Design and Optimization of Outer-Rotor Permanent Magnet Synchronous Machine with Amorphous Stator Core

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The Properties Comparisons of AAM and Silicon Steel

- Amorphous alloy material (AAM) has low iron loss benefiting from its low coercivity and high resistance.
- The saturation flux density of AMM is about 1.5 T which is lower than that of the traditional silicon steel.
- The Vickers hardness of AAM is higher than 900HV and that of traditional silicon steel is usually lower than 200HV.
- The AAM ribbon is very hard and brittle, which makes AAM difficult to process using the traditional stamping technology.

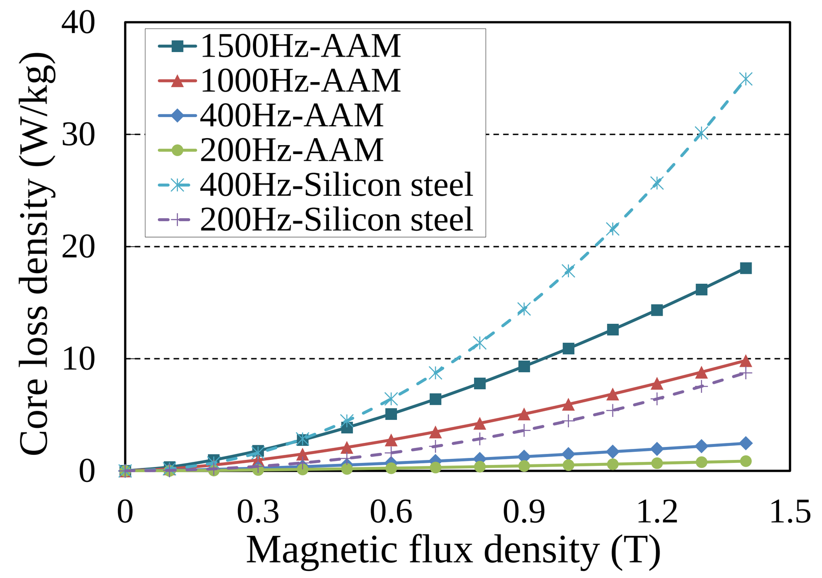

Fig. 1. Iron loss curve of amorphous alloy material and silicon steel.

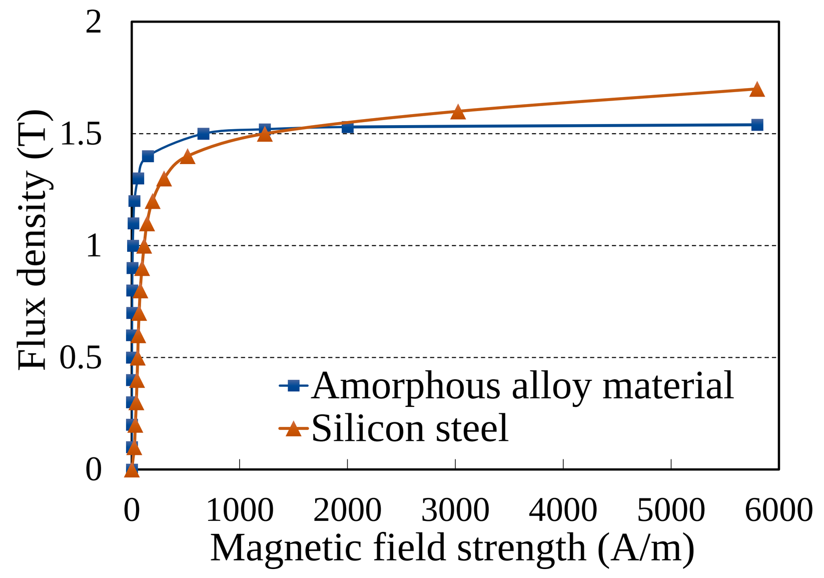

Fig. 2. BH curve of amorphous alloy material and silicon steel.

The Topology and Application Backgrounding of OR-PMSMASC

Fig.3 illustrates the structure of the outer-rotor permanent magnet synchronous machine with amorphous stator core (OR-PMSMASC). The outer-rotor structure is selected for improving the loading capacity and the condition of heat dissipation. Considering the most iron loss is distributed in the stator core and the low saturation flux density of AMM, the stator core is only selected to manufactured by AAM. The stator core is stacked by the thin amorphous alloy material laminations, and the outer-rotor is manufactured by the solid electrical steel with arc-shaped rare-earth PMs pasted in its interiorly surface.

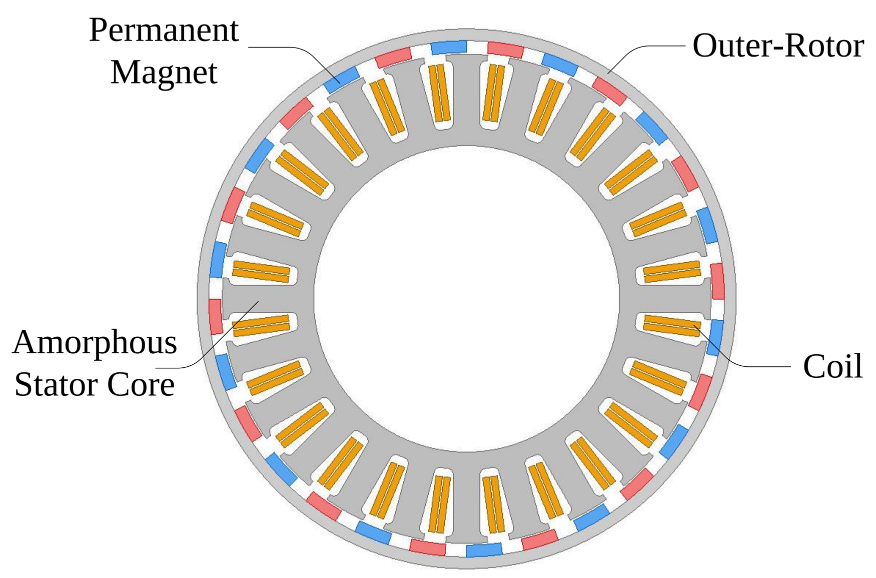

Fig. 3. The topology of the OR-PMSM with amorphous stator core.

This OR-PMSMASC is applied to the PPUAV which is used to spray liquid. The electric machine is mounted on the body of PPUAV and the propeller is installed on the outer-rotor. The rotary propeller generates lift to balance the gravity GUAV of the PPUAV. The load torque is transfered to the motor shaft through the propeller.

Load Profile and Cycle

The load gravity of PPUAV is reducing with the liquid spraying. The solid line in Fig.5 shows the load cycle of the PPUAV during one flight assuming that the mass of liquid being sprayed in unit time keeps constant. In order to present the whole load cycle, the values have been normalized based on the maximum value in one flight. To launch the optimal design process based on the load cycle, the continuous load cycle is discretized into 10 sections.

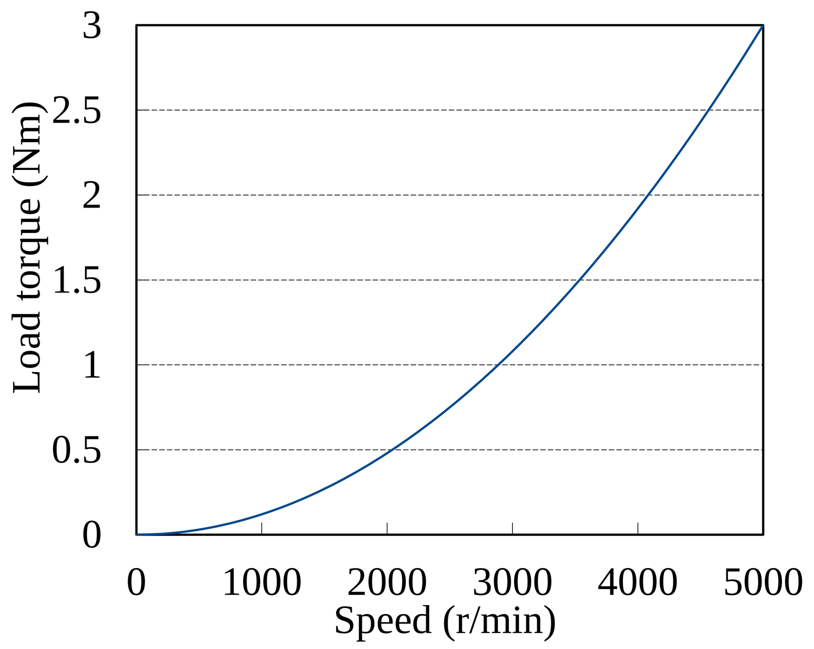

Fig. 4. Load torque profile of the propeller.

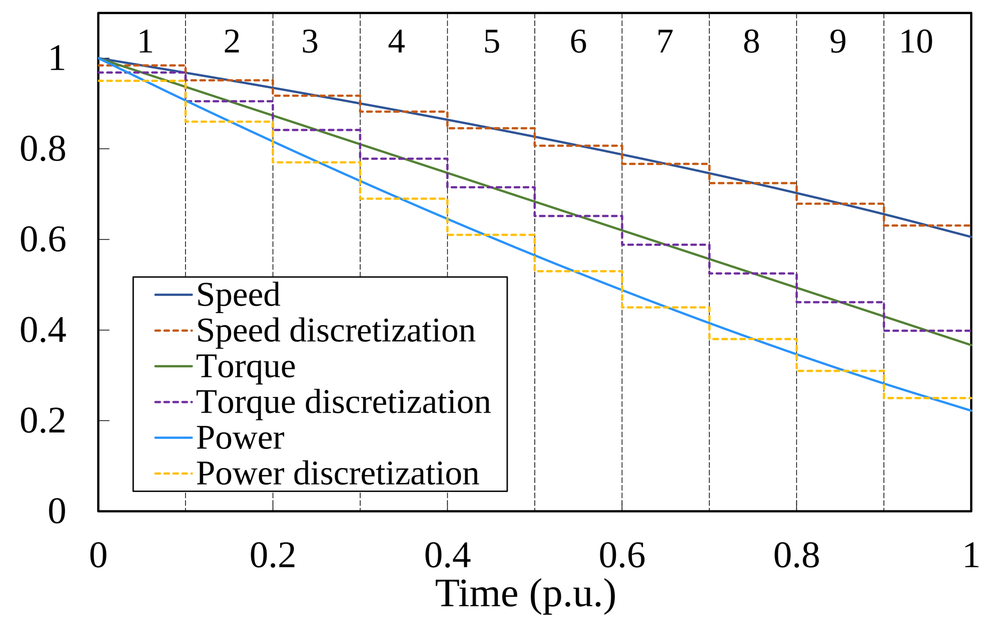

Fig. 5. Normalized load cycle of the PPUAV in one flight.

Optimization Deign Results and Comparison

To extend the range of one flight and reduce the cost of the motor, minimizing the energy consumed in one flight and minimizing the cost are selected to be the optimal objectives. Two optimization procedures are performed using 2-D FEA based the load cycle and the rated power point respectively. Maximization of the efficiency at rated power point (@ 4200r/min and 2Nm) is selected as the optimization objective. Eight main parameters of OR-PMSMASC are chosen to be the design variables and the structure parameters are shown in Fig.6.

$$x_i = [R_{1out}, R_{2out}, l_{PM}, \alpha_{PM}, W_{tooth}, l_{yoke}, J_c, N]$$

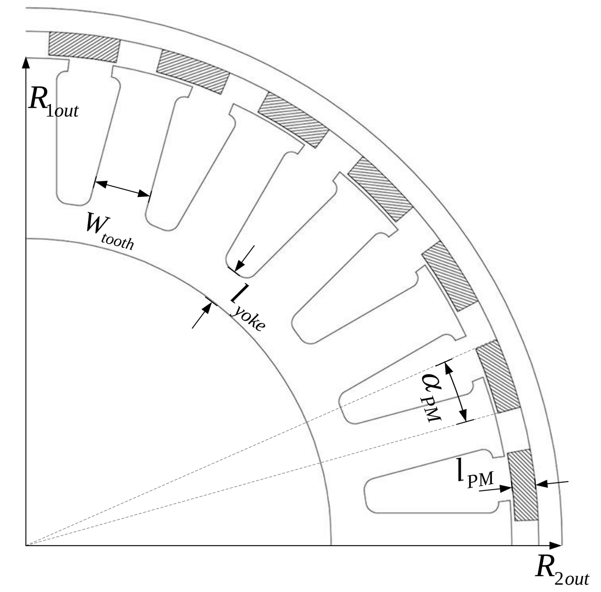

Fig. 6. Geometric parameter model of the OR-PMSMASC

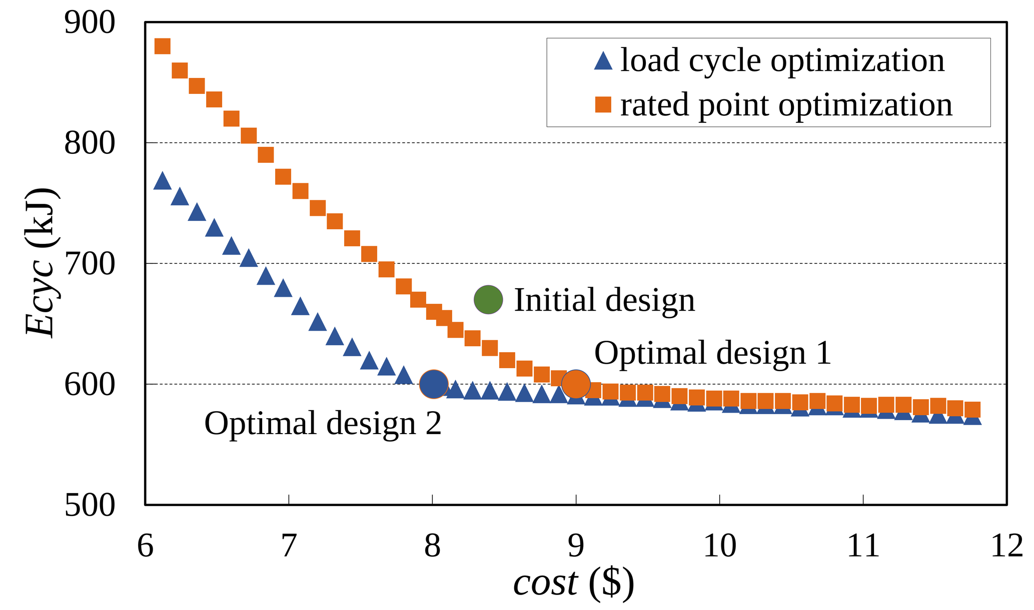

Fig. 7. Pareto front of the optimization results

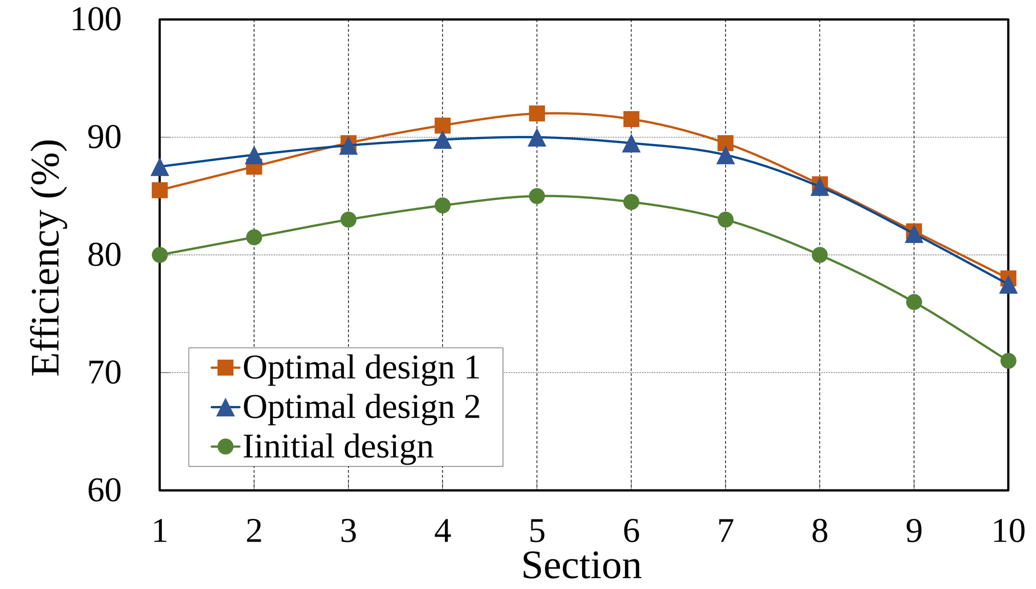

Fig. 8. Efficiency of the initial and optimal designs in one load cycle.

Fig. 9. The prototype of OR-PMSMASC.

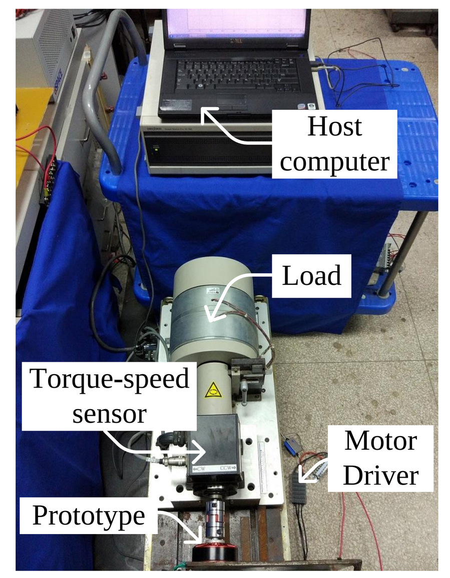

Fig. 10. The test platform of prototype.

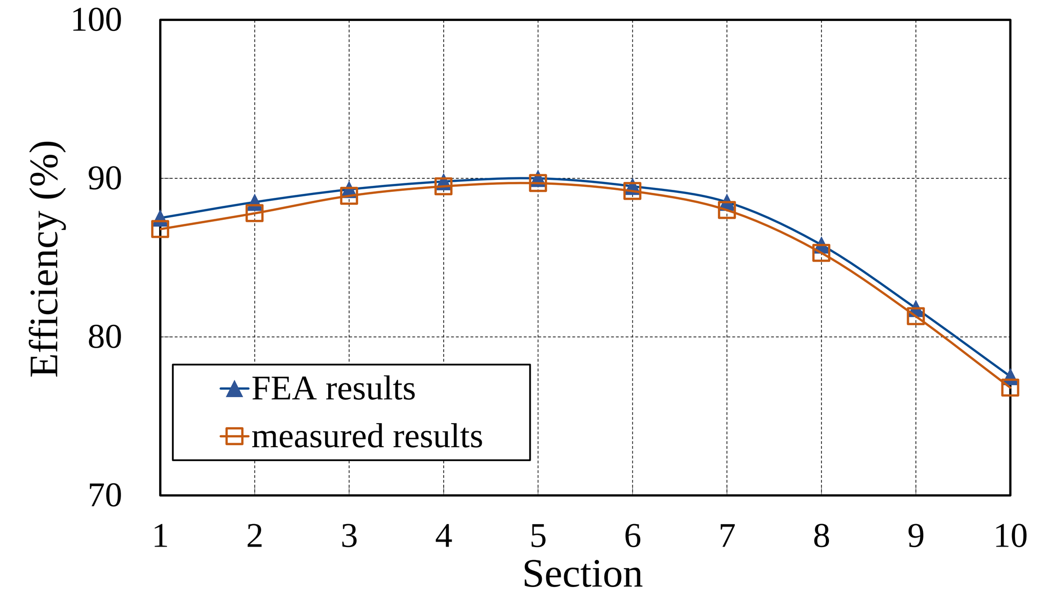

Fig. 11. The efficiency FEA and measured results of the OR-PMSMASC prototype.

Conclusion

In this paper, the OR-PMSMASC is designed which is applied to the PPUAV. The load cycle of the PPUAV is studied and an optimal procedure based on the load cycle is launched. The efficiency and energy consumed in a load cycle of the initial and optimal designs are investigated and compared based on the 2-D FEA. A optimal procedure aims at a low cost high efficiency design based on the load cycle is presented. A prototype of OR-PMSMASC based on the optimal design 2 is manufactured and tested.

The PPUAV can reach a larger range of one flight equipped with the same capacity of battery after the optimal procedure. The optimal procedure based on the load cycle can provide a better tradeoff between the performance and cost. Comparison with the optimal design based on the rated power point, the optimal design based on the load cycle consumes the same energy with much lower material cost. The cost reduction can be a considerable number in the volume production process.