Motore sincrono a magneti permanenti

brush-less sinusoidale
Challenge the future
Challenge the future
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>No.</td>
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<tr>
<td>Nmax RPM</td>
<td>19000</td>
</tr>
<tr>
<td>BEMF V/kRPM</td>
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</tr>
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<td>IP</td>
<td>54</td>
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<tr>
<td>Tn Nm</td>
<td>53</td>
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<tr>
<td>In Arms</td>
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<tr>
<td>IC</td>
<td>400</td>
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<tr>
<td>Tp Nm</td>
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<tr>
<td>Ip Arms</td>
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<tr>
<td>Transd.</td>
<td>82RM</td>
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<tr>
<td>Brake</td>
<td>Nm - 24Vdc</td>
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<td>Tamb. max</td>
<td>40°C</td>
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<tr>
<td>cl. F</td>
<td></td>
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</tbody>
</table>
### Solids

1. Protected against a solid object greater than 50 mm such as a hand.
2. 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 is 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.
La geometria scelta per questo progetto è di tipo a magneti permanenti interni (IPM) con magnetizzazione radiale, un esempio è riportato in Figura 3.1, per i casi a 4 e 6 poli, le frecce indicano la direzione di magnetizzazione dei magneti, i quali sono evidenziati in verde. Il vantaggio dei motori IPM, rispetto ai motori SPM, è la tenuta dei magneti soggetti a forge centrifughe. Nel caso di motori IPM con magnetizzazione tangenziale o V-Spoke sarebbe necessario optare per un elevato numero di poli, soluzione non considerata in quanto l'aumento delle frequenza richiederebbe un inverter più performante.

3.3 Caratteristiche materiali

3.3.1 Ferromagnetico
Il materiale ferromagnetico scelto per questo progetto è di tipo M400-50A. Le figure 3.2a e 3.2b riportano rispettivamente la curva di magnetizzazione e le curve di perdita specifica a diverse frequenze, queste sono il risultato di prove sperimentali su lamierini M400-50A, come riportato nei file allegati.

3.3.2 Magneti
In fase preliminare sono stati considerati magneti sia in Neodimio Ferro Boro (NdFeB) che Ferrite, in quanto quest'ultimo, sebbene presenti deboli caratteristiche magnetiche, ha un costo molto contenuto se paragonato a magneti in terre rare.
The geometry of the flux-barrier is simply described by the thickness placed on the inner surface of the stator. Then, a structure with two flux-barriers per pole that is considered in the analysis. As shown in Fig. 3, the subscript “1” is used for the potentials of each rotor magnetic island.

The magnetic potential of the rotor is the harmonic order, \( \nu \) of the stator winding configuration. (a) Torque ripple. (b) 12th harmonic. (c) 24th harmonic.

\[
U_1 = \sum_{n=1}^{\infty} \left( U_{n1B} \cos(n \beta) \sin(n \theta) r \right)
\]

\[
U_2 = \sum_{n=1}^{\infty} \left( U_{n2B} \sin(n \beta) \sin(n \theta) r \right)
\]

where \( \beta \) is the harmonic order, \( \theta \) is the variable of position, \( r \) is the variable of radius. The quantities are defined in the rotor reference frame.

Finally, the air-gap flux density distribution is given by:

\[
B_{g}(r) = \frac{1}{2 \pi} \int_{\theta_{m}}^{\theta_{m} + 180^\circ} B_{s}(r, \theta) d\theta
\]

Even though the analytical model is affected by inevitable simplifications that yield imprecision in predicting the absolute values, it still allows us to individuate optimal rotor configurations.

TABLE I: The magnetic potential of the rotor within an electrical pole. Therefore, the rotor potential can be expressed as the composition of the potential in each flux-barrier and the air-gap, and zero elsewhere. It follows that the rotor potential can be computed as the sum of the separate contributions due to the stator magnetic potential, and Fig. 5(b) shows the air-gap potential.

Fig. 6 presents the comparison between the torque behavior achieved with the analytical model and the FE analysis with linear model. (a) Stator magnetic potential. (b) Air-gap flux density.

Referring to the 12-slot 10-pole machine, a parametric analysis of flux-barrier angles \( \beta \) is reported in [19]. It could be noted that flux-barrier angles \( \beta \) that exhibit a low value of the 24th-order harmonic have been selected.

In Fig. 7(b) and (c) but also in phase according to the position of flux-barrier angles \( \beta \), it is possible to select two couples of flux-barrier angles \( \beta \), along the air-gap angle for the synchronous reluctance machine.

In particular, Fig. 5 shows the adopted reference frame and the simplified rotor structure with two flux-barriers per pole has been adopted to validate the proposed model. The iron and steel that are additional simplification is related to the iron and steel that are considered in the analysis results with linear model.
\[ \frac{\Delta w}{\Delta t} = 0.5 \]

\[ \frac{\Delta w}{\Delta t} = 0.8 \]
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)
Equazione del tutto generale

\[ \begin{align*}
\sigma_a &= R_{ie} + \frac{d\lambda e}{de} \\
\sigma_b &= R_{ib} + \frac{d\lambda b}{de} \\
\sigma_c &= R_{ic} + \frac{d\lambda c}{de}
\end{align*} \]

Equazione del tutto generale

R: Resistenza [\Omega] di ciascuna fase
Sono colte anche se l'interazione
\( \lambda \) dipende da \( \sigma_{ie,ib,ic} \), per cui

\( \lambda \): TRASZUCO SATURAZIONE

\[ \begin{align*}
\lambda e &= \lambda em + \lambda ei \\
\lambda b &= \lambda bm + \lambda bi \\
\lambda c &= \lambda cm + \lambda ci
\end{align*} \]

Fissate le resistenze

\( \lambda \): CONSIDERO MACCHINA ISOTROPA

amb e minus seconde \( (\lambda x_1) \) non dipendono dalla posizione

\[ \begin{align*}
\lambda_{ei} &= \lambda_{eie} + M_{eb} + M_{ec} \\
\lambda_{bi} &= M_{be} + \lambda_{b} + M_{bc} \\
\lambda_{ci} &= M_{ce} + M_{bi} + \lambda_{c}
\end{align*} \]

\[ \begin{align*}
\lambda_{ei} &= \lambda_{eie} + M_{eb} + M_{ec} \\
\lambda_{bi} &= M_{be} + \lambda_{b} + M_{bc} \\
\lambda_{ci} &= M_{ce} + M_{bi} + \lambda_{c}
\end{align*} \]

\[ \begin{align*}
\lambda_{ei} &= (L - M) \cdot i_e = L \cdot i_e \\
\lambda_{bi} &= (L - M) \cdot i_b = L \cdot i_b \\
\lambda_{ci} &= (L - M) \cdot i_c = L \cdot i_c
\end{align*} \]
\[ L = L_a - M \quad \text{INDUTTANZA sincrona} \]

Ricorda: \[ M = -\frac{1}{2} L_a \quad L = \frac{3}{2} L_a \]

\[ \begin{align*}
\lambda_{am} &= \lambda m \cos \varphi_m^e \\
\lambda_{bm} &= \lambda m \cos (\varphi_m^e - \frac{\pi}{2}) \\
\lambda_{cm} &= \lambda m \cos (\varphi_m^e - \frac{\pi}{4})
\end{align*} \]

\[ \varphi_m^e = p \varphi_m \quad 2p \text{ è poli del motore} \]

\[ \begin{align*}
\lambda_a &= \lambda m \cos \varphi_m^e + L i_a \\
\lambda_b &= \lambda m \cos (\varphi_m^e - \frac{\pi}{2}) + L i_b \\
\lambda_c &= \lambda m \cos (\varphi_m^e - \frac{\pi}{4}) + L i_c
\end{align*} \]