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JOHANNES KEPLER UNIVERSITY LINZ

SyMSpace Days

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Reducing the Finite Element Analysis Based Electric Machine Simulation Effort to a Sixth without the Requirement of Specific Mesh Settings

Outline

Introduction

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- For the design of electric machines, **optimization tools** are used to find the best configuration for given objectives and constraints.
- Several approaches concerning the **reduction of the simulation effort** of electrical machines for the finite element method (FEM) include the use of techniques such as ***model reduction***, ***adaptive meshes*** and ***parallel processing***.
- Spatial **symmetries** are utilized such that only a sector assigned with periodic boundaries is evaluated.
- Considering the rotor angle dependency, it is well known that torque and flux linkage of a symmetric three-phase machine can be determined based on only **analyzing a sixth of an electrical period**.

Introduction

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- Generally, **flux reconstruction** is a well known technique and has been widely used in electric machine modeling.
- To make use of such **periodic symmetries**, typically a symmetric and thus **equal mesh** with regard to the individual components is required.
- Given the technology in **commercial FE analysis**, the symmetric mesh is a quite common technique. A **symmetric mesh** facilitates a flux reconstruction in a very simple way, because the vector potential between nodes **does not need to be interpolated**.
- While some tools allow for specifying such a particular mesh setting, the major share does not.
- FEMM4.2 is used as the finite element simulation tool the software platform ***SyMSpace***.
- This tool is suitable for using **complex post-processing** tasks.

FE-Model

- A permanent magnet synchronous machine with twelve slots and four pole-pairs (12-slot-8-pole topology) is investigated here:
  - Pol pairs, $p_z = 4$
  - Number of teeth, $N_s = 12$
  - Number of phases, $m = 3$, double-layer, concentrated winding

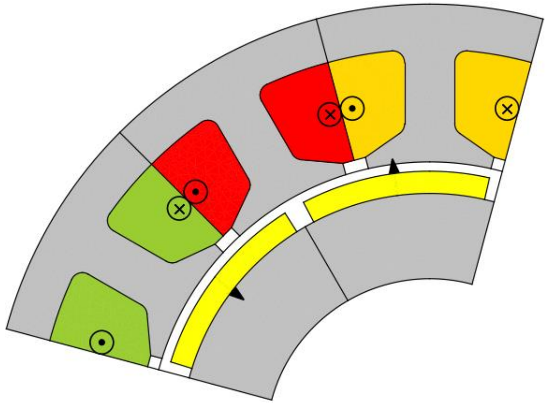


Figure 1. Machine design model

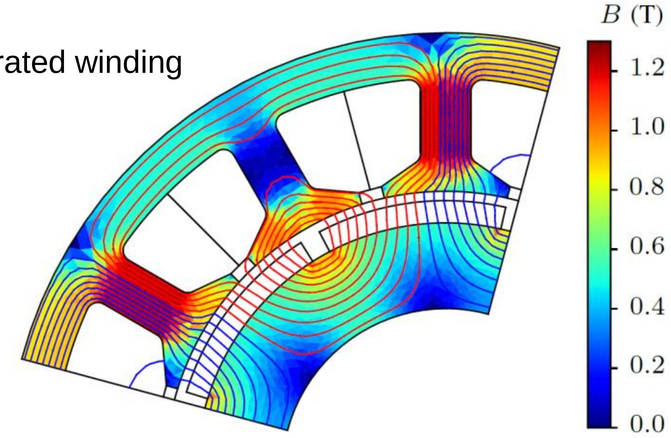


Figure 2. Instant flux density distribution for no-load of the machine design under investigation.

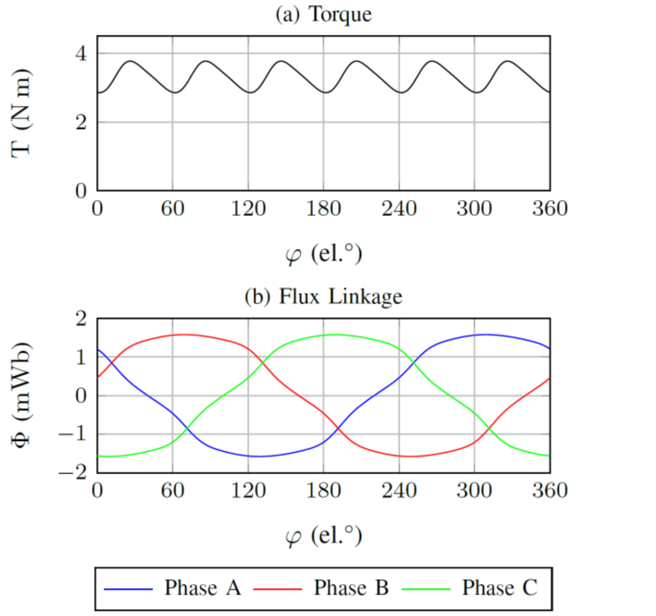
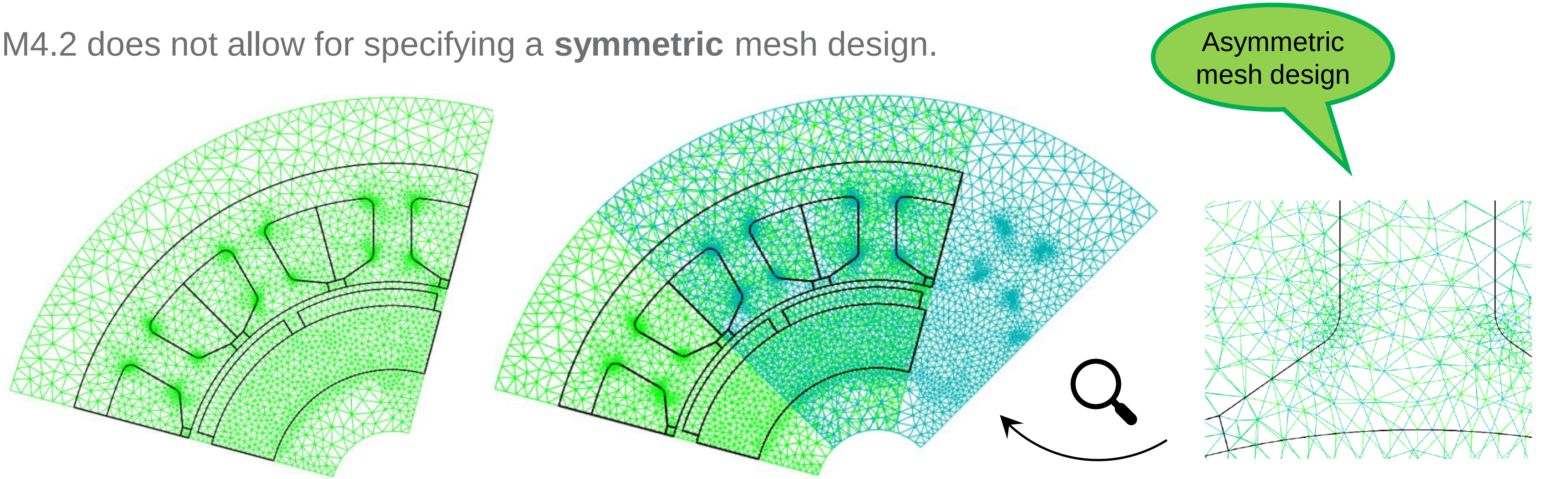


Figure 3. Results of (a) Torque T and (b) Flux Linkage Φ of load simulation.

Modeling Approach

- FEMM4.2 does not allow for specifying a **symmetric** mesh design.



(a) Initial FE mesh.

(b) FE mesh rotated by one tooth pitch.

(c) Detail zoom for mesh asymmetry clarification.

Figure 4. Finite element mesh of model under investigation.

- When comparing the mesh design in the teeth, the asymmetry of the mesh becomes obvious.

Modeling Approach

- **Flux** and **torque reconstruction** is a well known technique and has been widely used in electric machine modeling.

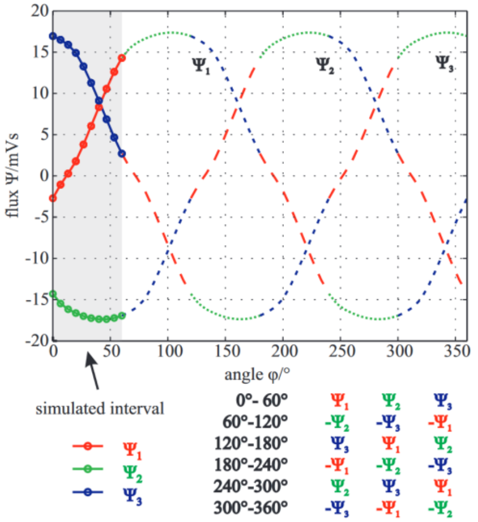


Figure 5. Principle of flux reconstruction. [15]

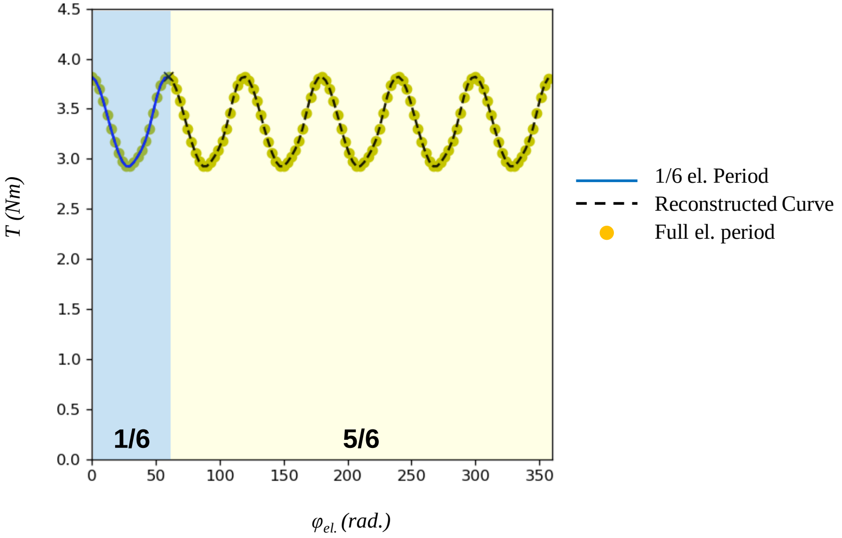
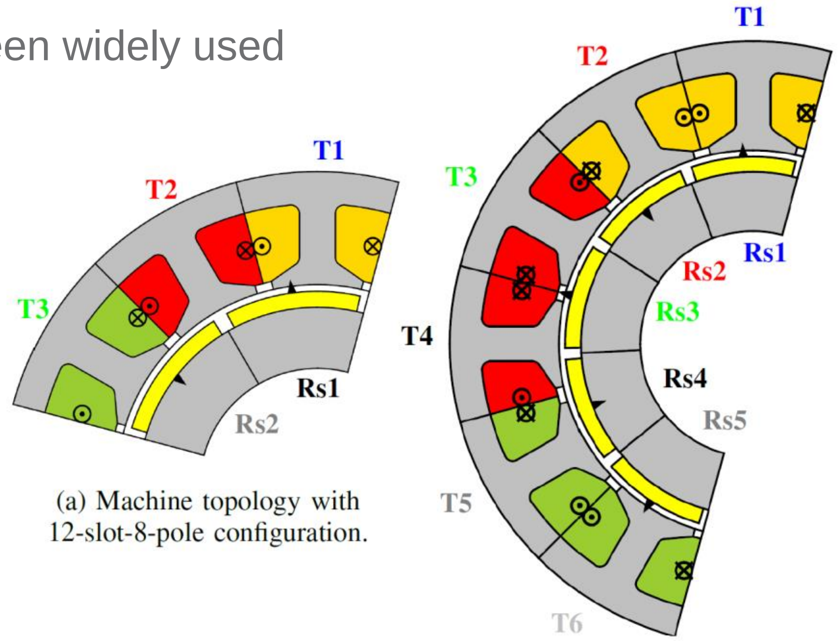


Figure 6. Principle of torque reconstruction.



(a) Machine topology with 12-slot-8-pole configuration.

(b) Machine topology with 12-slot-10-pole configuration.

Figure 7. Machine design models under investigation.

Modeling Approach

- In order to calculate the iron losses, the **flux density** curve of each finite element must be determined. The **iron loss model** used is based on this.
- The basis for determining the flux density is the **vector potential** of nodes in the FE mesh. Due to the **asymmetry** of the finite element mesh, the vector potential has to be **interpolated**.
- A load point is simulated for further investigation.
- Depending on the machine topology, the **waveforms** of the vector potentials are **reconstructed differently**.

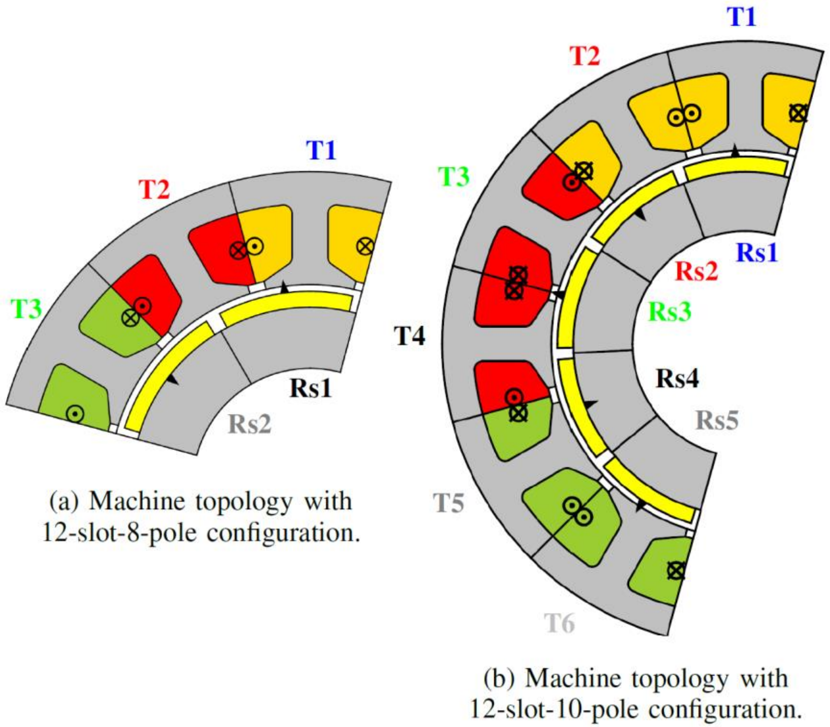


Figure 7. Machine design models under investigation.

Finite Element Modeling Results

- Due to the symmetry of the geometry and topology in case of a 12-slot-8-pole topology, as considered here in more detail, the vector potential curves at points P_A, P_B, and P_C are basically the same, but phase-shifted.
- The stator is divided into three sections (**T1**, **T2**, and **T3**) as shown in Fig. 5.
- For the vector potential signals in the stator tooth **T1**, a simulation over 1/6 of an electrical period results in the sequence **T1**, **-T2**, **T3**, **-T1**, **T2**, **-T3**, each representing 1/6 of an electrical period to achieve a complete electrical period.
- In order to reconstruct the vector potential for a complete electrical period in the rotor, the sequence of **Rs1**, -**Rs2**, **Rs1**, -**Rs2**, **Rs1**, -**Rs2** must be fulfilled for points in the rotor segment **Rs1**.

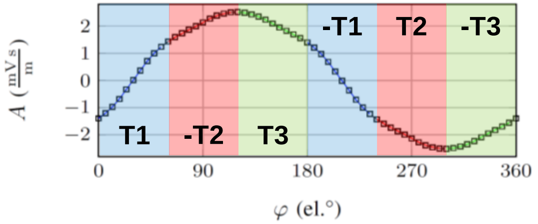


Figure 9. Principle of vector potential reconstruction.

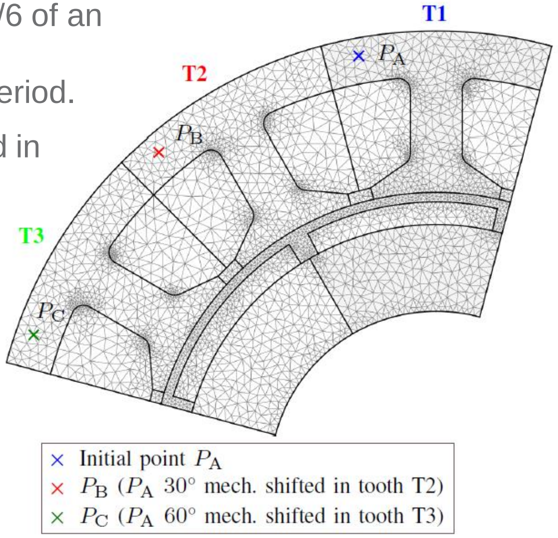


Figure 8. Initial asymmetric FE mesh.

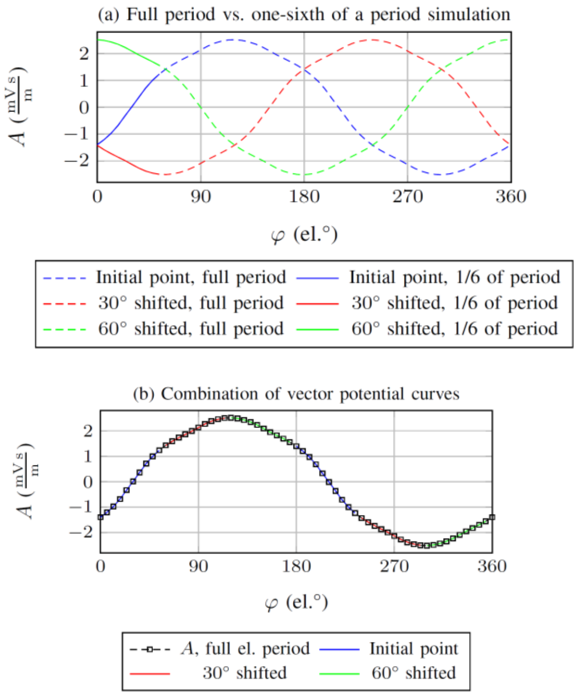


Figure 10. Vector potential characteristics for the evaluation points illustrated in Fig. 8 and the comparison of results for original data and 60° information for all three points.

SyMSpace Integration

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- The specification for simulation over 1/6 of an electrical period and reconstruction of the signals is defined via the parameter "*ReducedSimulation*".

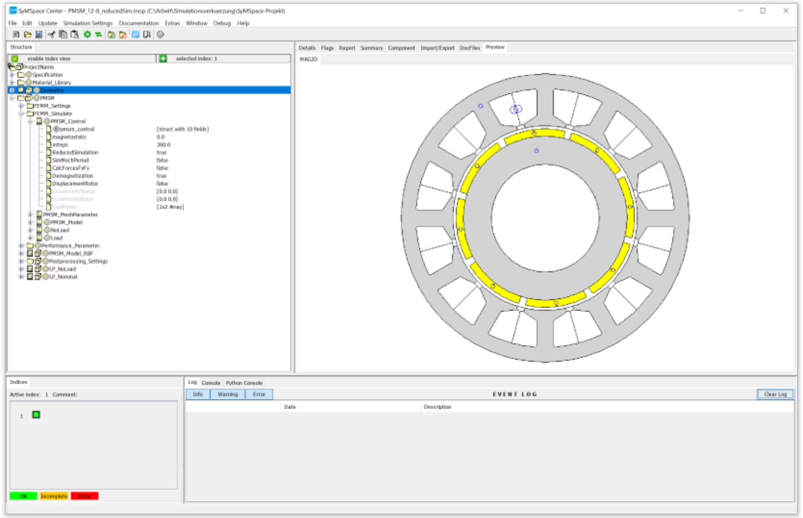


Figure 11. SyMSpace project.

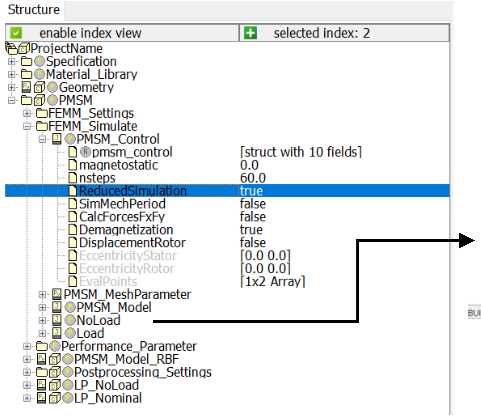


Figure 12. SyMSpace project structure.

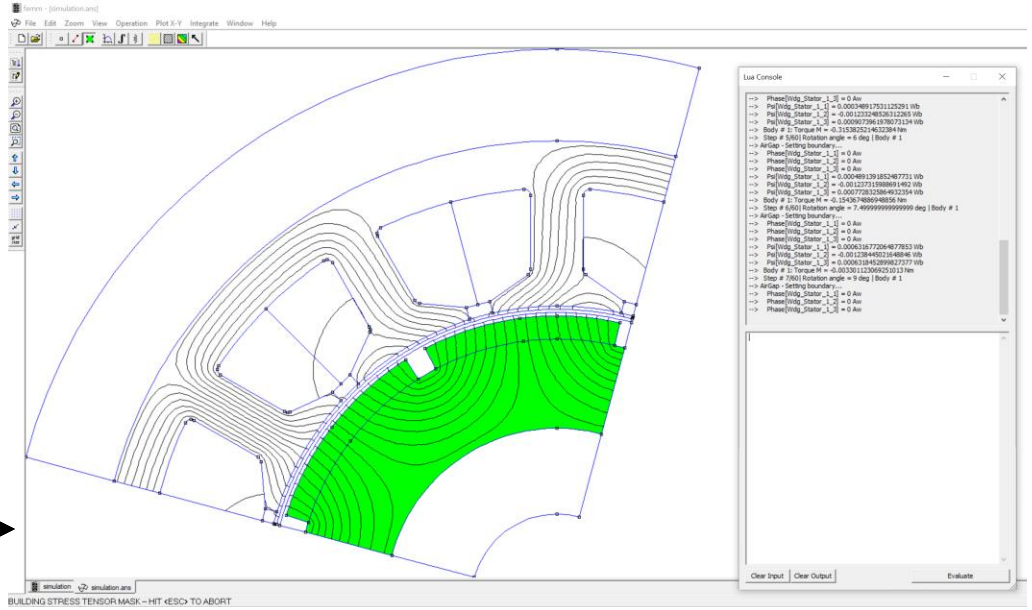
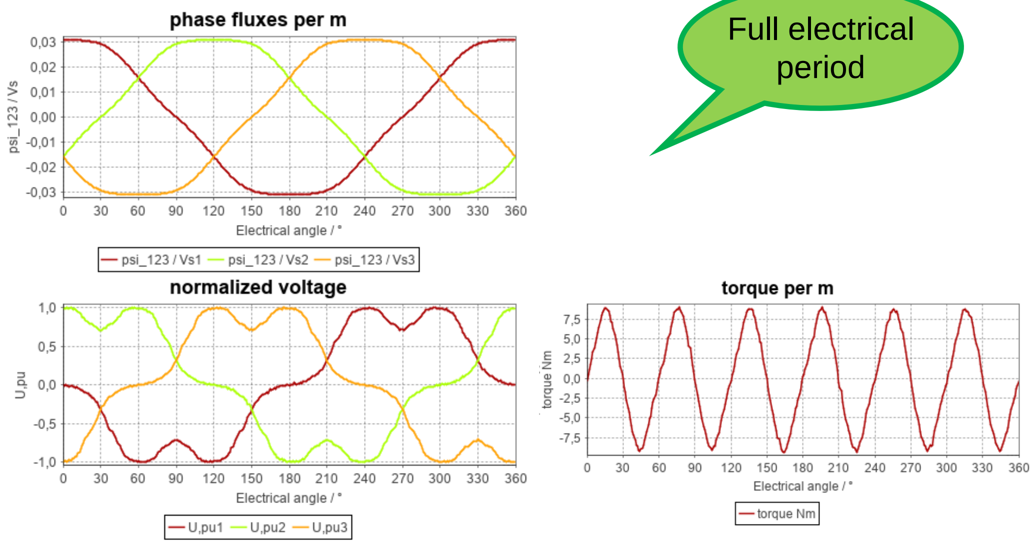


Figure 13. Finite element simulation (no-load).

SyMSpace Integration

- **Comparison -- *NoLoad*-Simulation-Results:**
  - **Results seem to be in good agreement.**

Full electrical period



One sixth of an electrical period.

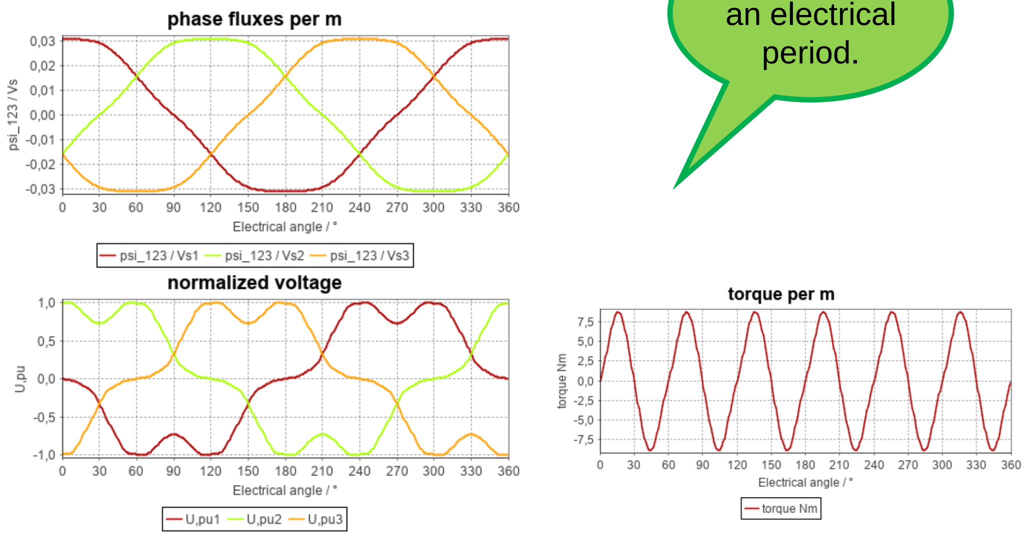


Figure 14. SyMSpace noload-results.

Simulation Results

- **Comparison -- *Load*-Simulation-Results:**
  - In addition to the **torque** and the **flux** linkage, the **iron losses** are also relevant for a comparison.
  - The computation time t_s required for different mesh densities including post-processing methods for a full electrical period (cases 1 and 2) and the approach proposed here (cases 3 and 4).
  - By reducing the mesh density ρ_{fem} and considerung a full electrical period, the calculation accuracy decreases insofar as this results in a difference of Δ_{pfe} equal to 2.5% in the estimated specific iron losses (case 2). are listed.
  - Considering the proposed approach for reducing the computation effort to 1/6 of an electrical period, it is obvious that the computation accuracy is significantly reduced (case 4).
  - Case 3 provides the most satisfactory results in terms of an effective improvement in computation effort taking into account accurate results.

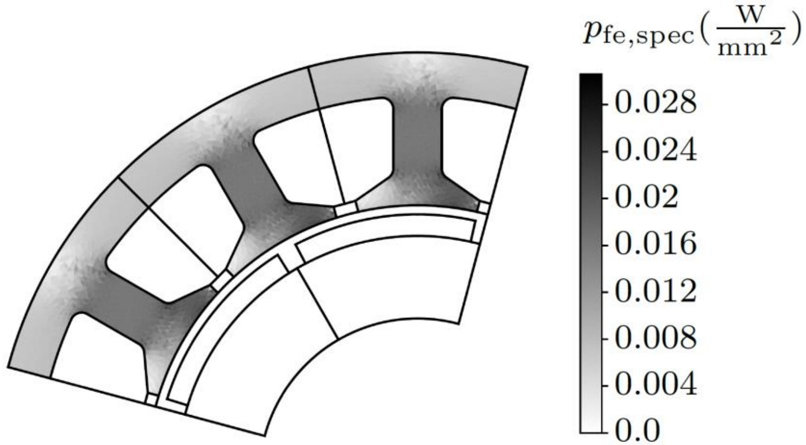


Figure 15. Specific stator iron loss distribution.

Table I
FE SIMULATION RESULTS FOR 12-SLOT-8-POLE MACHINE TOPOLOGY.

Case	Simulation conditions	ρ_{fem} [mm^{-2}]	t_s [s]	Δp_{fe} [%]
1	full el. period (reference)	24.5	1286	0.0
2	full el. period	5.1	645	2.5
3	sixth el. period	24.5	217	0.9
4	sixth el. period	5.1	102	3.1

Conclusion

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- The approach presented here uses the symmetries of the motor topologies to reduce the simulation effort to 1/6 of an electrical period.
- It was demonstrated that the approach proposed here to reduce the calculation effort makes it possible to use an asymmetric FE mesh.
- The results were analyzed by evaluating the differences to simulation results recorded for a complete electrical period.
- Generally, the proposed approach is suitable for simulation tools that do not support a symmetric mesh design.
- In addition, a more detailed study of the influence of neighboring nodes regarding the optimization of interpolation methods is part of further investigations.
- In the next steps, other topologies will be considered and the procedure will be tested in detail in SyMSpace.

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