Multiphysics Design of High Power Density Electrical Machines

Mostafa Ahmadi Darmani

Supervisor: Prof. Andrea Cavagnino

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Research context and motivation

Electric machine is a very complicated devices involved to electromagnetics, thermal, and mechanical aspects. Therefore, the design and comprehensive analysis of electrical machines is a multi-domain problem, and it requires a multiphysics methodology to deliver efficient, optimized electric machine as well as predicting their performances specifically for high power density electrical machines. Therefore, the design stage is consisted of three parts:

1) Electromagnetic design
2) Thermal analysis and cooling design
3) Structural and stress analysis

This research is based on advanced design and analysis of electrical machines, develop production procedure, material characterization, and applying new cooling materials.

Addressed research questions/problems

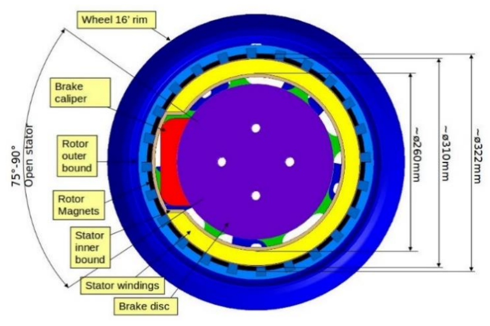
The main topics of the research are mainly focus on design and modelling of non-conventional electrical machines. They are:

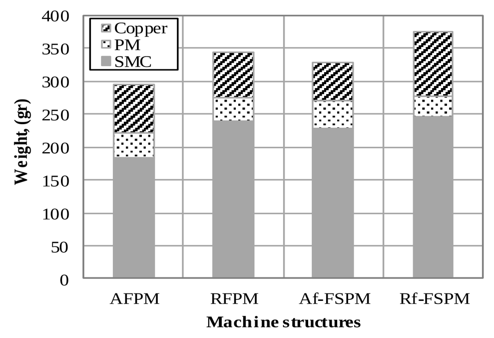
1) **Advanced design and analysis of electrical machines:**
   a. Evaluating the performance of external-rotor sectored-stator PM machine for in-wheel applications.
   b. Design, analysis, and prototyping flux-switching PM machines (FSPM).
   c. Assessment of the new developed nano-additive and ferrofluids for rotating electrical machines coolant system.
   d. Multiphysics design and analysis of electrical machines for automotive application.
2) **Magnetic Materials Characterization:**
   Study of simultaneous compaction of soft magnetic composite (SMC) and bonded PM powder to obtain a multiple layer block for electrical machine applications [4].

Novel contributions

1) **Advanced design and analysis of PM machines**

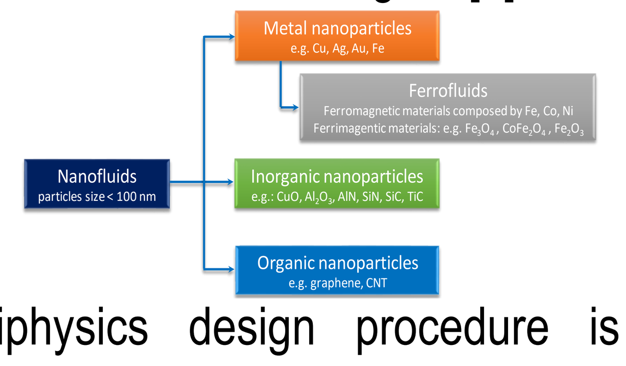
a. A new structure of external-rotor PM machine with a sectored-stator is studied for in-wheel application, and the impacts of removal of a sector of stator on the machines performance are investigated [1].

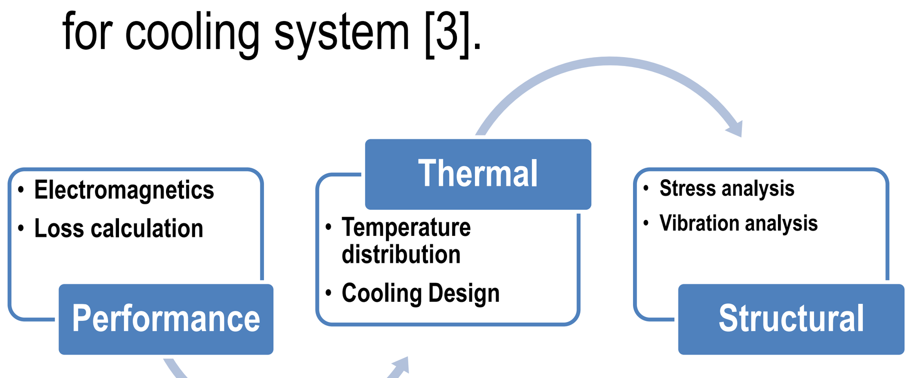




b. Trade-off analysis of well-known stator-PM, FSPM machine, and surface-mounted structures base on same cost for material. Design and construction of a segmented axial-filed flux-switching machine using SMC and bonded magnet [2].

c. Study of using nano-particle additive in the fluid used for cooling system [3].

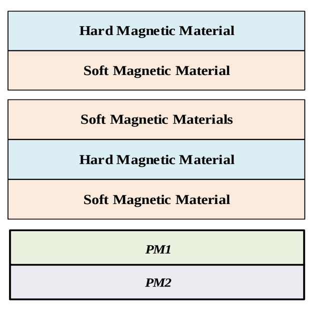




d. A multiphysics design procedure is approached for electromagnetic, temperature distribution, structural stress to design electrical machines.

2) **Characterization of powdered SMC and magnet**

Double and triple layer compaction of soft and hard magnetic materials are investigated in terms of mechanical and electrical characteristics [4].



Submitted and published works

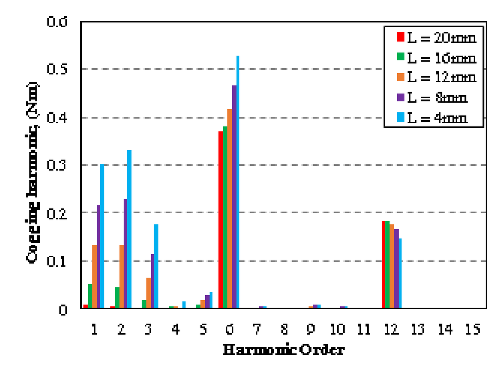
1. M. A. Darmani, G. Bramerdorfer, S. Vaschetto, A. Cavagnino and S. Carabelli, "Analysis of PM Machines with Sectored-Stator," *2019 IEEE International Electric Machines & Drives Conference (IEMDC)*, San Diego, CA, USA, 2019, pp. 745-750.
2. M. A. Darmani, E. Poškovic, G. Bramerdorfer, S. Vaschetto, A. Cavagnino, A. Tenconi, "Surface-Mounted and Flux-Switching PM Structures Trade-off for Automotive Smart Actuators," *2019 IEEE Energy Conversion Congress and Exposition (ECCE)*, Baltimore, MD, USA, 2019.
3. S. Vaschetto, M. A. Darmani, A. Cavagnino, A. Tenconi,"Nanofluids for Rotating Electrical Machines Cooling: Perspectives and Challenges," *2019 International Conference and Exposition on Electrical and Power Engineering (EPE)*, Genova, Italy., 2019.
4. M. A. Darmani, E. Poškovic, L. Ferraris,, A. Cavagnino, "Multiple Layer Compression of SMC and PM Powdered Materials," *IECON 2019 : 45th Annual Conference of the IEEE Industrial Electronics Society (IES)*, Lisbon, Portugal, 2019.

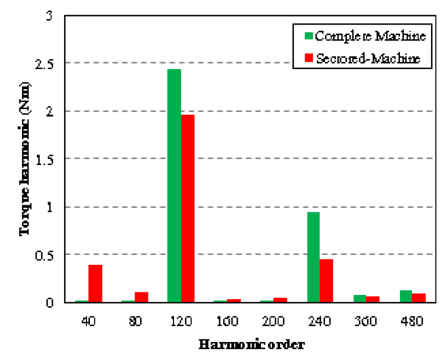
Adopted methodologies

1) **Advanced design and analysis of electrical machines:**

i. **Sectored-Stator PM machines**

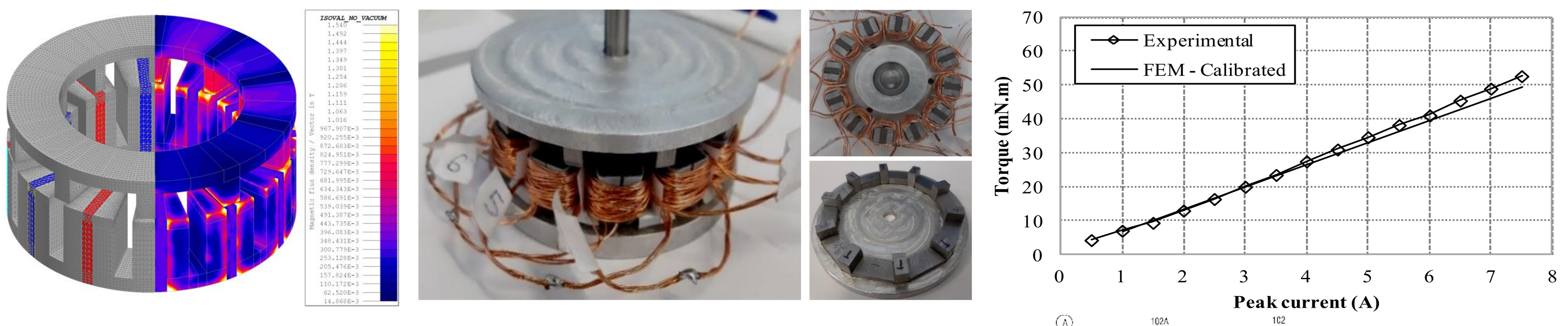
FEA analysis and numerical approach is used to investigate the PM machine with removal of a 90°sector explored.





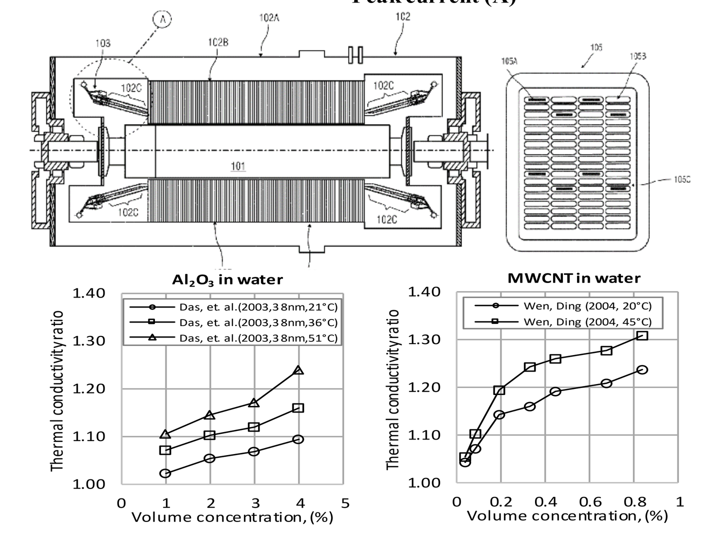
ii. **Design FSPM machine**

Analytical approach is performed to design the axial-field FSPM machine design. In addition, the machine is built using self-produced SMC and phenolic bonded magnets to verify the numerical FEM analysis.



iii. **Nanofluids Coolant for Rotating Electrical Machines:**

Preliminary evaluation by using nanofluids in electrical motors is studied in depth. Literature review is focused on the principle of nanofluids and their pros and cons as coolant.



2) **Magnetic Material:**

Double and triple layer blocks of soft and hard magnetic material are built. Surface profile, and magnetic momentum of the double layer in tested.

Future work

1) **Advanced design and analysis of electrical machines:**
   - ❑ Design and analysis of radial- and axial-flux vernier PM machines to complete the trade-off study.
   - ❑ Prototyping of an axial-flux vernier PM machine using SMC and bonded magnets.
2) **Magnetic Material:**
   - ❑ Characterization of the multiple layer block consisting of soft magnetic materials and permanent bonded magnet powder.
   - ❑ Simultaneous compaction of two or more hard magnetic material (Hybrid magnet).
3) **Multiphysics design of high power density electrical machines**
   - ❑ Advanced electromagnetic design of high power density nonconventional electrical machines
   - ❑ Advanced thermal design of high power density nonconventional electrical machines

List of attended classes

Hard Skill Courses:

- 01QFFRV – Innovative techniques for optimization (08/03/2019, 20h)
- 01OYCIV – Hybrid propulsion systems (19/04/2019, 10h)
- 02ITTRV – Generators and photovoltaic systems (running, 25h)
- 20th edition of the European PhD School in Gaeta, Italy (May 20-24, 2019, 40h)
- Tutorial course on LaTeX (26/09/2019, 4h)

Soft Skill Courses:

- 02LWHRV – Communication (09/03/2019, 5h)
- 01PJMRV – Computer Ethics (04/01/2019, 20h)
- 01RISRV – Public speaking (02/02/2019, 5h)
- 01SWPRV – Time management (02/02/2019, 5h)
- 01SYBRV – Research integrity (5h)
- 08IXTRV – Project management (5h)