{I}\cos(\omega t)$$

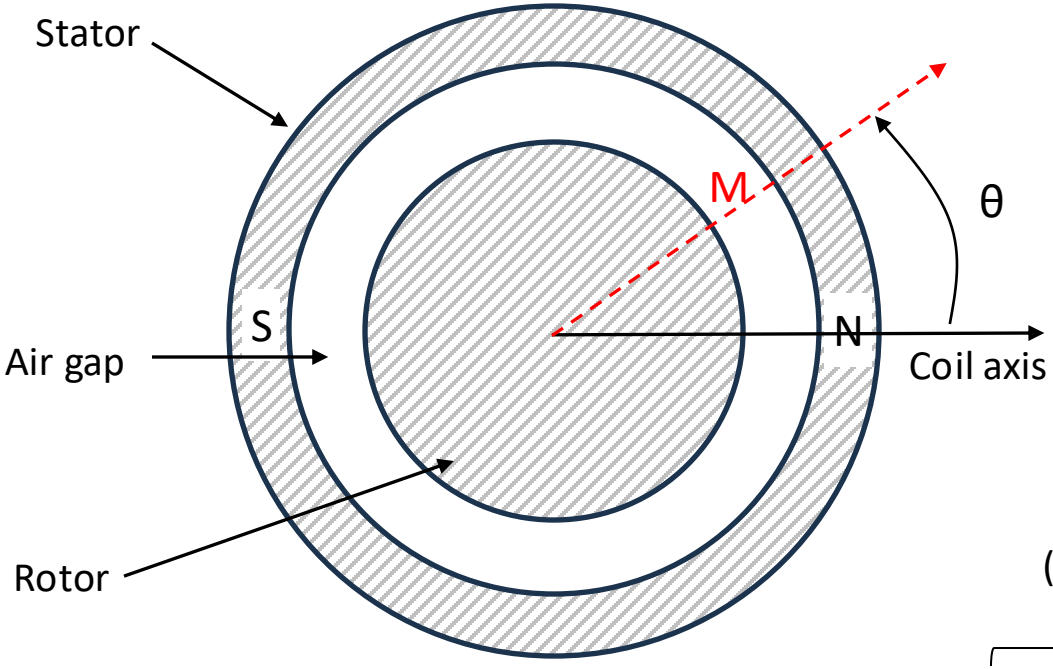
$$B(\theta, t) = k.i(t)\cos(\theta)$$



3-phase motors

- Stator: field distribution

- Rotating B fields created by a **single-phase stator** in which an AC current flows: **bipolar stator**

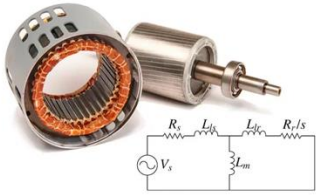


- The winding creates 2 rotating fields of same amplitude, with sinusoidal spatial distribution, rotating in opposite directions at the same speed.

B_d (direct field)

B_i (indirect field)

$$B(\theta,t) = \frac{1}{2}k\hat{I}\cos(\theta - \omega t) + \frac{1}{2}k\hat{I}\cos(\theta + \omega t)$$



3-phase motors

- Stator: field distribution

- Rotating B fields created by a **single-phase stator** in which an AC current flows: **multipolar stator**

=> Leblanc's theorem

- A fixed, single-phase, p-polar stator with sinusoidal spatial distribution, through which flows a sinusoidal current of pulsation ω leads to two rotating fields (direct and inverse):

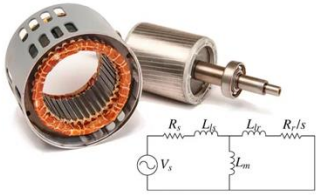
=> Of same amplitude, with sinusoidal spatial distribution

=> Turning in opposite directions to each other at rotation speed $\Omega_S = \frac{\omega}{p}$

=> whose axes coincide with the winding axis at maximum current

$$B(\theta, t) = k\hat{I}\cos(\omega t)\cos(\theta)$$

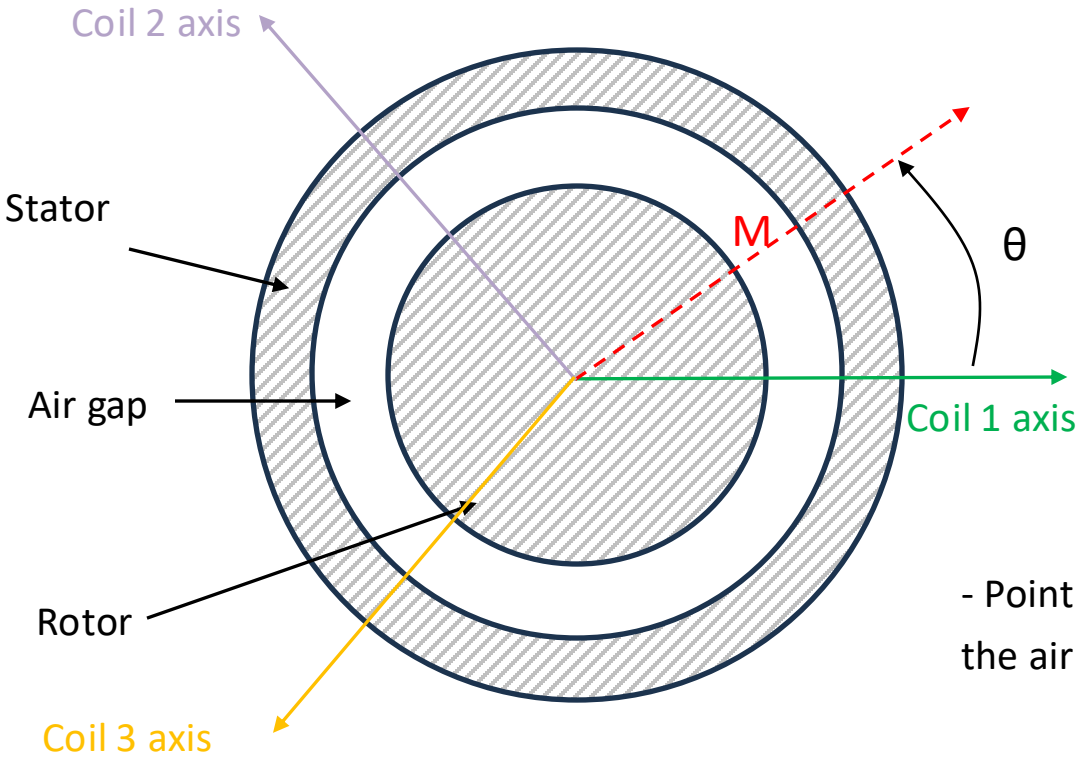
$$B(\theta, t) = \frac{1}{2}k\hat{I}\cos(p\theta - \omega t) + \frac{1}{2}k\hat{I}\cos(p\theta + \omega t)$$



3-phase motors

- Stator: field distribution

- Rotating B fields created by a **3-phase stator** in which AC currents flow: **bipolar stator**



Construction:

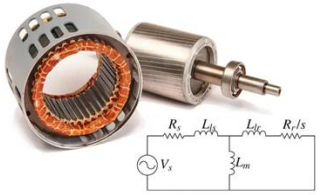
- 3-phase winding

- Each coil creates a sinusoidal spatial distribution

- The coil axes are shifted by an angle of 2π/3.

- Point M located in the air gap at angles:

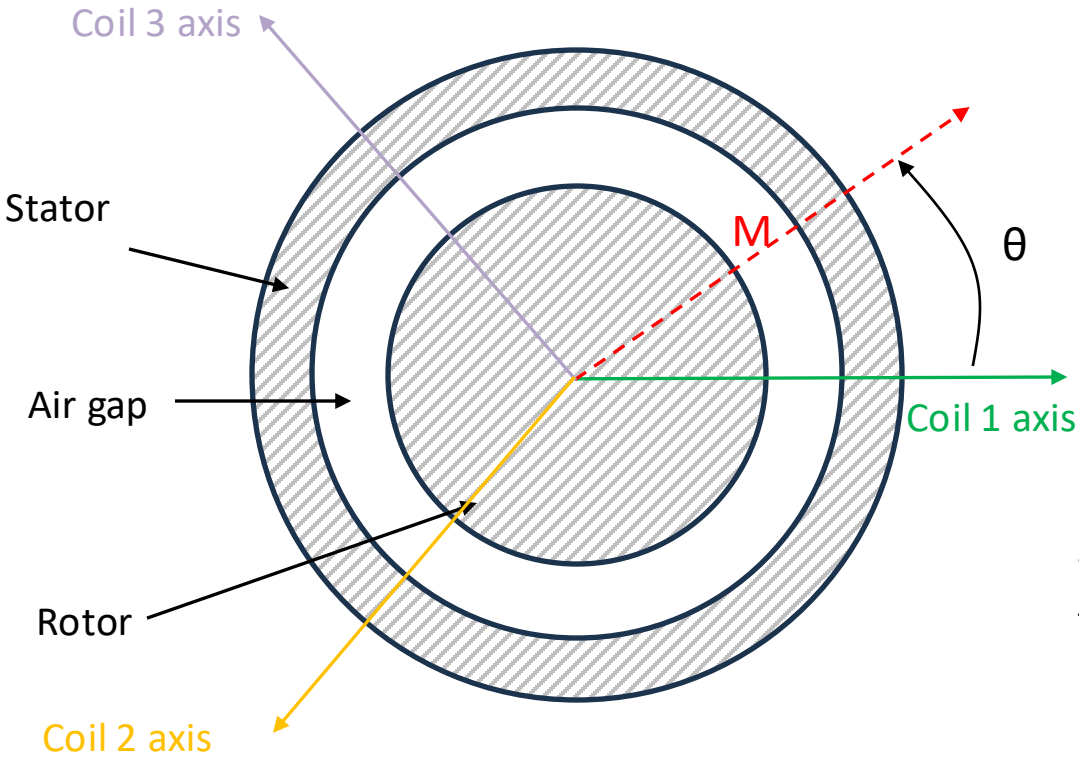
$$\begin{cases} \theta_1 = \theta \\ \theta_2 = \theta + \dfrac{4\pi}{3} \\ \theta_3 = \theta + \dfrac{2\pi}{3} \end{cases}$$



3-phase motors

- Stator: field distribution

- Rotating B fields created by a **3-phase stator** in which AC currents flow: **bipolar stator**



- 3-phase current systems at the windings:

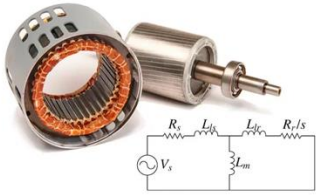
$$i_1(t) = \hat{I}\cos(\omega t)$$

$$i_2(t) = \hat{I}\cos(\omega t - \frac{2\pi}{3})$$

$$i_3(t) = \hat{I}\cos(\omega t - \frac{4\pi}{3})$$

- The resulting B-field is the sum of the fields generated by each winding:

$$B(\theta, t) = \frac{3}{2} k\hat{I}\cos(\omega t - \theta)$$



3-phase motors

- Stator: field distribution

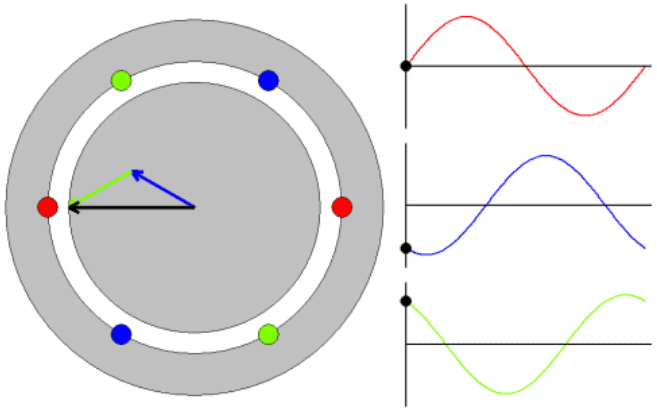
- Rotating B fields created by a **3-phase stator** in which AC currents flow: **multipolar stator**

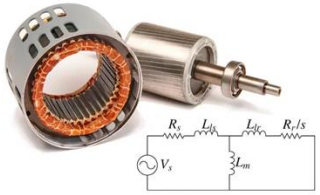
=> Ferraris's theorem

- A fixed, 3-phase, p-polar stator with sinusoidal spatial distribution, through which flows a sinusoidal current of pulsation ω leads to one rotating field (direct and inverse):

=> rotation speed $\Omega_S = \frac{\omega}{p}$

$$B(\theta, t) = \frac{3}{2} k\hat{I} \cos(\omega t - p\theta)$$

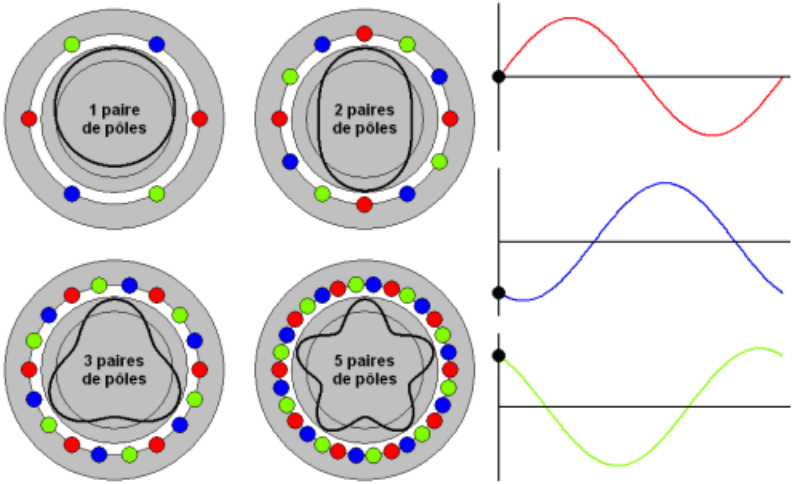




3-phase motors

- Stator: rotating field speed

- Influence of the number of pole pairs (p)



Number of pole pairs	f = 50Hz	f = 60Hz
1	3000 tr/min	3600 tr/min
2	1500 tr/min	1800 tr/min
3	1000 tr/min	1200 tr/min
4	750 tr/min	900 tr/min

NB: Rotation of fields distribution