Investigation of the magneto-mechanical effect on the magnetic properties of PMSMs using finite element analysis

Achref Douiri[a], Timo Hörmann[a], Simon Steentjes[a] and Nora Leuning[a]

[a] *Institute of Electrical Machines (IEM), RWTH Aachen University, Germany.*

The magnetization behavior of non-oriented electrical steels, commonly used in Permanent Magnet Synchronous Machines (PMSMs), is sensitive to mechanical stress, leading to increased iron losses and reduced magnetic permeability. However, standard PMSM models often overlook the spatial orientation of magnetization and mechanical stress, simplifying magneto-mechanical effects through scalar approximations. This paper models the multi-axial relationships instead of relying on such approximations. By implementing a magneto-mechanical magnetization model within a finite element analysis (FEA), the paper investigates the combined effects of magnetic field orientation and mechanical stress on PMSM performance.

Keywords: PMSM; mechanical stress; magneto-mechanical effects; electrical steel; finite element analysis

1. Introduction

High-efficiency electrical machines are developed to meet the growing demand for energy-efficient solutions in electric mobility, renewable energy, and industrial automation. PMSMs are recognized for their high-power density and dynamic performance, driven by laminated electrical steel sheets. One major factor affecting PMSM performance is mechanical stress, which influences magnetic properties. Non-oriented electrical steels, widely used in these machines, show mechanical-stress-dependent magnetization behavior [1]-[3]. Mechanical stress from manufacturing, assembly, or operation alters permeability, increases core losses, and reduces efficiency [4]. However, standard models often simplify magneto-mechanical effects, relying on scalar approximations that fail to capture the multi-directional interactions, leading to performance prediction errors [5]. Additionally, the lack of advanced measurement techniques for mechanical stress and the challenges posed by both static and dynamic mechanical stress in rotating machines contribute to this knowledge gap. To address this, the paper presents an FEA accounting for multi-axial stress to improve PMSM performance prediction.

2. Methods and Expected Results

To evaluate the impact of magneto-mechanical effects on PMSM performance, a modeling approach is developed that incorporates the influence of mechanical stress and magnetic field strength on polarization. Figure 1 presents the simulation workflow. The material model replicates the dependence of magnetic properties on the principal mechanical stress σ and the angle $\theta_{\sigma B}$, which represents the orientation between the maximum principal stress and the applied magnetic flux density as shown in Figure 2. The results illustrate a strong correlation between reluctivity and the magnetic field strength, with ν increasing significantly at higher values of B^2, particularly for larger angles $\theta_{\sigma B}$. Due to this dependence, a 2D-mechanical-stress analysis is also conducted to capture the influence of mechanical stress distribution in the machine. By integrating these factors into the finite element model, the study offers a more accurate simulation of magneto-mechanical interactions. The simulations are conducted across different operating points and conditions, demonstrating how mechanical stress influence the magnetic properties of PMSMs.

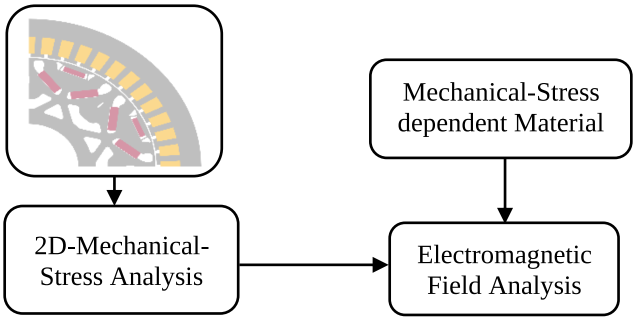

Figure 1: Simulation Workflow for Magneto-Mechanical Analysis.

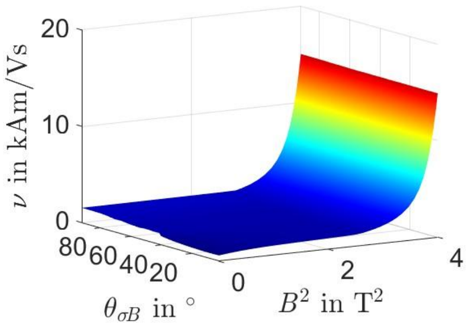

Figure 2: The magnetic reluctivity ν as a function of B^2 and $\theta_{\sigma B}$ for a mechanical stress of σ = 330 MPa

References

[1] Weiss, H. A., Leuning, N., Steentjes, S., Hameyer, K., Andorfer, T., Jenner, S., & Volk, W. (2017). Influence of shear cutting parameters on the electromagnetic properties of non-oriented electrical steel sheets. *Journal of Magnetism and Magnetic materials, 421*, 250-259.

[2] Leuning, N., B. Schauerte, and K. Hameyer. "Interrelation of mechanical properties and magneto-mechanical coupling of non-oriented electrical steel." *Journal of Magnetism and Magnetic Materials* 567 (2023): 170322.

[3] PremKumar, R., Samajdar, I., Viswanathan, N. N., Singal, V., & Seshadri, V. (2003). Relative effect (s) of texture and grain size on magnetic properties in a low silicon non-grain oriented electrical steel. *Journal of Magnetism and Magnetic Materials, 264(1)*, 75-85.

[4] Karthaus, J., Steentjes, S., Leuning, N., & Hameyer, K. (2017). Effect of mechanical stress on different iron loss components up to high frequencies and magnetic flux densities. *COMPEL-The international journal for computation and mathematics in electrical and electronic engineering, 36(3)*, 580-592.

[5] Fonteyn, K., Belahcen, A., Kouhia, R., Rasilo, P., & Arkkio, A. (2010). FEM for directly coupled magneto-mechanical phenomena in electrical machines. *IEEE Transactions on Magnetics, 46(8)*, 2923-2926.