Esempio

$V_{m,rms} = 250\,V$ concatenata

$I_{m,rms} = 200\,A$

$L = 0{,}15\,mH$

$2p = 8$

$K_E = 0{,}6 \ \dfrac{V_{rms}}{rad/s}$ ← concatenata

$R \cong 0$

$\lambda_m = ?$

$V_m = \dfrac{\sqrt{2} \cdot 250}{\sqrt{3}} = 204\,V$

$I_m = \sqrt{2} \cdot 200 = 282{,}8\,A$

concatenata

$K_E \omega_{m} = V_{rms} = \dfrac{\sqrt{3}E}{\sqrt{2}} = \sqrt{\dfrac{3}{2}}\,\omega_m^e \lambda_m = \sqrt{\dfrac{3}{2}}\,\omega_m \cdot p\,\lambda_m$

$\lambda_m = \sqrt{\dfrac{2}{3}}\,\dfrac{K_E}{p} = \sqrt{\dfrac{2}{3}}\,\dfrac{0{,}6}{4} = 0{,}122\,Vs$

① Velocità a vuoto

$\begin{cases} I_d = 0 \\ I_q = 0 \end{cases}$ $\begin{cases} \lambda_d = \lambda_m \\ \lambda_q = 0 \end{cases}$ $\begin{cases} V_d = \cancel{R I_d} - \cancel{\omega_m^e \lambda_q} \\ V_q = \cancel{R I_q} + \omega_m^e \lambda_d \end{cases}$ $\begin{cases} V_d = 0 \\ V_q = \omega_m^e \lambda_d = \omega_m^e \lambda_m \end{cases}$

Se alimento con V_m

$\omega_0^e = \dfrac{V_m}{\lambda_m} = \dfrac{204}{0{,}122} = 1672\,\dfrac{rad}{s}$

$\omega_0 = \dfrac{\omega_0^e}{p} = \dfrac{1672}{4} = 418\,\dfrac{rad}{s} \cong 4000\,rpm$

② Calcolare la ω_B

$\begin{cases} I_d = 0 \\ I_q = I_m \end{cases}$ $m = \dfrac{3}{2} p \lambda_m I_m = \dfrac{3}{2}\,4 \cdot 0{,}122 \cdot 282{,}8 = 207\,Nm$

$\begin{cases} \lambda_d = \lambda_m \\ \lambda_q = L I_m \end{cases}$ $\begin{cases} V_d = -\omega_m^e \lambda_q = -\omega_m^e L I_m \\ V_q = \omega_m^e \lambda_d = \omega_m^e \lambda_m \end{cases}$

$\left.\begin{array}{l} V_d^2 + V_q^2 = V_m^2 \\ \omega_m^e = \omega_B \end{array}\right\}$ $\begin{array}{l} (\omega_B L I_m)^2 + (\omega_B \lambda_m)^2 = V_m^2 \\ \omega_B^2\left[(L I_m)^2 + \lambda_m^2\right] = V_m^2 \end{array}$

$\omega_B = \dfrac{V_m}{\sqrt{(L I_m)^2 + \lambda_m^2}} = \dfrac{204}{\sqrt{(0{,}15 \cdot 10^{-3}\, 282{,}8)^2 + 0{,}122^2}} = 1579{,}4\,\dfrac{rad}{s}$

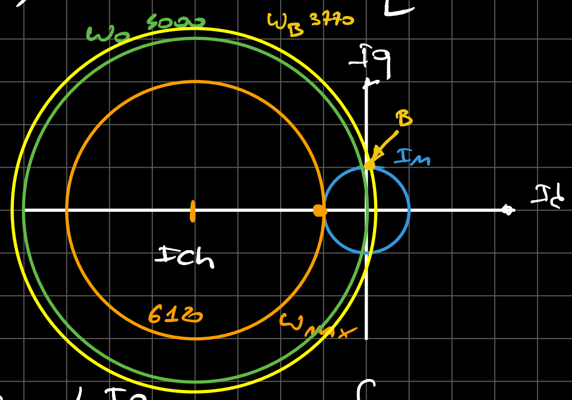
$$\omega_{B,m} = \frac{\omega_B}{p} = \frac{1579,5}{5} = 395,8 \ rad/s$$
$$= 3770 \ rpm$$

③ Massima Velocità di funzionamento

Calcolo I_{ch}

$$\begin{cases} V_d = 0 = -\omega_m^e L I_q \\ V_q = 0 = \omega_m^e (\lambda_m + L I_d) \end{cases} \qquad \begin{cases} I_q = 0 \\ I_d = -\frac{\lambda_m}{L} = I_{ch} = -\frac{0,122}{0,15 \cdot 10^{-3}} = -813,3 \ A \end{cases}$$

$$|I_{ch}| > I_M$$



Per ω_{max}

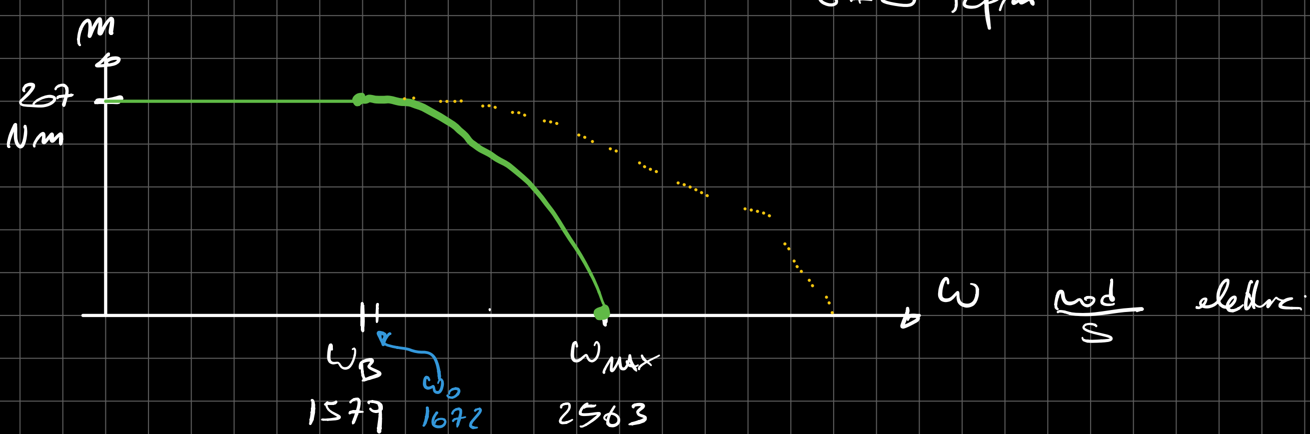
$$\begin{cases} V_d = -\omega_{max} L I_q \\ V_q = \omega_{max} (\lambda_m + L I_d) \end{cases} \qquad \begin{cases} \omega_{max} = \frac{V_M}{\lambda_m - L I_M} \end{cases}$$

$$\begin{cases} I_d = -I_M \\ I_q = 0 \end{cases}$$

$$= \frac{205}{0,122 - 0,15 \cdot 10^{-3} \cdot 282,8}$$

$$= 2563 \ \frac{rad}{s}$$

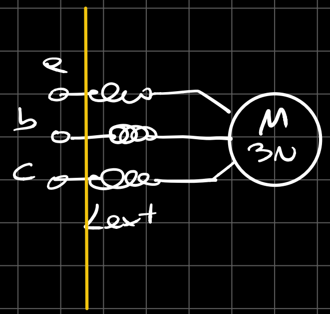
$$\omega_{max,m} = \frac{\omega_{max}}{p} = \frac{2563}{5} = 650,8 \ \frac{rad}{s}$$
$$= 612 \ rpm$$



5 Calcolare L_{ext} per aumentare ω_{max}

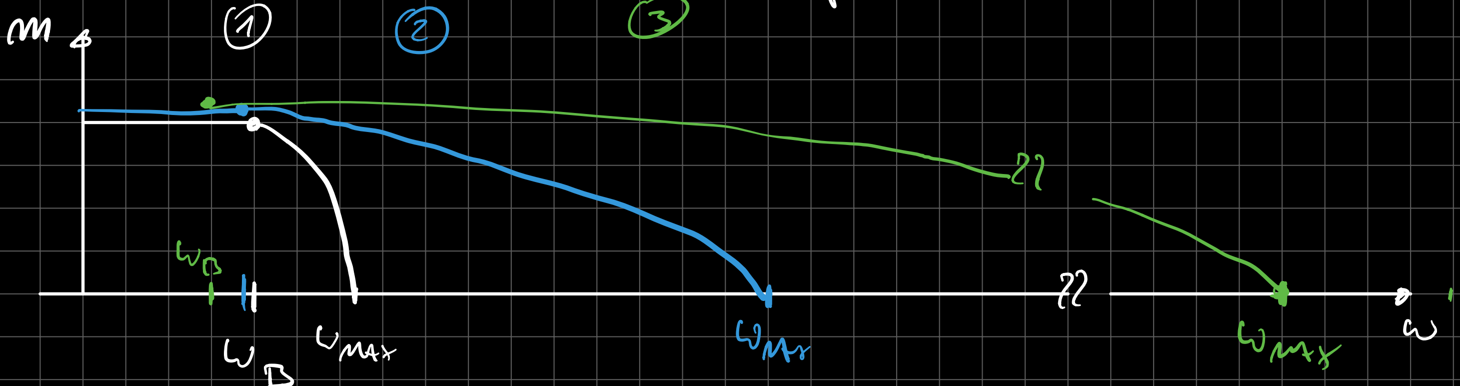
$$\omega_{max} = \frac{U_m}{\Lambda_m - L I_m}$$

$$\omega_B = \frac{U_m}{\sqrt{(\Lambda_m)^2 + (L_{tot} I_m)^2}}$$



$\Lambda_m = 0{,}122$ Vs
$U_m = 265$ V
$I_m = 282{,}8$ A
$L_{tot} = L_{ext} + L$
$L = 0{,}15$ mH

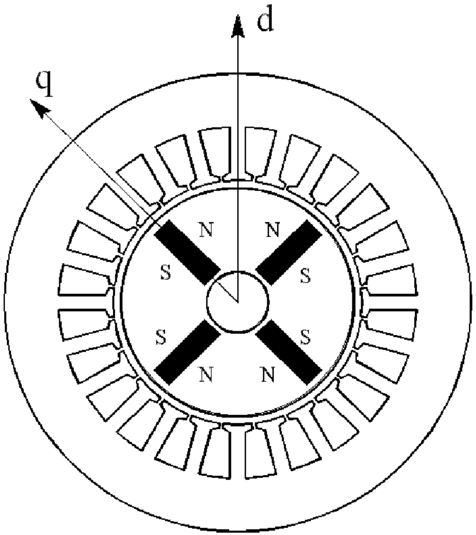
L_{ext}	0	0,15	0,25	mH
L_{tot}	0,15	0,30	0,40	mH
ω_B mecc.	395	343	306	rad/s
	3770	3270	2927	rpm
ω_{max} mecc.	640	1372	5743	rad/s
	6120	13105	54845	rpm
	1	2	3	

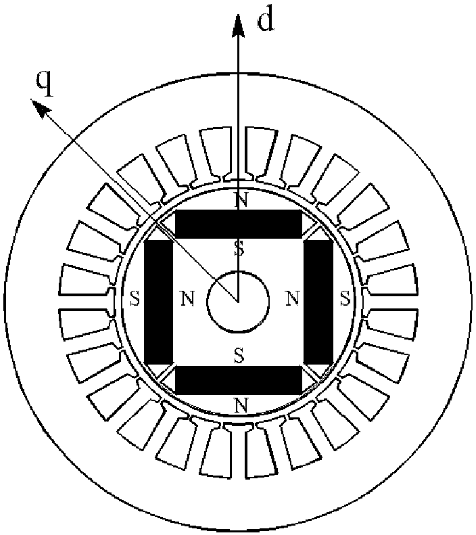


MACCHINA SINCRONA ANISOTROPA

The rotor configurations

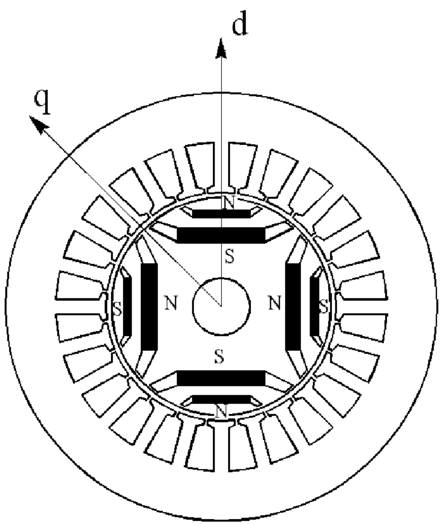
- tangentially magnetized PMs
- radially magnetized PMs

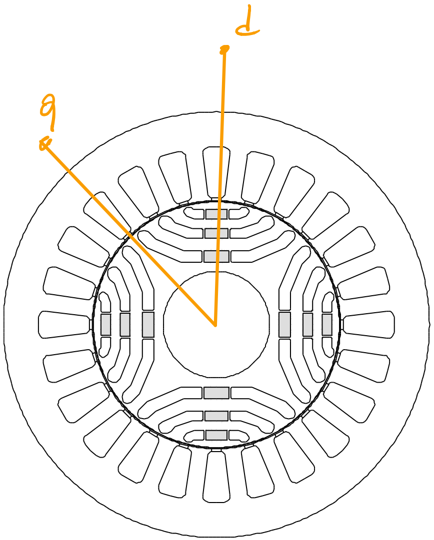


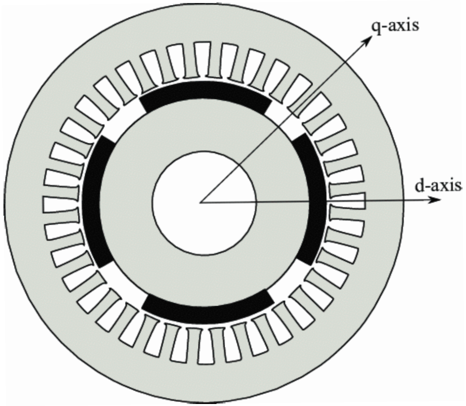


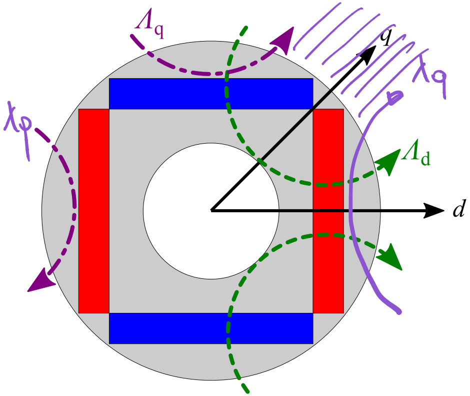
The rotor configurations

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



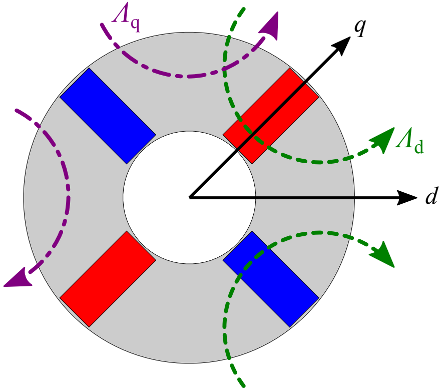


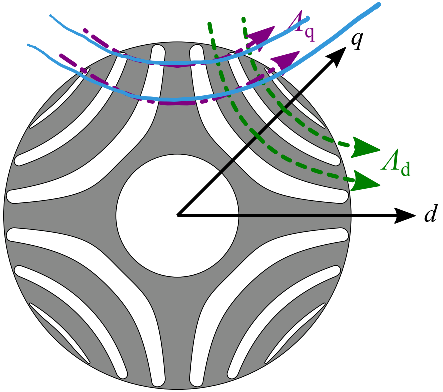




$$M = \frac{3}{2} p \, (L_d - L_q) \, i_d \, i_q$$

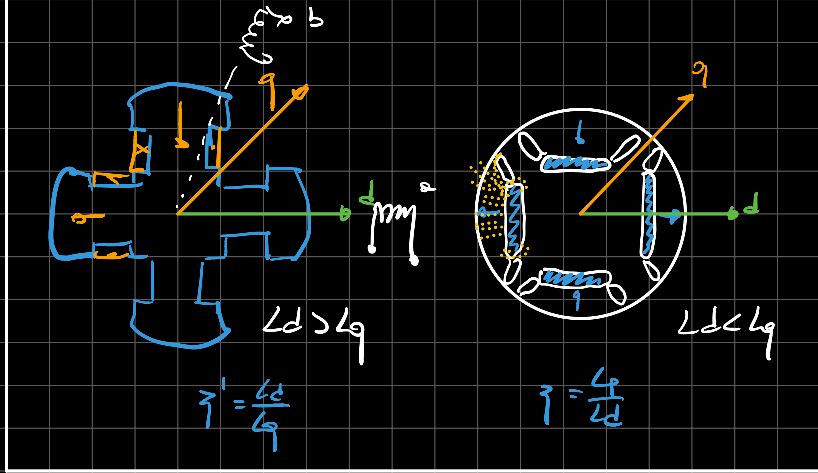
$L_d > L_q$





Per le macchine isotrope:

$$\begin{cases} v_a = R i_a + L \dfrac{di_a}{dt} + e_a \\ v_b = R i_b + L \dfrac{di_b}{dt} + e_b \\ v_c = R i_c + L \dfrac{di_c}{dt} + e_c \end{cases}$$



$$\vec{v} = R\vec{i} + L\frac{d\vec{i}}{dt} + \vec{e} \quad \alpha\beta$$

L: induttanza sincrona

$$\vec{v}^R = R\vec{i}^R + L\frac{d\vec{i}^R}{dt} + j\omega_m^e \vec{\lambda}^R \quad \text{in } dq$$

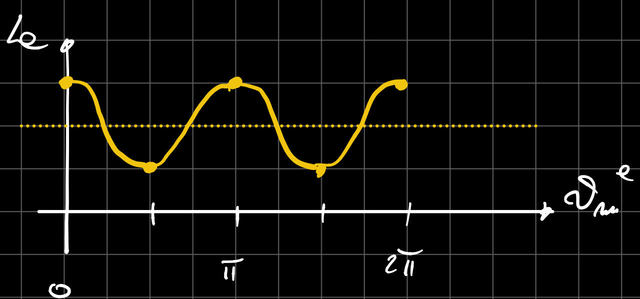
$$\begin{cases} V_d = R I_d - \omega_m^e \lambda_q \\ V_q = R I_q + \omega_m^e \lambda_q \end{cases}$$

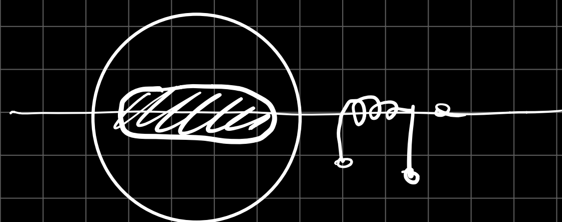
$$m = \frac{3}{2} p \lambda_m i_q$$

$$\begin{cases} \lambda_d = \lambda_m + L I_d \\ \lambda_q = L I_q \end{cases}$$

$$\begin{cases} v_a = R i_a + \dfrac{d\lambda_a}{dt} \\ v_b = R i_b + \dfrac{d\lambda_b}{dt} \\ v_c = R i_c + \dfrac{d\lambda_c}{dt} \end{cases} \qquad \begin{cases} \lambda_a = \lambda_{am} + \lambda_{a,i} \\ \lambda_b = \lambda_{bm} + \lambda_{bi} \\ \lambda_c = \lambda_{cm} + \lambda_{ci} \end{cases}$$

$$\begin{cases} \lambda_{ai} = L_a(\vartheta_m) i_a + M_{ab}(\vartheta_m) i_b + M_{ac}(\vartheta_m) i_c \\ \lambda_{bi} = M_{ab}(\vartheta_m) i_a + L_b(\vartheta_m) i_b + M_{bc}(\vartheta_m) i_c \\ \lambda_{ci} = \dots \end{cases}$$





Posso ancora usare $\alpha\beta$

$$\vec{v} = R\vec{i} + \frac{d\vec{\lambda}}{dt} \quad \text{in } \alpha\beta$$

Se sono in dq

$$\vec{v}^R = R\vec{i}^R + \frac{d\vec{\lambda}^R}{dt} + j\omega_m^e \vec{\lambda}^R$$

$$\begin{cases} v_d = R i_d + \frac{d\lambda_d}{dt} - \omega_m^e \lambda_q \\ v_q = R i_q + \frac{d\lambda_q}{dt} + \omega_m^e \lambda_d \end{cases}$$

tengo sempre i λ

Si può dimostrare

$$\begin{cases} \lambda_d = \lambda_m + L_d i_d \\ \lambda_q = L_q i_q \end{cases}$$

$$\begin{cases} v_d = R i_d + L_d \frac{d i_d}{dt} - \omega_m^e L_q i_q \\ v_q = R i_q + L_q \frac{d i_q}{dt} + \omega_m^e (\lambda_m + L_d i_d) \end{cases}$$

$$\vec{v} = R\vec{i} + \begin{bmatrix} L_d \\ L_q \end{bmatrix} \frac{d\vec{i}}{dt} \quad ?$$

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} L_d \\ L_q \end{bmatrix}^T \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 & -\omega_m^e L_q \\ \omega_m^e L_d & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega_m^e \begin{bmatrix} 0 \\ \lambda_m \end{bmatrix}$$

Calcolo la coppia

$$\underbrace{\frac{3}{2}(v_d i_d + v_q i_q)}_{④\ P_{in}} = \underbrace{P_J}_{①} + \underbrace{\frac{dW_m}{dt}}_{②} + \underbrace{P_{out}}_{③}$$

$$P_{out} = \frac{3}{2}\omega_m^e \left(\lambda_m i_q + L_d i_d i_q - L_q i_d i_q\right)$$

$$= \frac{3}{2}\omega_m \cdot p \left(\lambda_m i_q + (L_d - L_q) i_d i_q\right) = \omega_m \cdot m$$

$L_d = L_q \Rightarrow m = \frac{3}{2} p \lambda_m i_q$ "SPM"

$$m = \frac{3}{2} p \left[\underbrace{\lambda_m i_q}_{\text{COPPIA DI DOVUTA}} + \underbrace{(L_d - L_q) i_d i_q}_{\text{RILUTTANZA ANISOTROPIA}}\right]$$

$L_d < L_q \quad i_d < 0$

$\lambda_m = 0$ MOTORE A RILUTTANZA SynRM

Noto se $\lambda_m = 0$ $I_d > 0$

SALIENZA $\xi = \frac{L_q}{L_d} > 1$

SCHEMA A BLOCCHI

$$\begin{cases} v_d = R i_d + L_d \frac{d i_d}{dt} - \omega_m^e L_q i_q \\ v_q = R i_q + L_q \frac{d i_q}{dt} + \omega_m^e (\lambda_m + L_d i_d) \end{cases}$$

$$m = \frac{3}{2} p \left[\lambda_m i_q + (L_d - L_q) i_d i_q \right]$$

$$= m_L + B\omega_m + J \frac{d\omega_m}{dt}$$

- $L_d = L_q = L$
- $\lambda_m = 0$ $L_d \neq L_q$