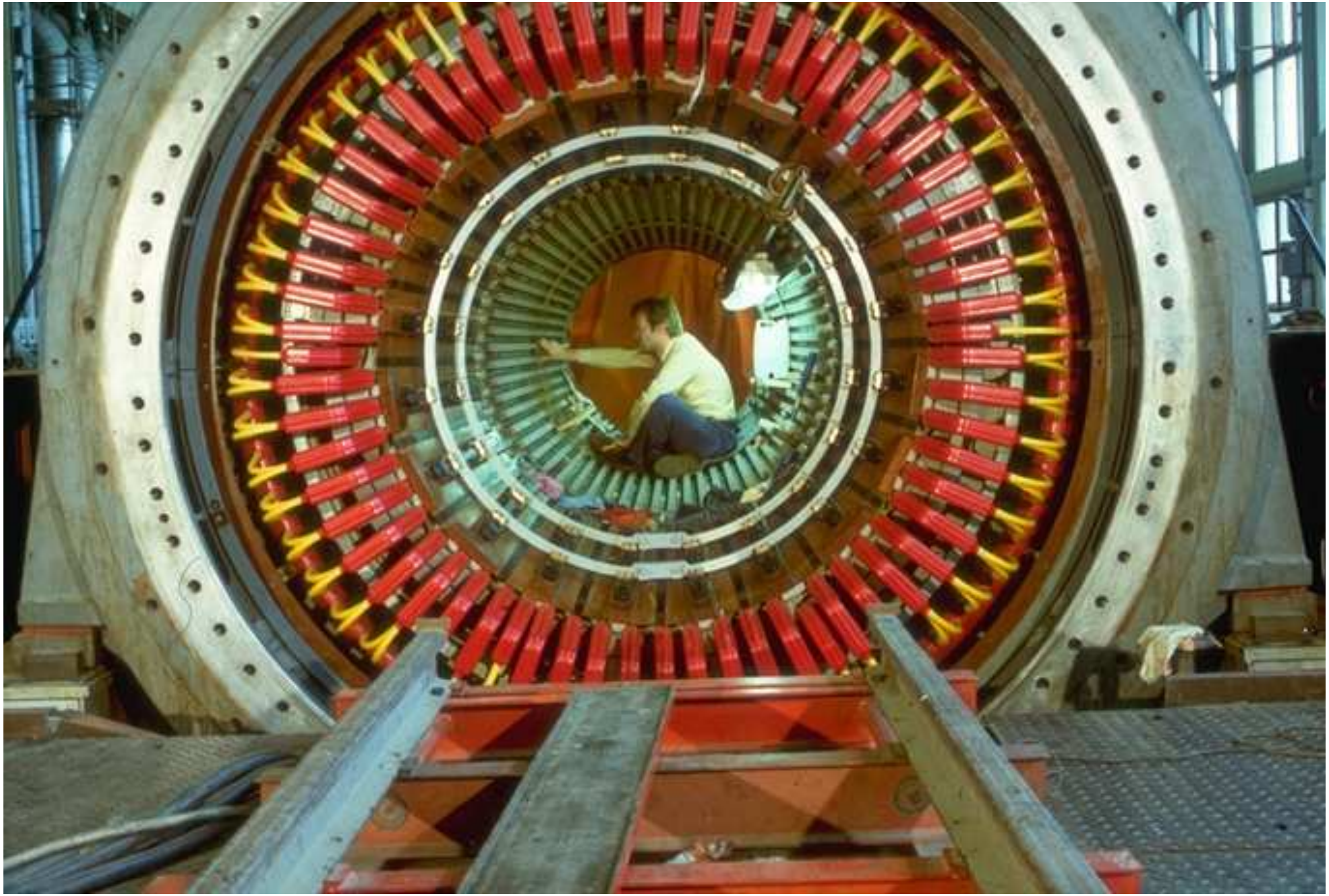
Motore sincrono a magneti permanenti

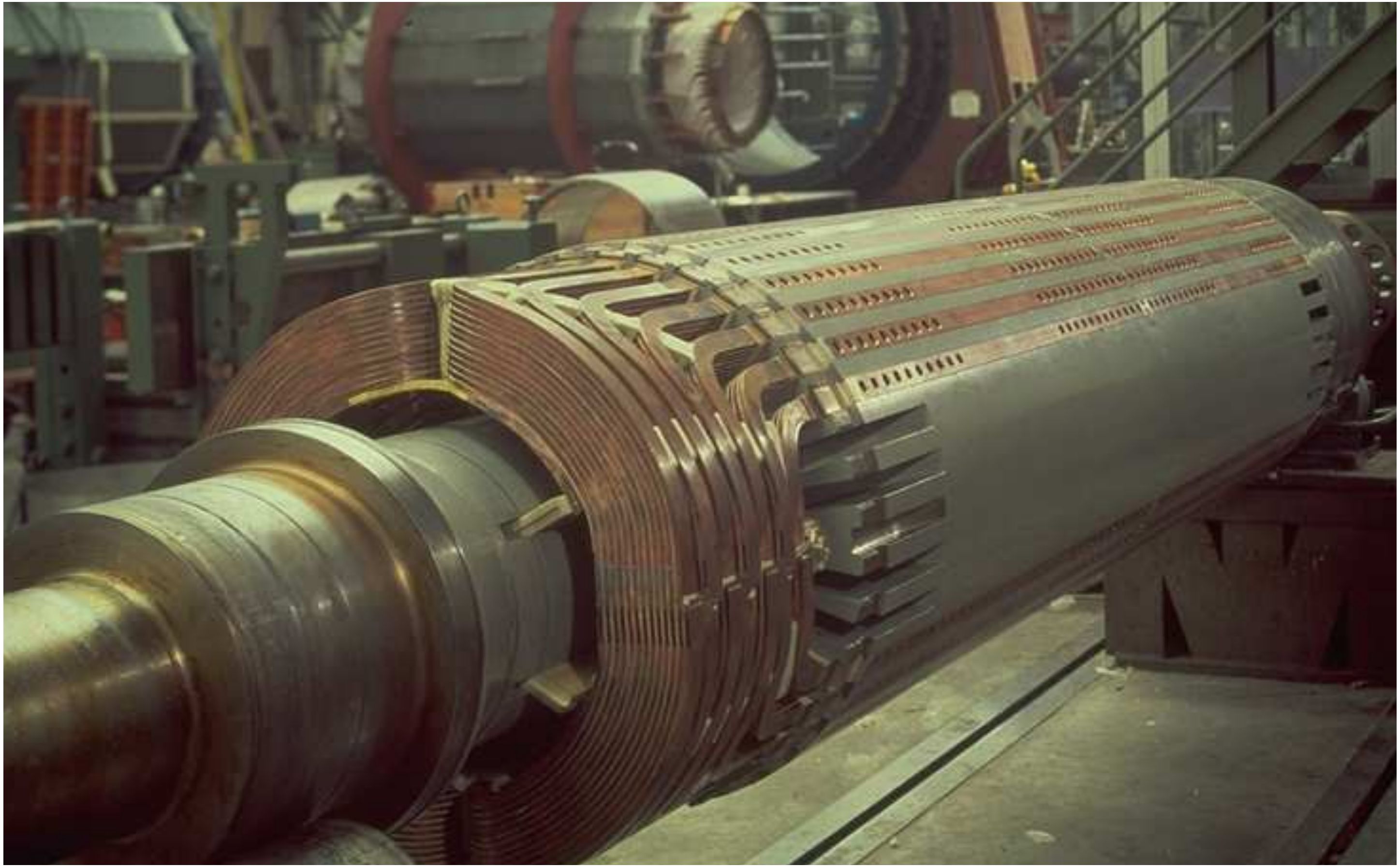
brush-less sinusoidale

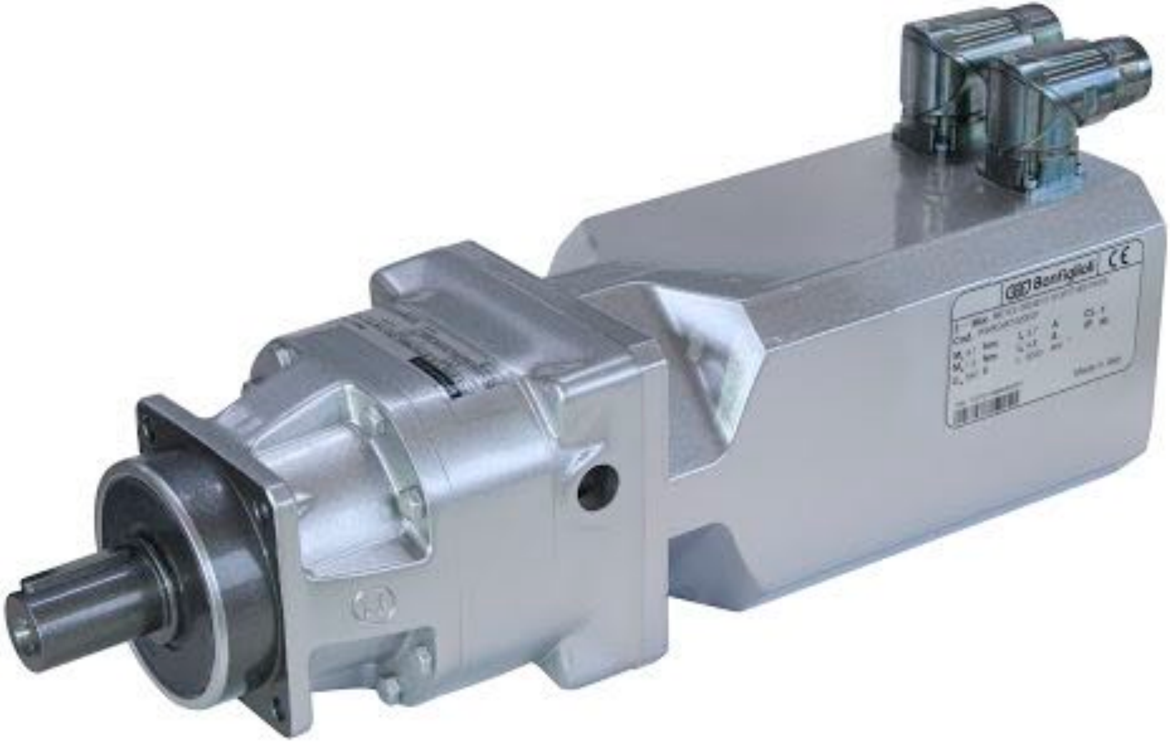
prof. Luigi Alberti
luigi.alberti@unipd.it

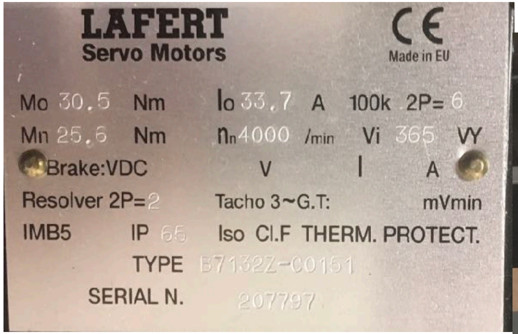
AA 2020/2021

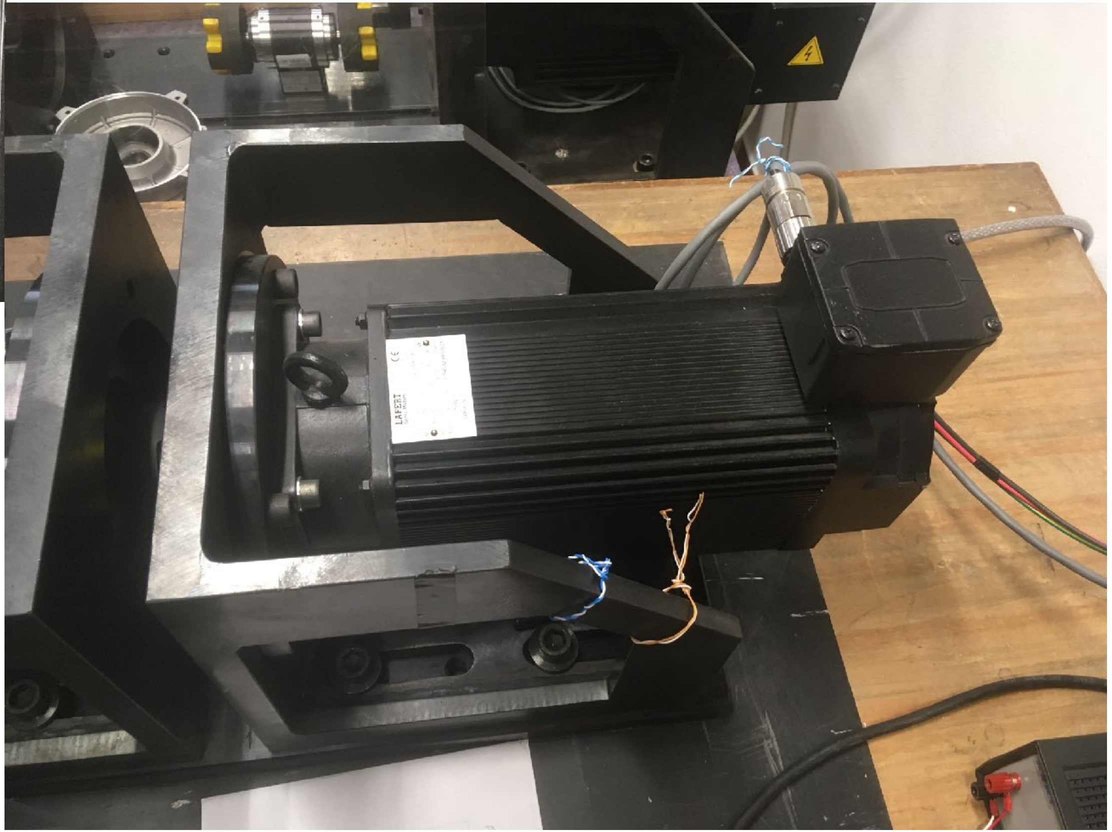

BBC
BROWN BOVERI

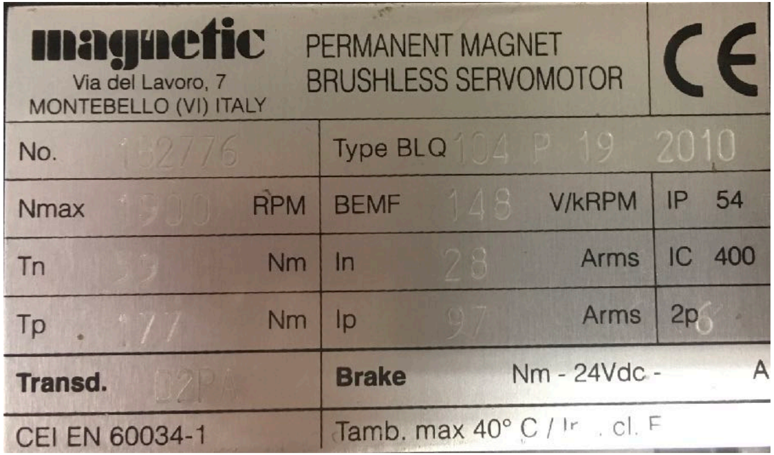




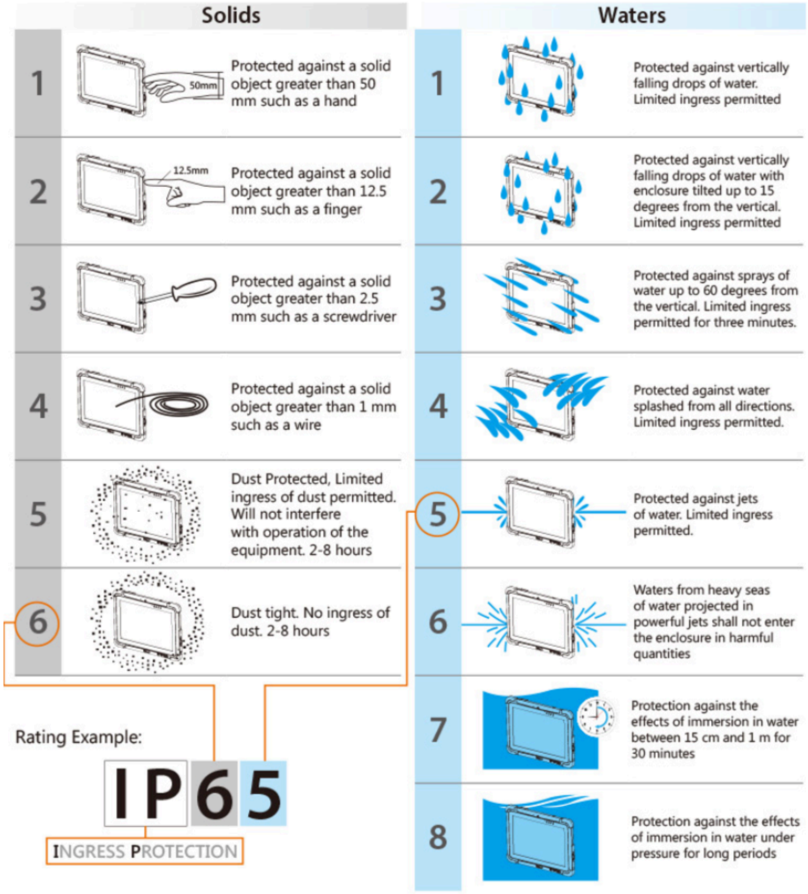

Bonfiglioli
CE


LAFERT
Servo Motors
CE
Made in EU
Mo 30.5 Nm
Io 33.7 A 100k 2P= 6
Mn 25.6 Nm
nn 4000 /min
Vi 365 VY
Brake:VDC V I A
Resolver 2P=2
Tacho 3~G.T: mVmin
IMB5 IP 65 Iso Cl.F THERM. PROTECT.
TYPE B7132Z-C0151
SERIAL N. 207797




magnetic
Via del Lavoro, 7
MONTEBELLO (VI) ITALY
PERMANENT MAGNET
BRUSHLESS SERVOMOTOR
CE
No.
Type BLQ 104 P 19 2010
Nmax RPM
BEMF 148 V/kRPM
IP 54
Tn Nm
In 28 Arms
IC 400
Tp 177 Nm
Ip 97 Arms
2p 6
Transd.
Brake
Nm - 24Vdc - A
CEI EN 60034-1
Tamb. max 40° C / Ir . cl. F

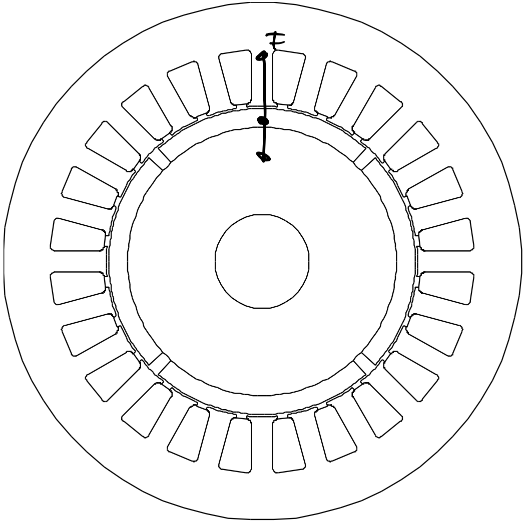

LUST
ANTRIEBSTECHNIK
TYP: PSM-21-20G52-410 Nr.7060368
U_N 330 V M_{dN} 7.00 Nm n_N 2000 min^{-1}
I_{dN} 3.10A M_{d0} 8.40 Nm f_N 100 Hz
Iso.-Kl. F IP 65 10.2kg
CE
Made in Germany

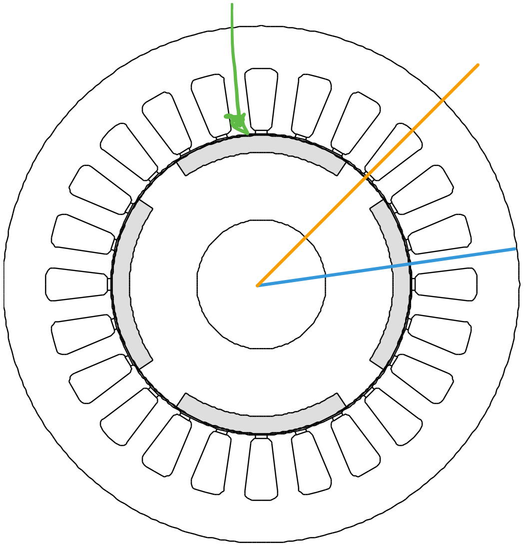

Solids
1
50mm
Protected against a solid object greater than 50 mm such as a hand
2
12.5mm
Protected against a solid object greater than 12.5 mm such as a finger
3
Protected against a solid object greater than 2.5 mm such as a screwdriver
4
Protected against a solid object greater than 1 mm such as a wire
5
Dust Protected, Limited ingress of dust permitted. Will not interfere with operation of the equipment. 2-8 hours
6
Dust tight. No ingress of dust. 2-8 hours
Waters
1
Protected against vertically falling drops of water. Limited ingress permitted
2
Protected against vertically falling drops of water with enclosure tilted up to 15 degrees from the vertical. Limited ingress permitted
3
Protected against sprays of water up to 60 degrees from the vertical. Limited ingress permitted for three minutes.
4
Protected against water splashed from all directions. Limited ingress permitted.
5
Protected against jets of water. Limited ingress permitted.
6
Waters from heavy seas of water projected in powerful jets shall not enter the enclosure in harmful quantities
7
Protection against the effects of immersion in water between 15 cm and 1 m for 30 minutes
8
Protection against the effects of immersion in water under pressure for long periods
Rating Example:
IP65
INGRESS PROTECTION

The rotor configurations

- SPM rotor
- inset rotor

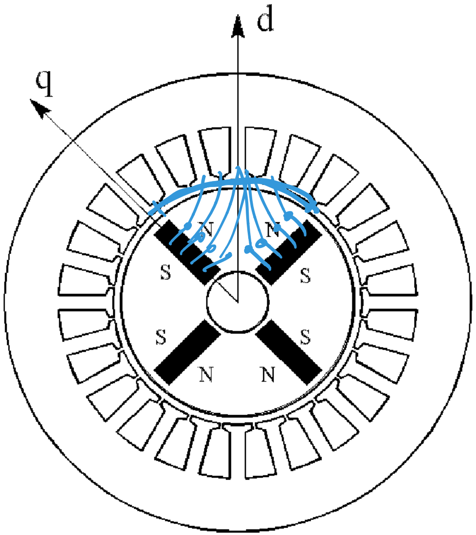
4-pole 24-slot motors.

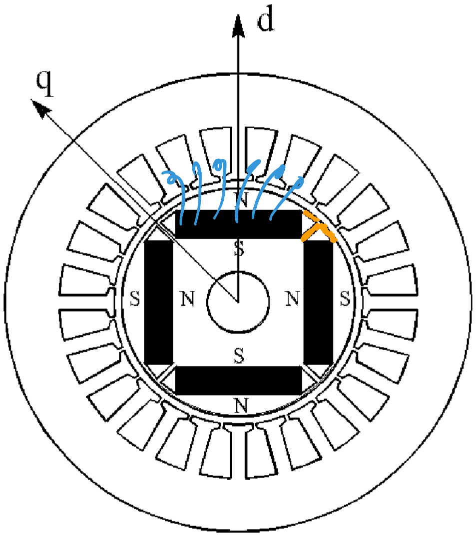




The rotor configurations

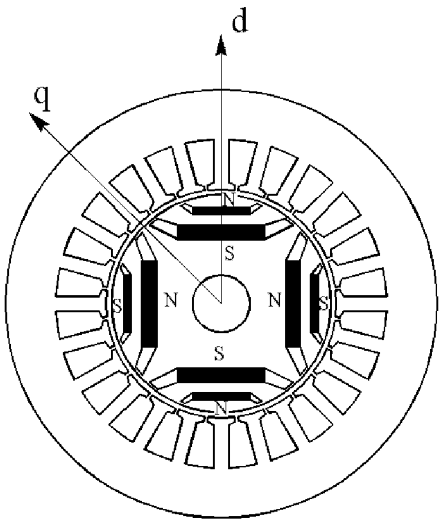
- tangentially magnetized PMs
- radially magnetized PMs

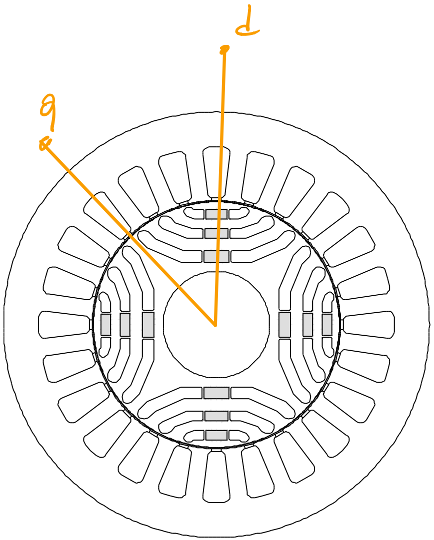


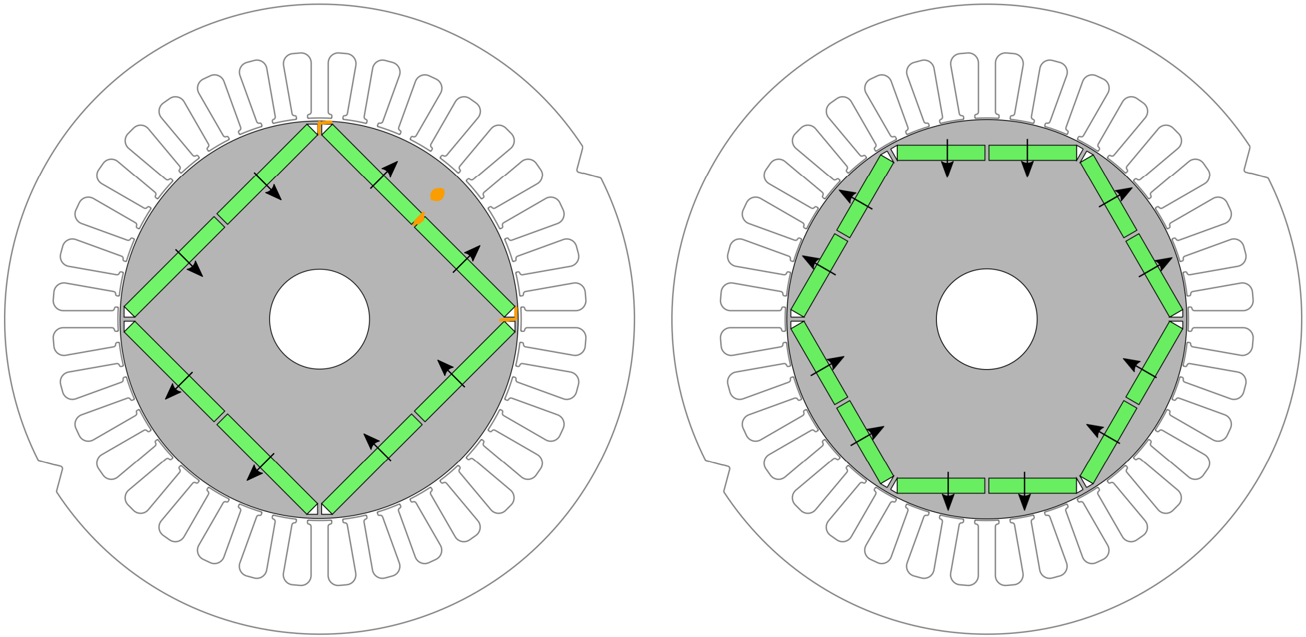


The rotor configurations

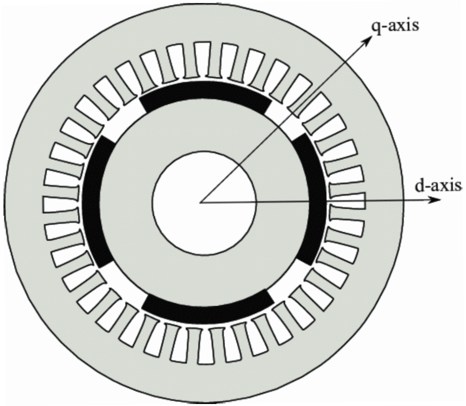
- two flux-barriers per pole
- more flux–barriers per pole
- axially laminated rotor.

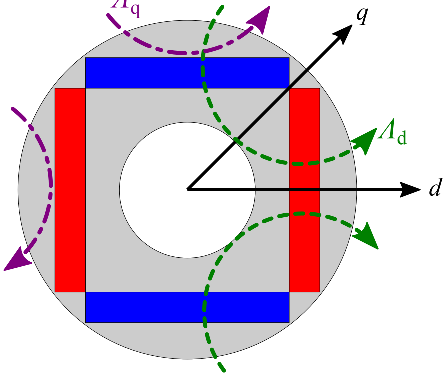


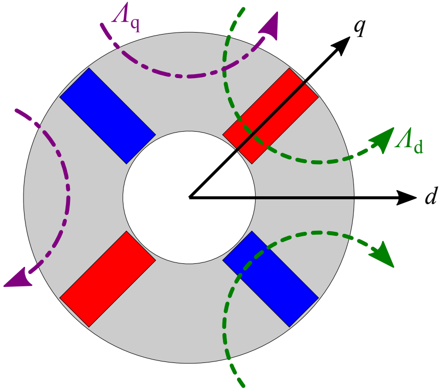


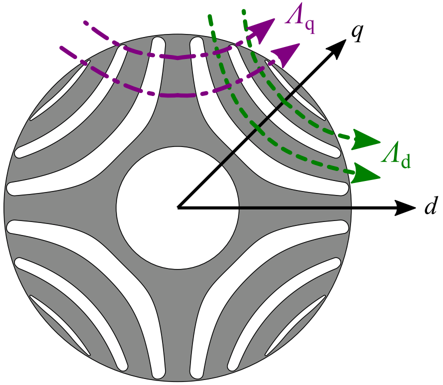


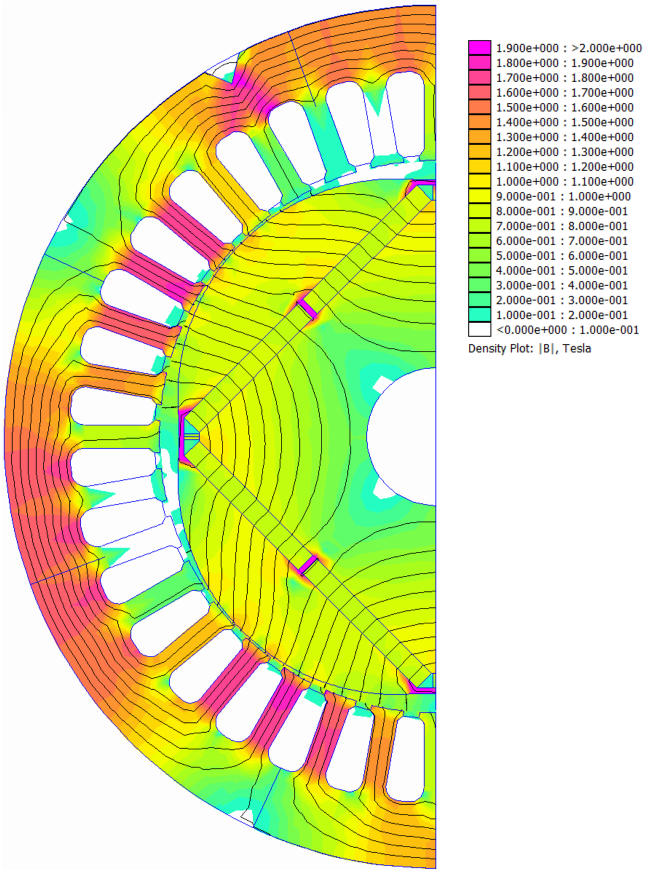
(a) 4 poli) **(b)** 6 poli

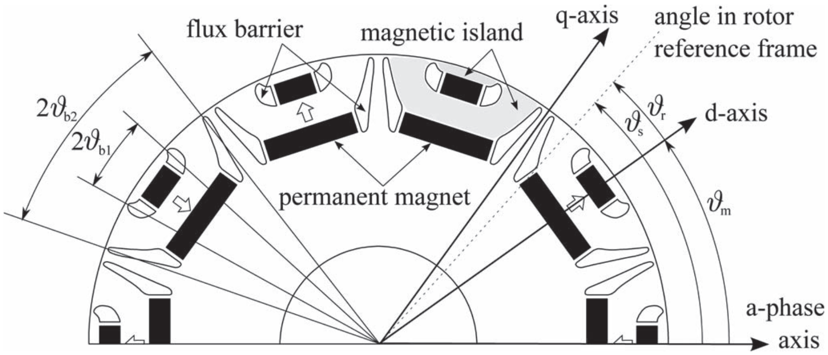

q-axis
d-axis

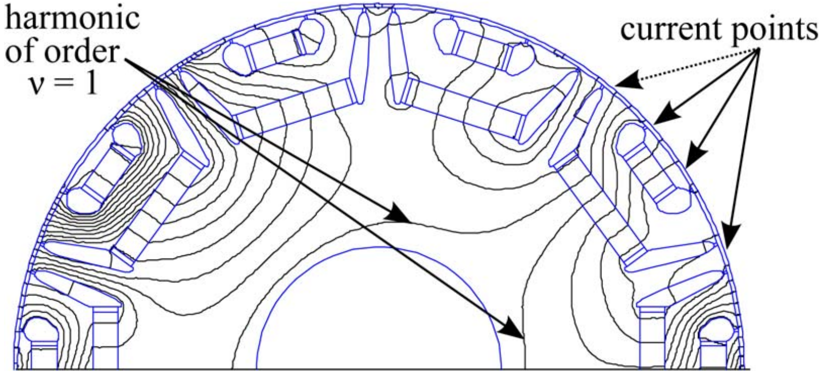

Λ_q
q
Λ_d
d

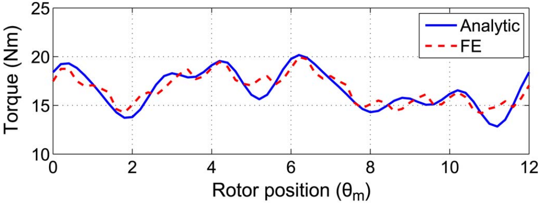

Λ_q
q
Λ_d
d


Λ_q
q
Λ_d
d

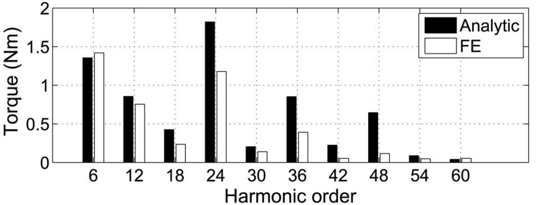

1.900e+000 : >2.000e+000
1.800e+000 : 1.900e+000
1.700e+000 : 1.800e+000
1.600e+000 : 1.700e+000
1.500e+000 : 1.600e+000
1.400e+000 : 1.500e+000
1.300e+000 : 1.400e+000
1.200e+000 : 1.300e+000
1.100e+000 : 1.200e+000
1.000e+000 : 1.100e+000
9.000e-001 : 1.000e+000
8.000e-001 : 9.000e-001
7.000e-001 : 8.000e-001
6.000e-001 : 7.000e-001
5.000e-001 : 6.000e-001
4.000e-001 : 5.000e-001
3.000e-001 : 4.000e-001
2.000e-001 : 3.000e-001
1.000e-001 : 2.000e-001
<0.000e+000 : 1.000e-001
Density Plot: |B|, Tesla



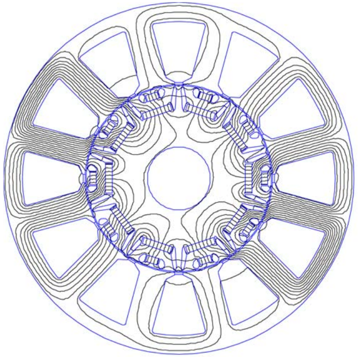


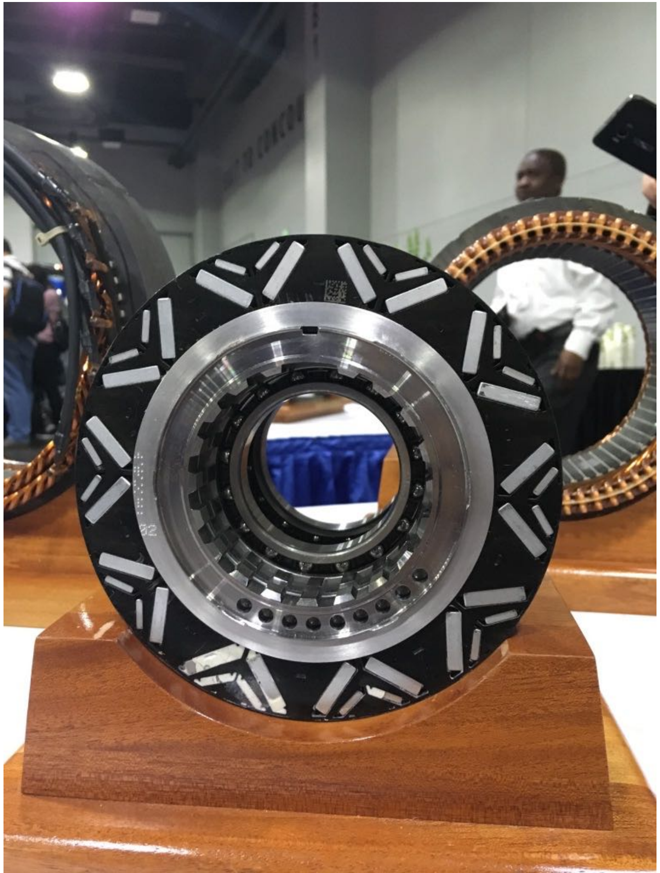


(a) Torque



(b) Harmonic content





Strutture di principio motore con rotore anisotropo (IPM)

a) SPM (isotropo)

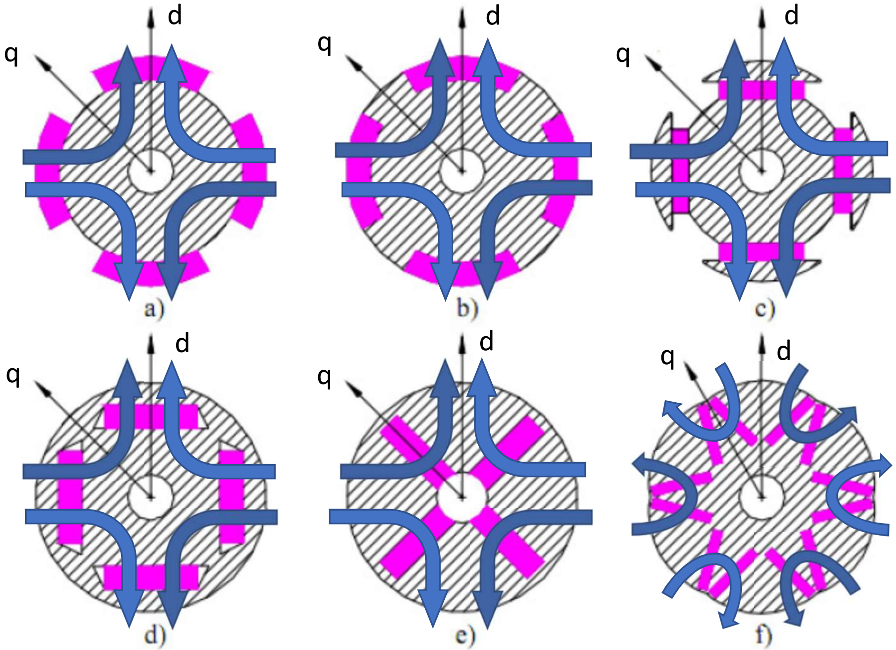
b) Inset PM (anisotropo)

c) Salient pole (isotropo|anisotropo)

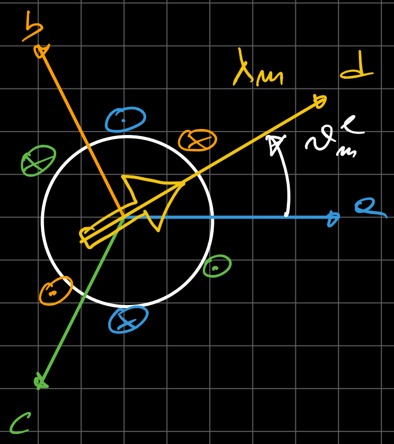
d) IPM (Interior PM) (anisotropo)

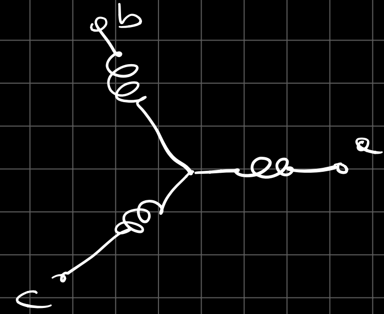
e) Spoke PM (anisotropo)

f) IPM (anisotropo)



Macchina sincrona trifase



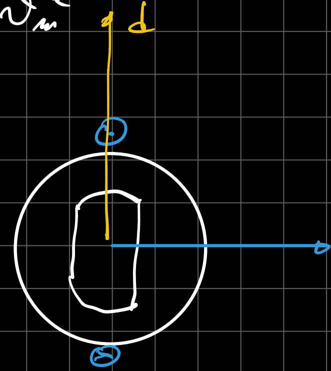


$$\begin{cases} v_a = R i_a + \frac{d\lambda_a}{dt} \\ v_b = R i_b + \frac{d\lambda_b}{dt} \\ v_c = R i_c + \frac{d\lambda_c}{dt} \end{cases}$$

Eq. Dinamiche generali

R: Resistenza di ciascuna fase

$\underbrace{\lambda_x}_{abc}$: $i_a, i_b, i_c, \vartheta_m^e$



TRASCURO LA SATURAZIONE

$$\begin{cases} \lambda_a = \lambda_{am} + \lambda_{ai} \\ \lambda_b = \lambda_{bm} + \lambda_{bi} \\ \lambda_c = \lambda_{cm} + \lambda_{ci} \end{cases}$$

↑ Flusso di rotore — ↳ Contributo della corrente

$$\begin{cases} \lambda_{am} = \Lambda_m \cos \vartheta_m^e \\ \lambda_{bm} = \Lambda_m \cos(\vartheta_m^e - 2/3\pi) \\ \lambda_{cm} = \Lambda_m \cos(\vartheta_m^e - 4/3\pi) \end{cases}$$

Hp: SIA ANCHE ISOTROPA (ROTORE LISCIO) NON DIPENDE DALLA POSIZIONE

$$\begin{cases} \lambda_{ai} = L_a i_a + M_{ab} i_b + M_{ac} i_c \\ \lambda_{bi} = M_{ba} i_a + L_b i_b + M_{bc} i_c \\ \lambda_{ci} = M_{ca} i_a + M_{cb} i_b + L_c i_c \end{cases}$$

$L_a = L_b = L_c = L_a$

$M_{ab} = M_{ba}$

$M_{ac} = M_{ba}$ ...

Possiamo scrivere dunque:

$$\begin{cases} \lambda_{ai} = L_a i_a + M i_b + M i_c = (L_a - M) i_a = L i_a \\ \lambda_{bi} = M i_a + L_a i_b + M i_c = (L_a - M) i_b = L i_b \\ \lambda_{ci} = M i_a + M i_b + L_a i_c = (L_a - M) i_c = L i_c \end{cases}$$

$i_a + i_b + i_c = 0 \qquad -i_b - i_c = i_a$

$$L = L_a - M$$ INDUTTANZA SINCRONA

$M \cong -\frac{1}{2} L_a \qquad L \cong \frac{3}{2} L_a$

I flussi sono dunque:

$$\begin{cases} \lambda_a = \Lambda_m \cos\vartheta_m^e + L i_a \\ \lambda_b = \Lambda_m \cos(\vartheta_m^e - \frac{2}{3}\pi) + L i_b \\ \lambda_c = \Lambda_m \cos(\vartheta_m^e - \frac{4}{3}\pi) + L i_c \end{cases} \qquad \vartheta_m^e = \omega_m^e t$$

$$\begin{cases} v_a = R i_a + L \frac{di_a}{dt} + \frac{d\lambda_{am}}{dt} \\ v_b = R i_b + L \frac{di_b}{dt} + \frac{d\lambda_{bm}}{dt} \\ v_c = R i_c + L \frac{di_c}{dt} + \frac{d\lambda_{cm}}{dt} \end{cases} \qquad \begin{cases} \frac{d\lambda_{am}}{dt} = -\omega_m^e \Lambda_m \operatorname{sen}\vartheta_m^e = \omega_m^e \Lambda_m \cos(\vartheta_m^e + \frac{\pi}{2}) \\ \frac{d\lambda_{bm}}{dt} = \dots = \omega_m^e \Lambda_m \cos(\vartheta_m^e + \frac{\pi}{2} - \frac{2}{3}\pi) \\ \frac{d\lambda_{cm}}{dt} = \dots = \omega_m^e \Lambda_m \cos(\vartheta_m^e + \frac{\pi}{2} - \frac{4}{3}\pi) \end{cases}$$

terna di forze contro-elettromotrici di ampiezza massima

Se ω_m^e è costante (a regime) è una terna simmetrica sinusoidale
BRUSH-LESS SINUSOIDALE SINCRONA COL ROTORE

$E_m = \omega_m^e \Lambda_m \qquad E_{RMS} = \frac{E_m}{\sqrt{2}} = \frac{\omega_m^e \Lambda_m}{\sqrt{2}}$ valori di fase

$V_{RMS} = \sqrt{3} E_{RMS} = \frac{\sqrt{3}}{\sqrt{2}} \omega_m^e \Lambda_m$ concatenato

$K_e = \sqrt{\frac{3}{2}} \Lambda_m p$: Costante di fem V·s

$K_e \cdot \omega_m = V_{RMS}$

Fine