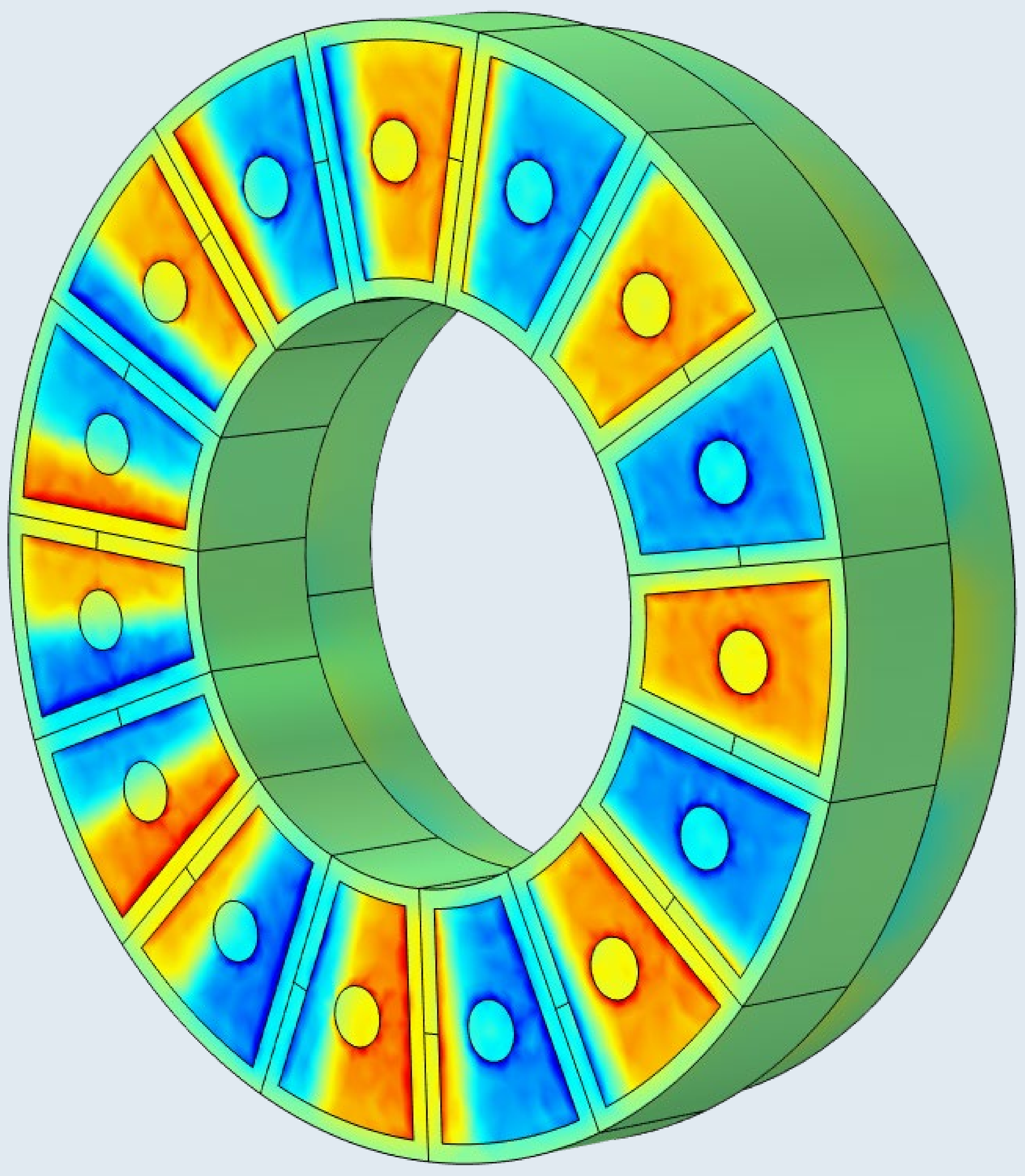

Comparison of analytics, FEM simulation and prototype data of an Axial Flux Synchronous Machine

FEM simulation is an essential part of design tool chains from analytics to prototype testing, yet templates and wider knowledge for simulation of Axial Flux Machines are missing. This work presents a full 3D simulation of a single gap design and makes comparisons to analytics and prototype data.

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Introductions & Goals

The Axial Flux Permanent Magnet Machine (AFPM) is a type of electrical engine, which possesses certain advantages compared to traditional radial flux machines (RFM). The pancake shape design leads to a lower moment of inertia, less magnet volume needed and in general a higher power density [1]. A FEM simulation of an AFPM should have been used in the drafting and designing of project protypes, but simulation stability could not be secured in past attempts [2]. After finalizing the simulation, results were compared with analytical calculations and test bench measurement data. In general, all three data sources come to a good match, while the occurring differences are expected due to idealisations and simplifications in analytical models as well as small discrepancies towards measurement data due to real machine behaviour. With the finalisation of the FEM model the design tool chain for prototype research could now be completed.

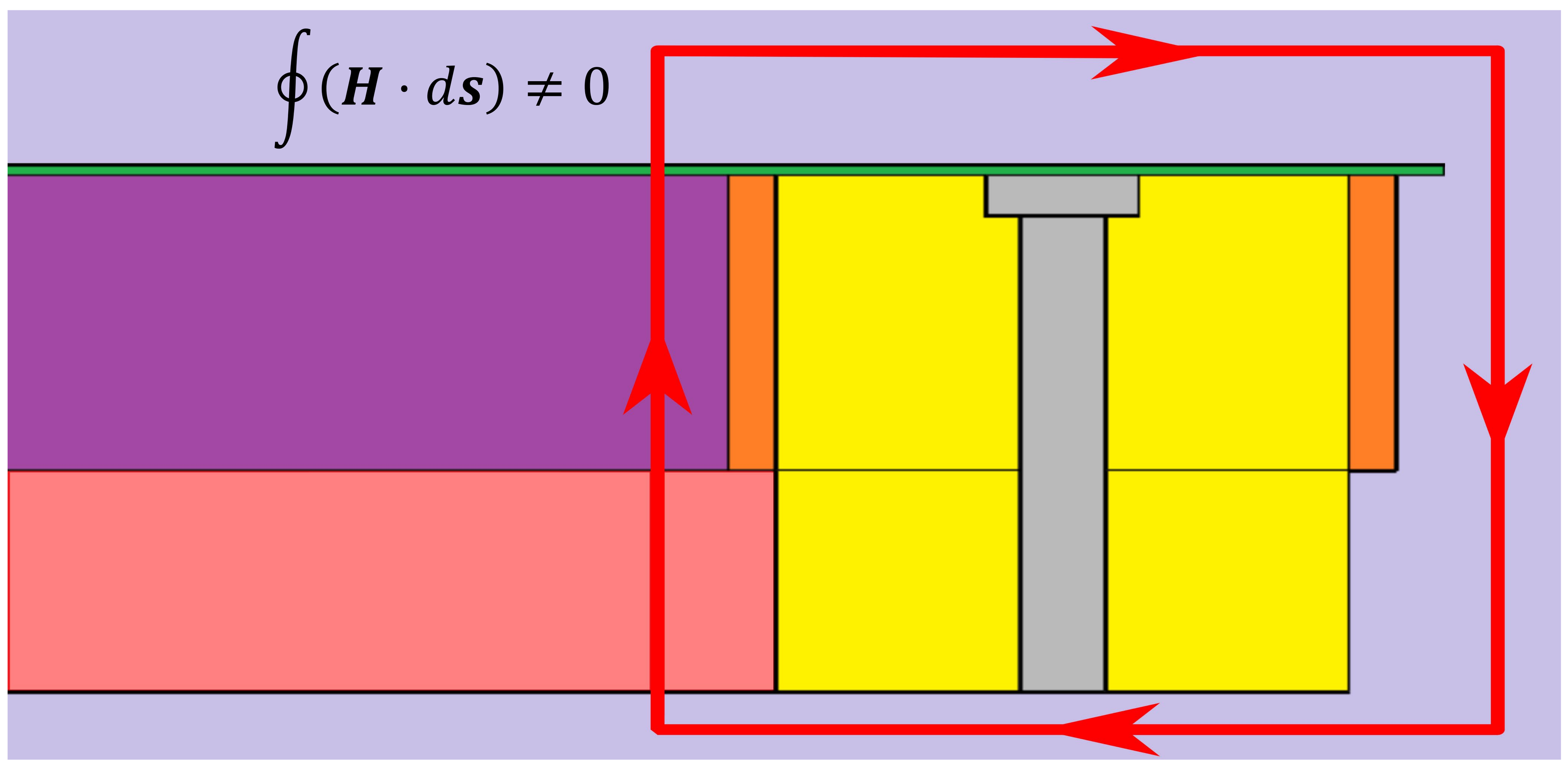

Figure 1. Air domains of magnetic scalar potential allocation (dark violet, violet, red) are not allowed to enclose active currents (yellow, orange), risking simulation stability.

Methodology

The AFPM design consists of 16 poles, 15 slots and three phases, while outer and inner diameter amount to 140 mm and 80 mm, respectively. Due to this no symmetry planes can be identified, and the machine needs to be simulated in its entirety as well as in 3D due to the magnetic flux path. Both factors into simulation stability and time.

Domains can be allocated as magnetic scalar (MSP) and vector (MVP) potentials, with the former decreasing simulation time and being therefore desirable to use. But currents inside MSP domains are not allowed to occur, since it would violate the basic condition of a curl free space ($\nabla \times \boldsymbol{H} = 0$), thus not achieving simulation stability. Therefore, special attentions needs to be paid during modelling. Materials used in the simulation as well as the AFPM prototype are construction steel for the rotor yoke and soft magnetic powder composite for the stator core with nonlinear permeability each.

Results

For final comparison parameters chosen were air gap flux density, output torque, resistances, inductances and EMF. The former shows deviations of up to 2 % for magnet surface flux density and 10 % - 22 % for air gap flux density, which is to be expected due to the idealized calculation configurations. Regarding output torque a similar conclusion is drawn with a relative error of 12 %.

Comparisons for resistances, inductances and EMF also include prototype measurements. Compared to analytic approaches relative errors for resistances and inductances amount to less than 4 %, while the EMF deviates by 20 % from COMSOL®. Test bench measurements on the other hand show differences of less than 3 % for inductances and EMF, underlined by Fig. 2. Resistances diverge by 23 % due to coil manufacture, overhang and mounting.

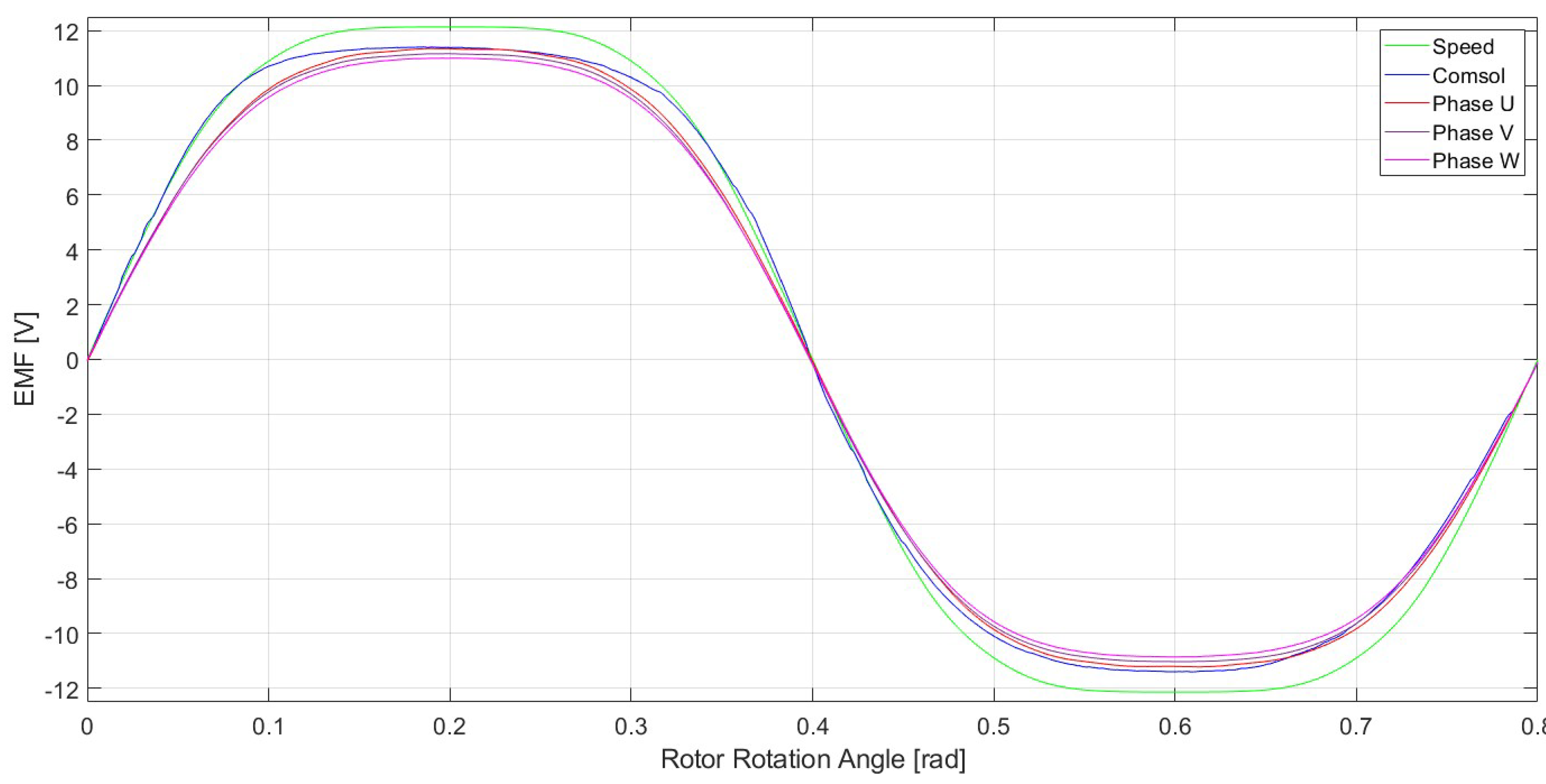

Figure 2. EMF by rotor angle for SPEED®, COMSOL® and the three phases of the AFPM prototype.

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