

ADDITIVE MANUFACTURING OF ELECTRIC MACHINES: RESEARCH ON THE POTENTIAL OF ADDITIVE MANUFACTURING IN PM SYNCHRONOUS MACHINE ROTORS

Metal components and assemblies can be manufactured layer by layer using Additive Manufacturing (AM). The process principles provide both design freedom and new possibilities regarding the material. The aim of this research project is to systematically investigate the potentials of additive manufacturing processes in electrical engineering, especially in rotors of permanent-magnet excited synchronous machines (PMSM). This project is a cooperation between the DMRC and the IAL (Institute for Drive Systems and Power Electronics) of Leibniz University Hannover.

PROJECT OVERVIEW

DURATION



03/2020 – 08/2020

PARTNER



- Paderborn University (KAT, LWK)
- Leibniz University Hannover (IAL)

FUNDED BY



German Research Foundation (DFG)

RESEARCHER



Research Leader
 Prof. Dr.-Ing. Bernd Ponick (IAL)
 Prof. Dr.-Ing. habil. Mirko Schaper
 Prof. Dr.-Ing. Detmar Zimmer (KAT)

Research Assistant
 Sebastian Magerkohl, M.Sc. (KAT)
 Lennart Tasche, M.Sc. (LWK)
 Stefan Urbanek, M.Sc. (IAL)

DFG Deutsche
 Forschungsgemeinschaft
 German Research Foundation

Motivation

Efficient drive systems are becoming more and more important in context of increasing automation in both private and industrial sectors. Electric motors in particular are interesting for many applications, but must meet the respective requirements. Additive manufacturing processes offer a high design freedom and a low influence of component complexity on unit costs. Accordingly, special solutions with a high functional density and component complexity can be manufactured economically.

The overall objective of this research project is to investigate the potential of additive manufacturing (AM) in electrical engineering. The existing design characteristics of rotors in permanent magnet synchronous machines (PMSM) are to be expanded by using AM. This requires design guidelines for the processing of soft magnetic materials. At the same time, the rotor-sided inclination and the surface structure of the rotor including its connection to the torque-transmitting structures will be implemented in an additively manufactured demonstrator (Figure 1).

Approach

In order to be able to exploit the above-mentioned potential, a suitable material must be identified. This is done in two steps. First, parameter studies are carried out on one selected iron-cobalt and two iron-silicon alloys. This is followed by the determination of mechanical and magnetic properties before and after heat treatment.

Based on the results of the material research, the effects of rotor-side inclination on additively manufactured PMSM rotors with buried magnets as well as concepts for the suppression of eddy current losses on the surface of PMSM rotors by means of AM will be investigated.

The resulting rotor design is going to be functional and suitable for production. It will display the benefits of AM in the field of PMSM rotors. For this purpose, an inclination with axially straight magnetic pockets is to be realized. Such a concept is only economically conceivable because of the progressive development of AM pro-

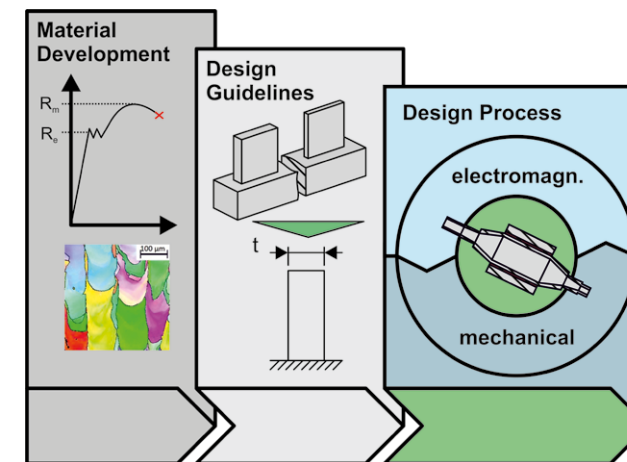


FIGURE 1 Project phases

cesses and is an example of the newly gained possibilities in the design of electrical machines.

Project status

The alloys CoFe50 and FeSi2.9 were chosen for the project to enable a comparison to the currently most common materials in electrical machines. Furthermore, the alloy FeSi6.5 was chosen to show the potential of AM. FeSi6.5 has the highest permeability in the iron-silicon phase diagram and a reduced electrical conductivity, which reduces the formation of electrical eddy currents and thus the resulting losses.

In the first step, parameter studies were carried out. Then, 16 different heat treatments with a focus on primary recrystallization with subsequent grain growth were analyzed for each alloy. To measure the magnetic properties as-built and after an adapted heat treatment, toroidal test specimen were printed, from which hysteresis curves were measured in different frequency ranges. FeSi6.5 showed the greatest potential with a maximum permeability of 7056 and exceeds the achieved values of FeSi2.9 by 254%. Due to its solid design and high electrical conductivity, FeCo50 has higher eddy current losses.

During the subsequent manufacturing of specimen, the brittle FeSi6.5 led to uncontrollable stress cracks in larger components. Therefore, FeSi2.9 is further used in this project. In order to qualify the promising FeSi6.5 for the SLM process and to further improve the magnetical values, tests will be carried out with a newly developed build chamber heater after the the project is finished.

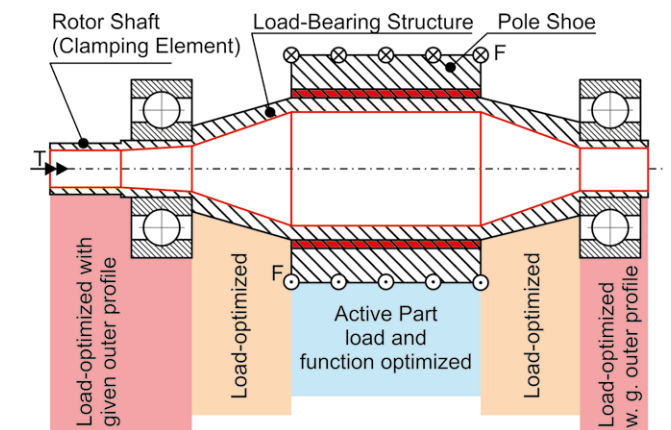


FIGURE 2 Exemplary illustration of a rotor with the different functional sections

Parallel to the material investigations, the possibility of implementing rotor functions by a AM-oriented design was investigated. Simulations of the electromagnetic flow in the active part of a conventional rotor show material areas that are not used optimally. The adapted active part allows a more homogeneous material utilization with regard to the flux density. In addition, torque fluctuations can be reduced by torsion of the external pole shoes when using axially straight permanent magnets.

Besides the optimization of the active part, which is essential for the electromagnetic function, the mechanical requirements have already been analyzed. The integration of the active part in the mechanically loaded structure (Figure 2) eliminates the need for form-fitting or force-fitting connection areas and replaced them by using material connections. This results in more design options and lightweight, heavy-duty structures, such as hollow structures. In particular dynamic tests of the torsional fatigue strength have to be carried out. These are necessary to characterize the material properties of additively manufactured FeSi2.9 and to take AM-specific features such as surface roughness into account. The collected knowledge is implemented in an overall design of a rotor demonstrator.