DESIGN OF A YASA AXIAL FLUX MOTOR WITH HALBACH ARRAY

DESTEC
DIPARTIMENTO DI INGEGNERIA
DELL'ENERGIA, DEI SISTEMI, DEL TERRITORIO E DELLE COSTRUZIONI

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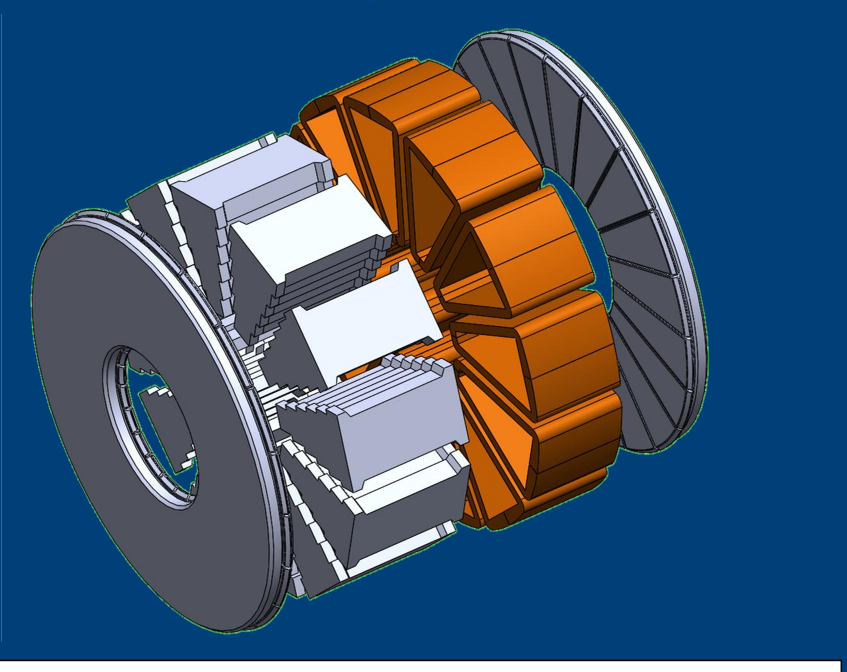
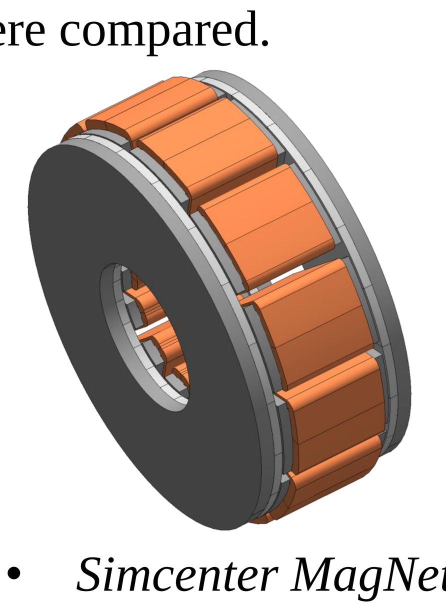


Axial Flux Machines have a higher power density than the *Radial Flux* ones, but their stator can be more difficult to build because of the required lamination process. Moreover, their *cogging torque* is typically higher than the one observed in *Radial Flux Machines*. ***YASA (Yokeless And Segmented Armature)*** configuration of axial flux motors can simplify the device's building process, since the stator is composed as an array of magnetically independent teeth [1]. The rotor is a disk where an ***Halbach Array*** of permanent magnets is placed. *Halbach Array* is able to focus the flux density on one side of the array (i.e., in the airgap), while canceling near to zero on the rotor yokes, that could be very thin, or even removed [2]. The total weight of the device is reduced improving the dynamic performance.

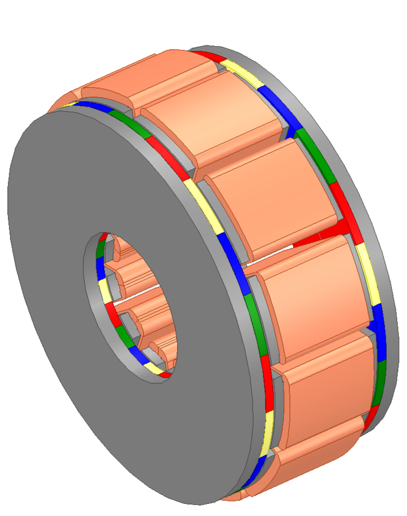
1. VALIDATION OF THE MODEL

The considered *YASA* machine has two twin external rotors with *Halbach Arrays* characterized by the presence of ten poles and a stator composed of twelve teeth. The shape of magnets and teeth is simplified in order to speed up the simulation time. The same model was built and simulated with two *Finite Element* software, and their results were compared.

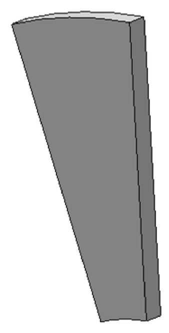


- *Simcenter MagNet*

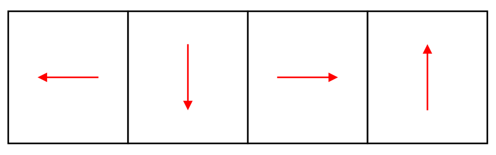
- *Ansys Maxwell*

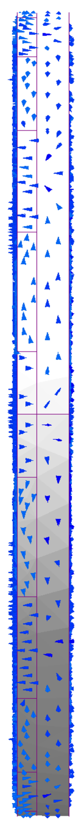


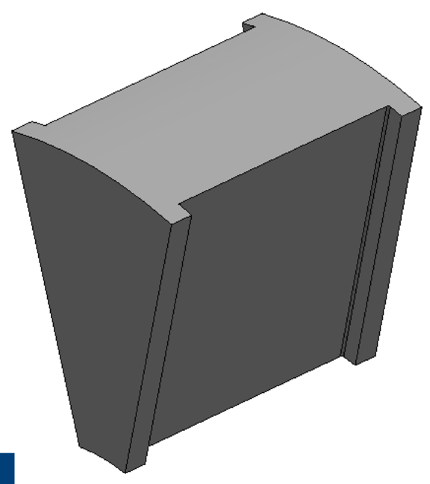
MAGNETS



- *90 deg* ***Halbach Array***





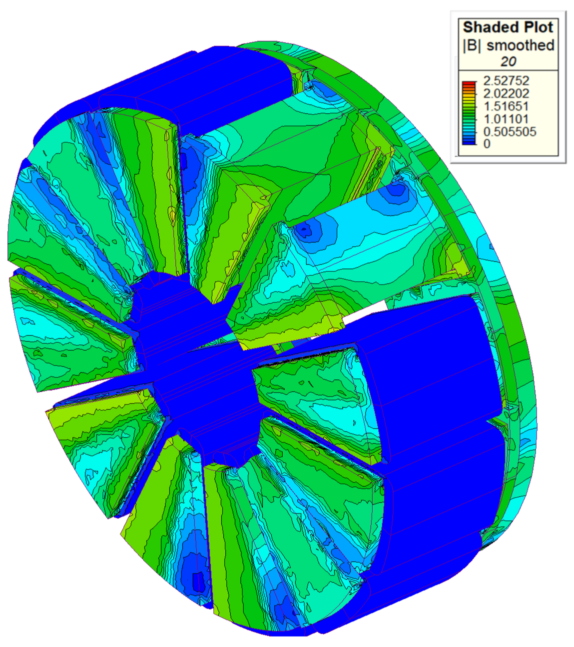


STATOR TEETH

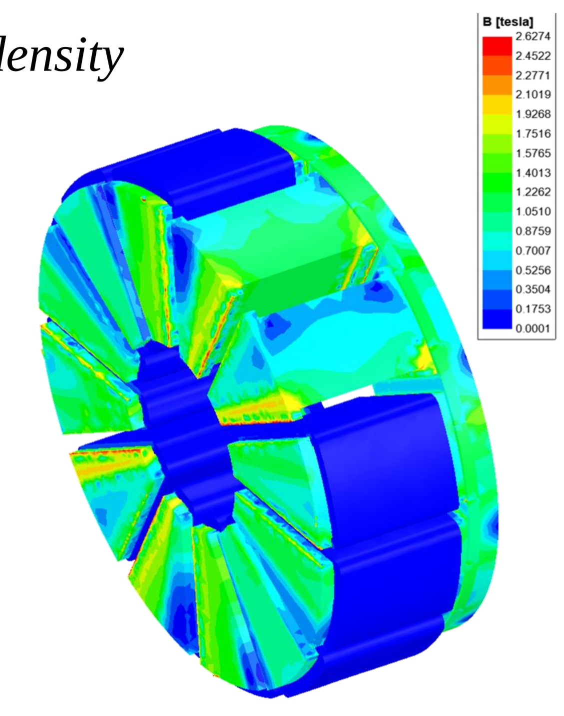
- Trapezoidal section
- Windings are prepared before the stator assembly

2. COMPARISON BETWEEN TWO SOFTWARE'S RESULTS

- *Magnetic flux density*



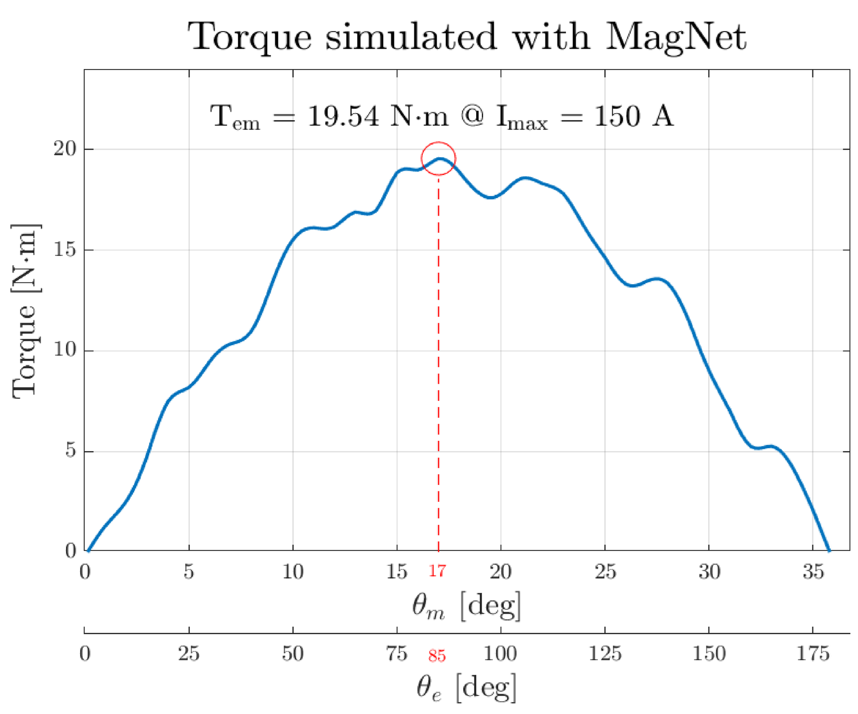
Simcenter MagNet

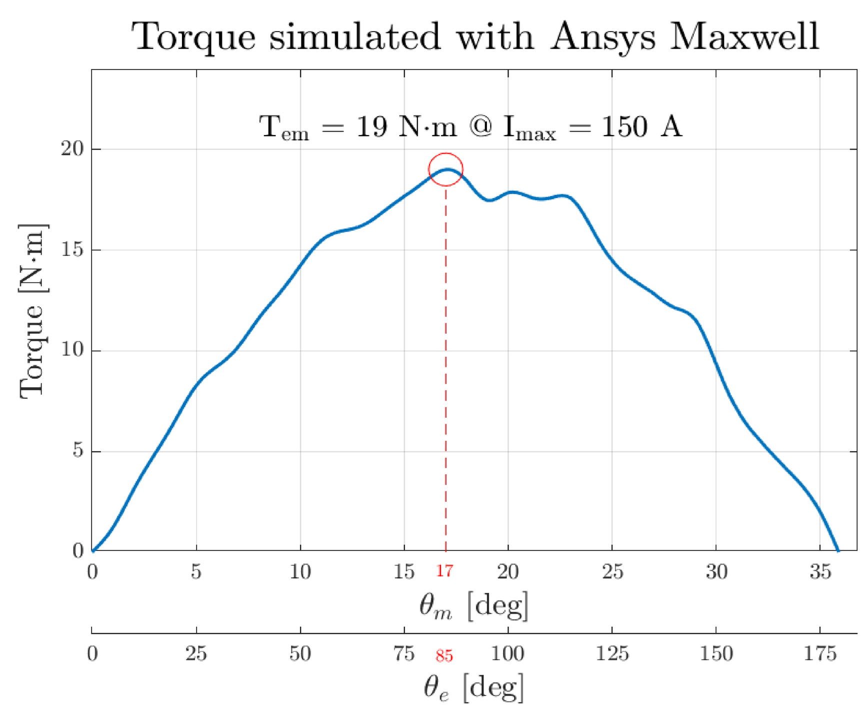


Ansys Maxwell

The maximum of the magnetic flux density is in the fitting radius that links the head and the body of a tooth.

- *Torque* vs *Torque Angle*



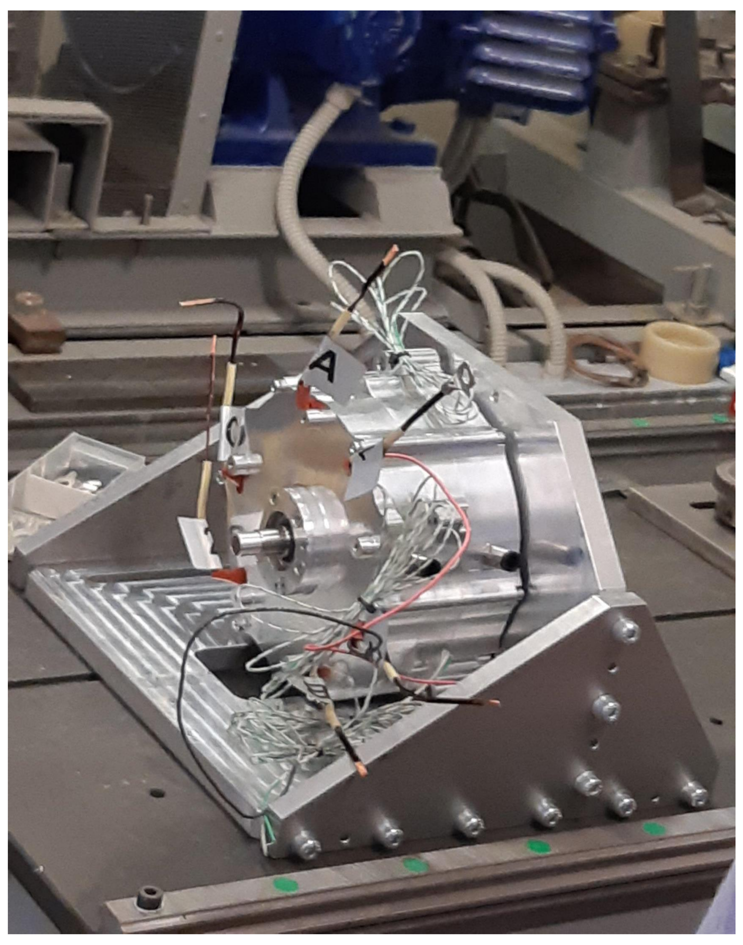


The developed torque depends on the angle between the spatial vector of stator currents and the vector representing the magnetic flux produced by permanent magnets (i.e. the torque angle). When the two vectors are perpendicular, electrically speaking, the device develops the maximum torque. Due to some torque oscillations this does not appear from simulation results.

Either the magnetic flux density and the developed torque are quite the same. We can conclude that, the obtained results are consistent with the simulated model.

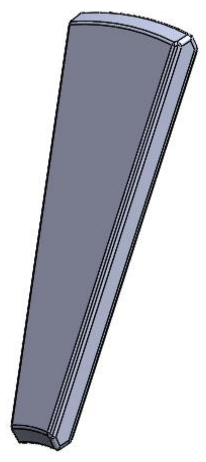
3. PROTOTYPE MANUFACTURING AND TESTING

Once the design has been validated by the analysis with two different Finite Element software, a prototype was manufactured. The device is currently under test in order to assess its performance (rated power, efficiency, power factor, overload). The results of the testing activities will provide guidelines for improving the design and the production of a second prototype.



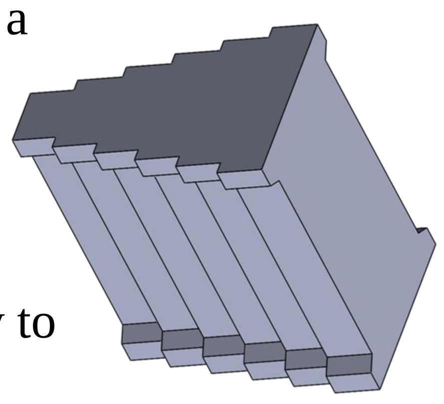
- MAGNETS

The shape makes the assembly process easier.



- STATOR TEETH

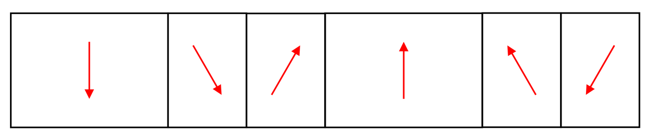
The main direction of the magnetic field in-side a tooth is the axial one, but it is impossible to make a continuous trapezoidal laminated section, it is necessary to discretize it.



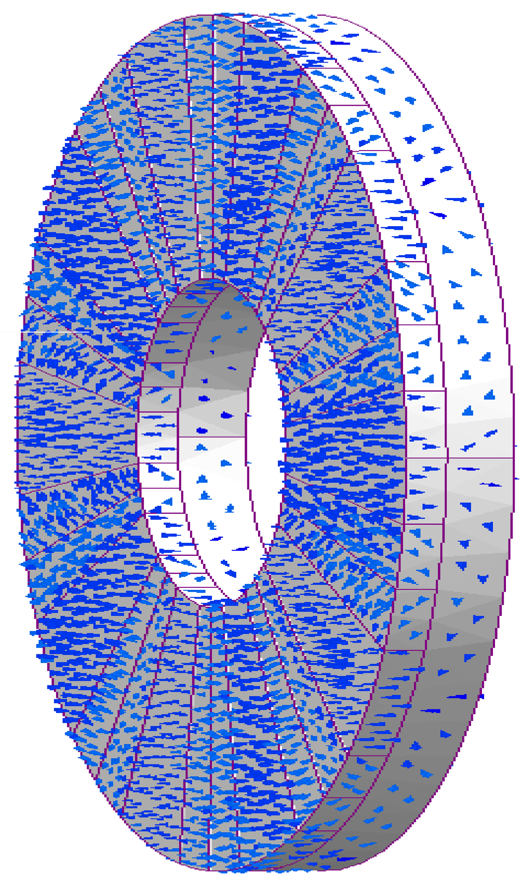
The magnetic field in the stator has just one main direction, thus it is possible to build the teeth with grain-oriented laminations, just like what it is done in transformers.

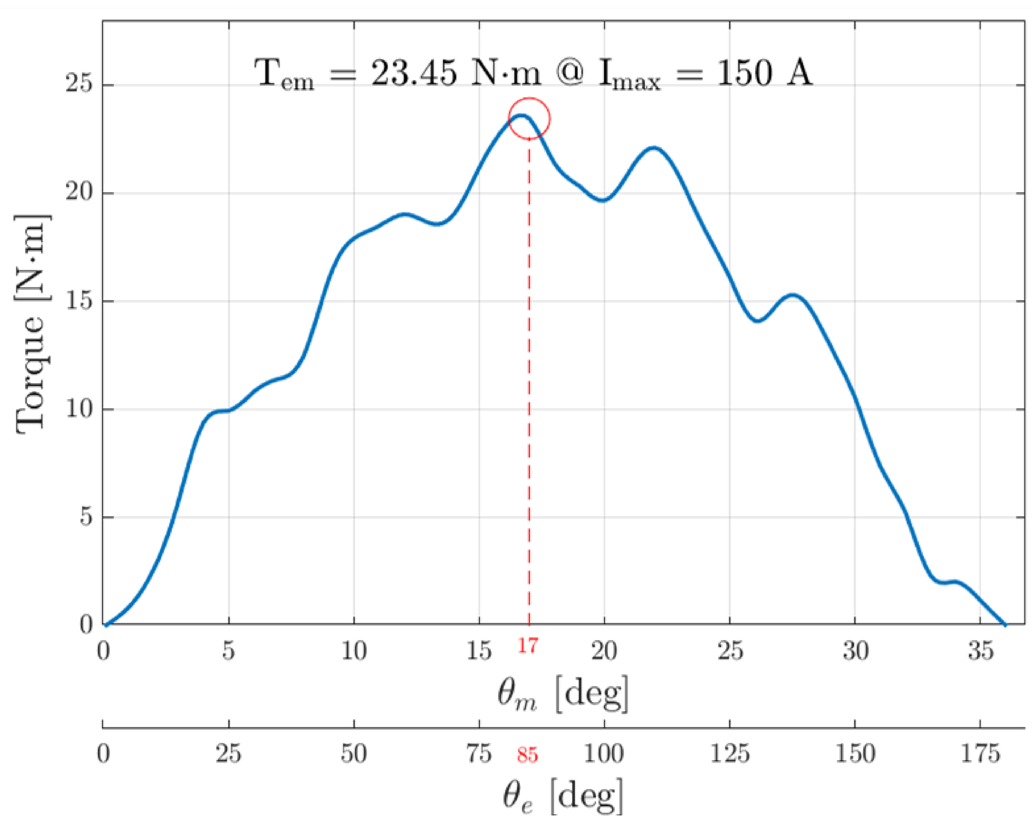
4.POSSIBLE IMPROVEMENT

- ➢ A possible improvement that is currently under investigation is related to the optimization of the magnetization pattern of the *Halbach Array*. The developed torque grows if the tangentially magnetized permanent magnets are substituted with a couple of a *60 degrees* magnetized permanent magnets.
- ➢ The best configuration is the one with the 60 degrees-oriented PMs having a length half the one of the axially magnetized PMs.



- ➢ *60 deg* ***Halbach*** between axially magnetized PMs
  - *Torque* vs *Torque Angle*





The rotor position for which we have the maximum torque does not change, but its value grows more than *10 %*.

5. FUTURE ACTIVITIES

- Manufacturing of a second prototype with increased performance
- Remove rare earth magnets without appreciable reduction of the performance

REFERENCES

[1] T. J. Woolmer and M. D. McCulloch, "Analysis of the Yokeless And Segmented Armature Machine," 2007 IEEE International Electric Machines & Drives Conference, 2007, pp. 704-708, doi: 10.1109/IEMDC.2007.382753
[2] Z. Q. Zhu, "Recent Development of Halbach Permanent Magnet Machines and Applications," *2007 Power Conversion Conference - Nagoya*, 2007, pp. K-9-K-16, doi: 10.1109/PCCON.2007.372911