Numerical Calculation of the Three Dimensional Inter-Bar Current Distribution in Induction Machines

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Abstract

The proposed numerical model is used to study the influence of inter-bar currents by investigating the three dimensional field solution in COMSOL Multiphysics. Since the focus is on the rotor, the whole stator geometry is replaced by surface current densities in terms of Neumann boundary conditions. This includes the winding heads. An alternative way of modelling the rotor lamination is presented. All iron sheets are replaced by one domain.

The simplifications help to reduce the size and by this also the effort to solve the model. The results show that the motors operating behaviour changes dramatically over the range of the inter-bar resistance. With the chosen approach to respect the rotor stacking, it is possible to investigate the behaviour of inter-bar currents for different rotor laminations. According to the results, the stacking only has a small influence on the inter-bar currents.

Model

1. Assumptions:

- $\mu \rightarrow \infty$ in the stator iron
- current sheets are placed on the airgap surface
- permeance functions for stator slotting

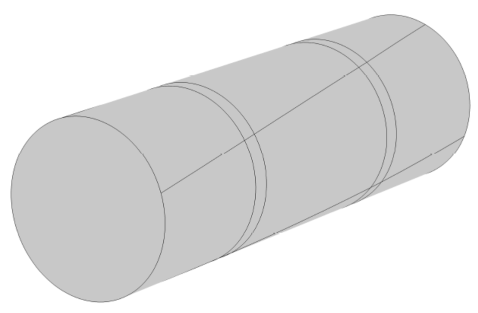


Figure 1: Geometry ends at airgap boundary

2. Geometry:

- stator is replaced by a Neumann BC
- rotor is geometrically skewed

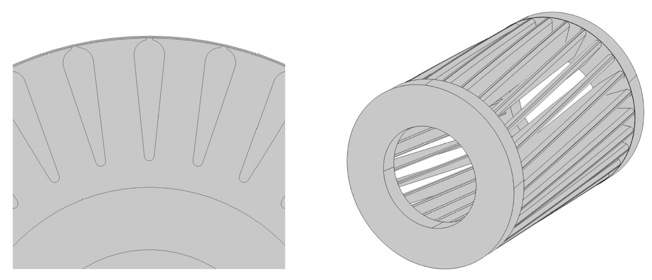


Figure 2: Cutted view and skewed rotor &

3. PDE & BC's & MMF

- harmonic approach for the magnetic vector potential and electric scalar potential:

$$\vec{\nabla} \times \tilde{\mu}^{-1} \left(\vec{\nabla} \times \underline{\vec{A}} \right) = -j\omega\tilde{\kappa}\underline{\vec{A}} - \tilde{\kappa}\vec{\nabla}\underline{\varphi} + \vec{J}_\mathrm{e}$$

- surface current (Neumann BC) is derived from the MMF

$${}^{\nu}\underline{\vec{j}}_{\mathrm{s,fe}}(x_2) = \begin{bmatrix} 0 \\ 0 \\ -j\nu\,{}^{\nu}c\,\sqrt{2}\underline{I}_1 \exp j\left[{}^{\nu}s\omega t - \nu x_2\right] \end{bmatrix}$$

$${}^{\nu}\underline{\vec{j}}_{\mathrm{s,air}}(x_2, z) = \begin{bmatrix} 0 \\ -\sin\left[\pi/h(z - l_\mathrm{z}/2)\right]/2 \cdot w\,{}^{\nu}c\,\sqrt{2}\underline{I}_1 \\ \cdot \exp j\left[{}^{\nu}s\omega t - \nu x_2\right] \\ -j\nu\,{}^{\nu}c\,\sqrt{2}\underline{I}_1 \cdot \left(\cos\left[\pi/h(z - l_\mathrm{z}/2)\right] + 1\right)/2 \\ \cdot \exp j\left[{}^{\nu}s\omega t - \nu x_2\right] \end{bmatrix}$$

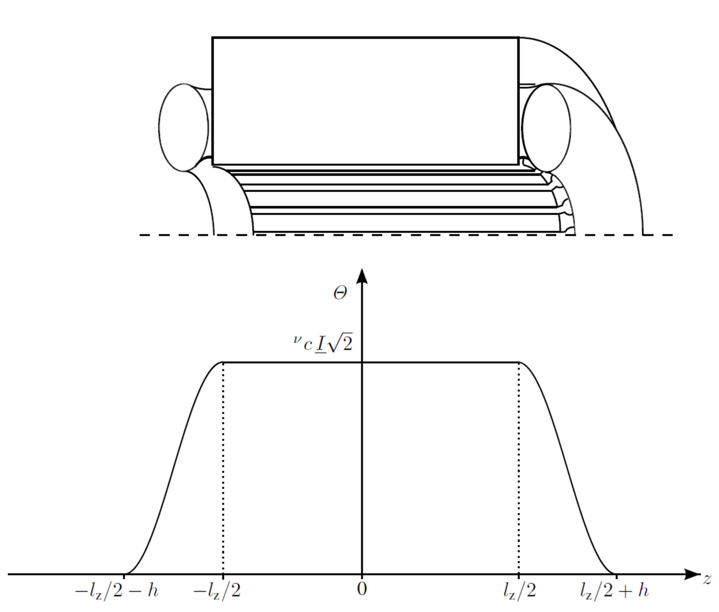


Figure 3: Magnetomotive force in the y,z-plane

4. Inter-bar resistance as transition condition

$$\vec{n} \cdot \vec{J} = \left(\frac{1}{r_\mathrm{q}} + j\omega C_\mathrm{q} \right) \cdot (\varphi_1 - \varphi_2)$$

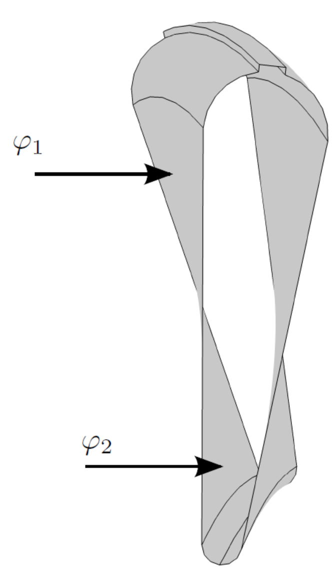


Figure 4: Substitution domain for the rotor iron core

Voltage Equation

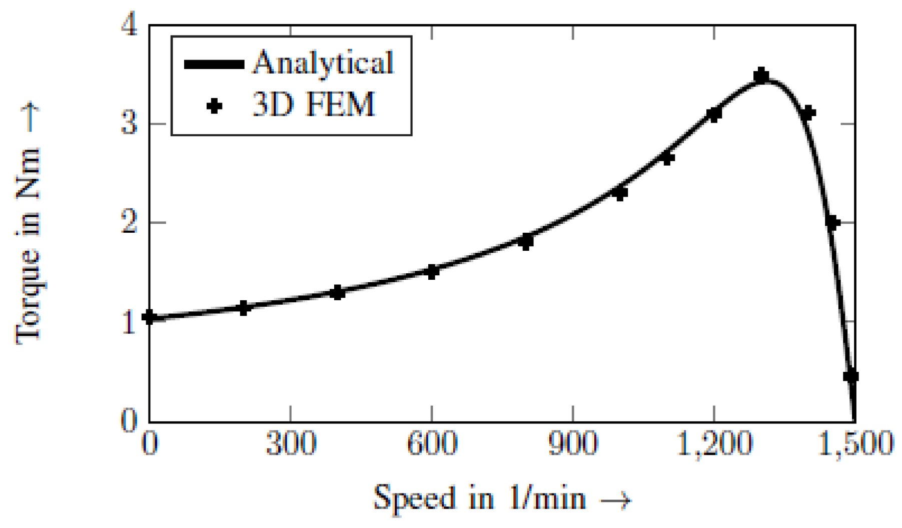
$$U = (R_1 + j\omega L_{\sigma,1}) \cdot \underline{I}_1 + j\omega\underline{\Psi}_\delta$$

$$\underline{\Psi}_\delta = k_\mathrm{w} w \, \underline{\Phi}_\mathrm{pole}$$

$$\underline{\Phi}_\mathrm{pole} = \iint_{\text{pole area}} \underline{\vec{B}}_\delta \, \mathrm{d}\vec{a}$$

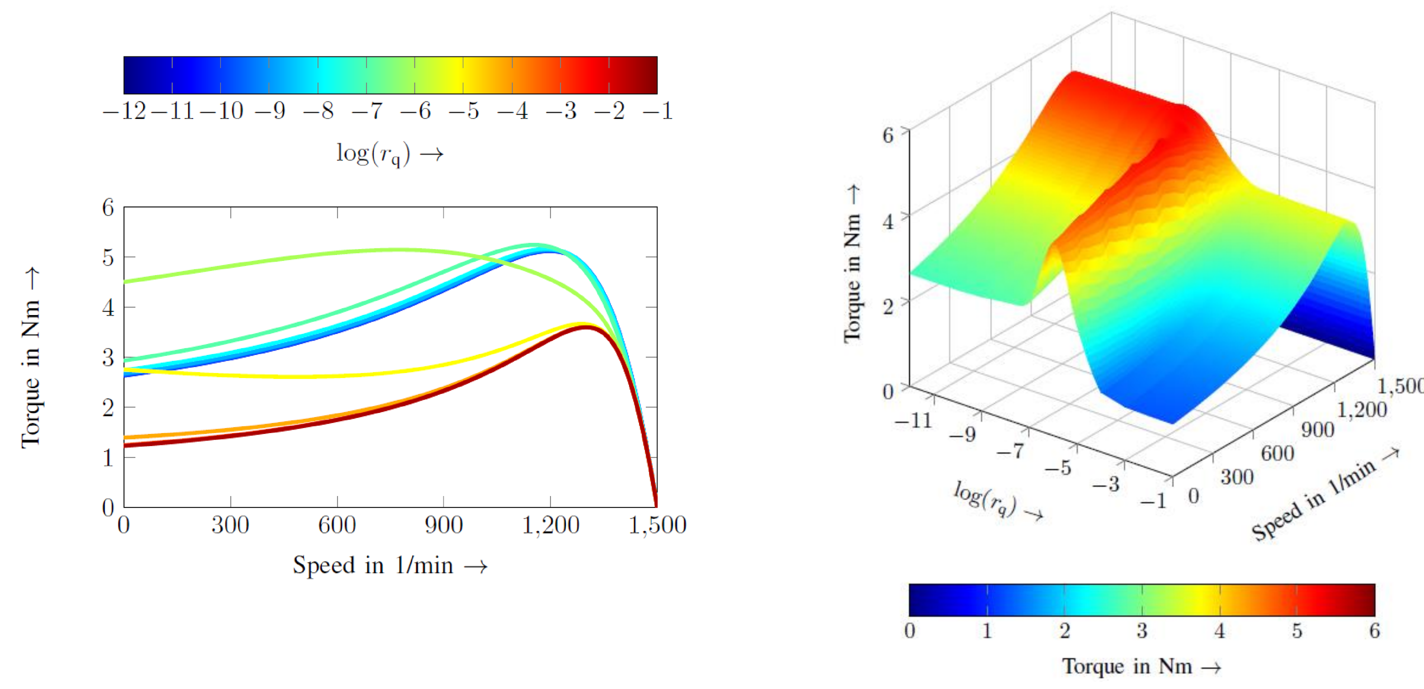
Verification

$U_{1,2}$ [V]	100
f [Hz]	50
ν_max [1]	2
$\mu_\mathrm{r,Fe}$ [1]	∞
k_s []	1
r_q [Ω/m^2]	∞



Results

1. Torque as a function of the inter-bar resistance:



2. Visualisation of the path of the inter-bar current

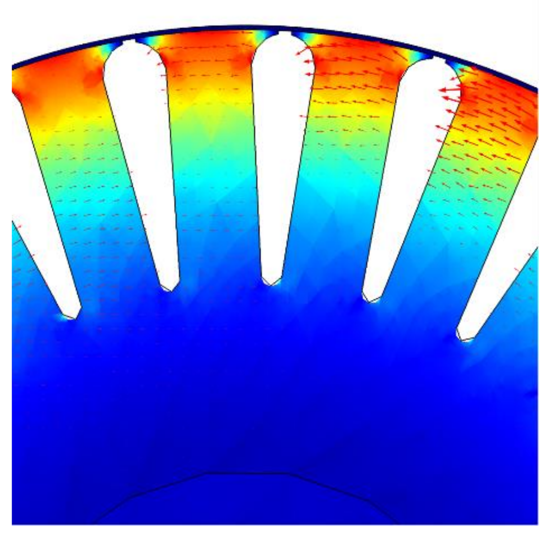


Figure 5: current path for a small inter-bar resistance

Conclusions

- The torque strongly depends on the inter-bar resistance,
- it seems that low inter-bar resistances neutralise the effects of skewing,
- the good agreement of the 3D FEM and the analytical results show that the implementation of the voltage equation, including the flux calculation, were programmed correctly.