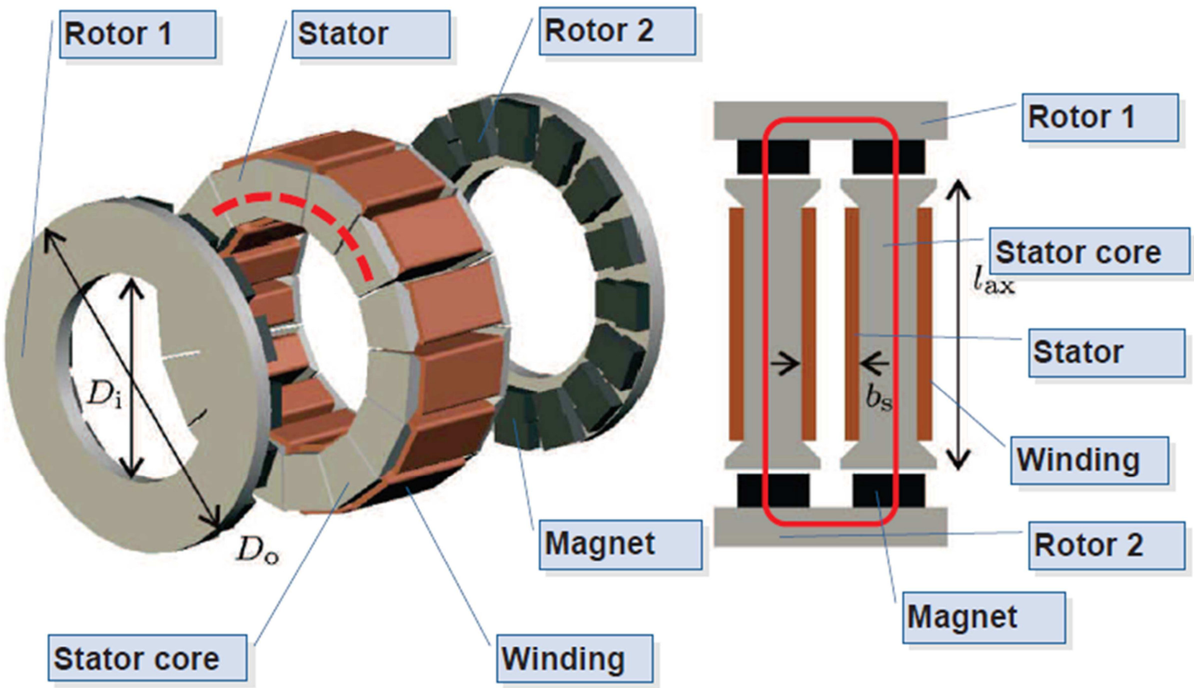
# Axial-flux permanent magnet machines with high efficiency and power density

*What is an axial-flux permanent magnet machine?*

The magnetic flux in this machine is in the direction parallel to the shaft, i.e. the axial direction. The rotors of these machines are thin discs on which the permanent magnets are glued. The permanent magnets are magnetized in the axial direction.

Depending on the configuration, single-rotor-single-stator, double-rotor-single-stator and single-rotor-double-stator are found. The is also the possibility to connect multiple axial flux machines on the same shaft in a multi-stack configuration.




Independent of the topology, axial-flux PM machines inherently combine a high torque density with a good energy-efficiency. Moreover, the high diameter to axial length ratio results in a typical pancake-shape of the machine.

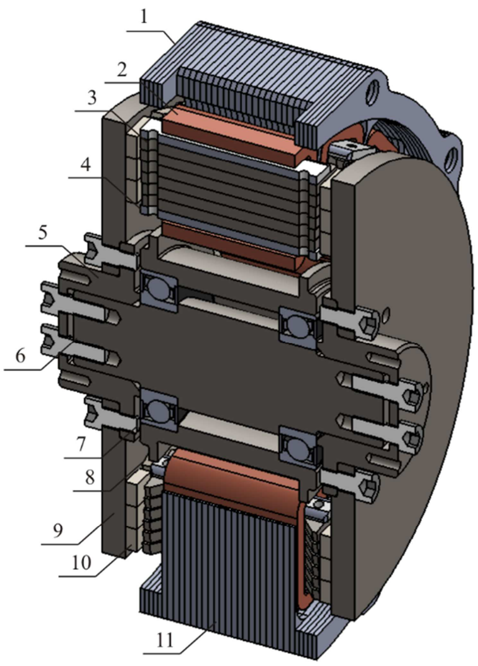
At EELAB a double double-rotor-single-stator topology is examined of which the stator is composed of multiple stator modules. This axial flux variant is called the segmented armature torus (SAT), or, yokeless and segmented armature (YASA) machine.

The absence of a stator yoke in this configuration reduces the size and weight as well as the core losses. Moreover, concentrated windings allow to achieve short end-winding and a very high filling factor of the winding. Therefore, the torque density and energy-efficiency is even more pronounced.

*Advantageous electric machine concept*

Due to the absence of a stator yoke and the excellent filling factor of the concentrated winding, the size/weight and power losses in the YASA-machine are strongly reduced.

The torque density and energy-efficiency of this topology are further improved by additional measures.




A strong reduction of the core losses is achieved by using grain-oriented material as stator core material. Moreover, the high permeability of these materials reduces the amount of permanent magnet material.

A modular construction method is possible which facilitates the manufacturing. Especially the manufacturing of the cores and the winding process are simplified.

The rotating disc at both sides of the stator have inherent ventilation properties and can have a significant contribution to the cooling of the machine. These convective heat flux can be optimized by modification of the shape of permanent magnets.

An advanced interconnection of the windings can be realized to increase the fundamental winding factor of the machine. This results in a higher torque density for the same current density in the windings.

Many parts in the design combine multiple functions: electromagnetic-thermal such as the ventilation effect and magnetic flux production in the air gap by the permanent magnets, thermal-mechanical such as the inward heat extraction fins on the stator housing. By combining different functions in one machine part, optimal use of the materials is made.

*Applications*

The YASA-machine is generally applicable, but is of particular interest in applications where torque density and energy-efficiency are crucial such as in electric mobility.

Adapted designs of the YASA-machine are particularly suitable for direct-drive (no gearbox) applications such as wheel motors and wind energy conversion. Here, the YASA-design has a very high outer and inner diameter in such a way that it has a ring shape. In direct-drive applications, a significant mass reduction can be obtained in comparison to conventional machines.

*Research at EELAB*

Electromagnetic analysis:

- optimization of the global machine's geometry in function of the application and/or drive cycle;
- comparison of different magnetic materials in the stator e.g. laminated, SMC, ...;
- increasing the machine's torque output by obtaining a higher winding factor through an
- advanced connection between the different stator coils;
- reduction of the magnet eddy-current losses by segmentation of the permanent-magnets;
- levelling of the magnetic flux-density distribution over the radial direction in the stator teeth.

Thermal analysis

- characterization and optimization of the convective heat exchange near the air gap using CFD (accurate, but high calculation time);
- development of fast evaluating, analytical equations for the calculation of the convective heat exchange near the air gap;
- detailed temperature distribution inside the different machine parts at steady state and during transients;
- evaluation and optimization of different cooling strategies to obtain high torque

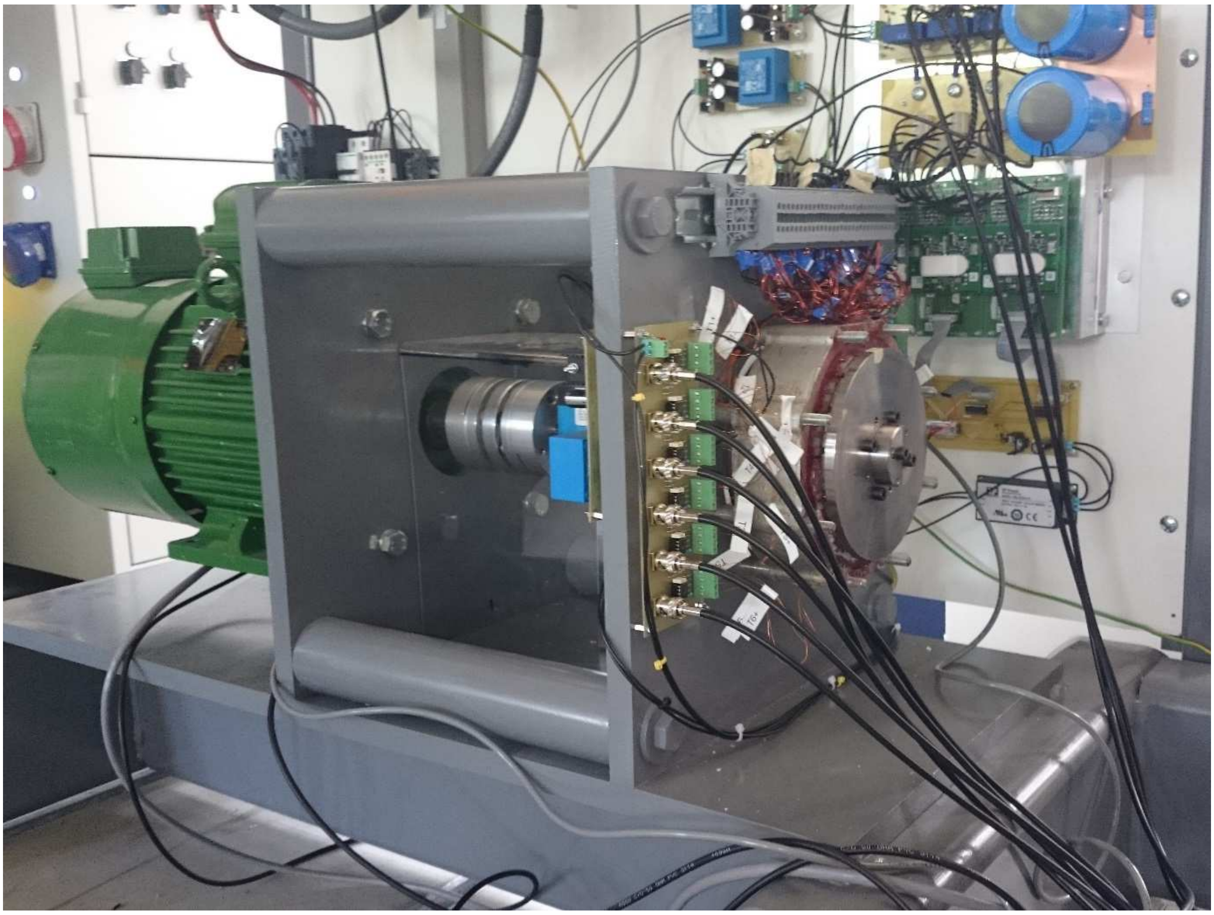
Mechanical analysis

- influence of the magnet-stator interaction on the stresses and strains inside the different machine parts;
- thermal stresses and strains inside the machine due to local power losses at operation;
- use of epoxy materials in the structural parts of the AFPM-machine.

*Test setup with 4kW prototype*

EELAB has a permanent test set-up for a 4kW YASA prototype. The prototype is equipped with additional sensors (temperature, search coils, etc.) to monitor different parameters.

The set-up allows to test the YASA-machine both as motor and generator. Measurement of the mechanical power though a torque and speed measurement as well as a measurement of the electrical power through a power analyzer, allow to measure the YASA-machine energy-efficiency for every speed-torque working point (efficiency map) or load cycle.



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