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# Optimizing Electric Machines

The aim of the talk is to give the local Pro Scientia group in Linz a brief introduction into the project I am working in. It is called “Creator- Computational Electric Machine Laboratory” and is a Special Research Project (Spezialforschungsbereich SFB) of TU Darmstadt, TU Graz and JKU Linz. Within the project research about optimizing electric machines, for example enhancing the performance, reducing material needed, exploring new designs, around 60 Phd and student assistant are guided by professors. It is an interdisciplinary project with engineers and mathematicians working together and combining simulation and measurement techniques. The CRC Creator started in March 2022 and is funded by DFG (Deutsche Forschungsgesellschaft) and FWF (Forschung- und Wissenschaftsfonds) until February 2026. Right now there are the reviews for a second funding period.

**Motivating the topic:**

The talk starts with a question that should rise the awareness of the importance of the research topic explored in Creator. “How many electric machines are there per person in Europe?”, was the introductory question. The answer to this question is between 500 and 1000 machines below 250 Watts and around 15 above that level. Not only in household where we use machines (like vacuum cleaner, washing machine, dryers, electric toothbrush…) undertaking many tasks, but also industrial machines are running to produce something for us. To make the audience aware that also in the mobility sector many electric machines are needed no matter if we drive with electric cars or combustion engines, I asked a second question. “How many electric motors are there in three different car types? The answers are 7-10 for the car from the 1970s, over 250 for a modern combustion engine and over 250+1 for an electric machine. Of course, the traction motor is of importance, however, the necessity of optimizing all types of electric machines should be emphasized now.

Further reasons for the necessity of optimizing electric machines are the climate change with the need to transfer the energy and mobility sector towards no carbon exhaustion, decreasing the demand of rare earth and other critical materials, the competitiveness of companies meeting standards and enhancing the performance of their products. In order to achieve progress in the development of electric machines it is of importance to create new designs and smaller machines. To ensure that the machine does not run hot, the thermal behaviour of the machine must be investigated. But before I go into detail on how we do that, I describe the state of the art. Therefore, I have chosen the article *"Thermal Monitoring and Modelling of Electrical Machine – A Mini Review*", retrieved on 10th of May 2025 from https://journal.ump.edu.my/mekatronika/article/download/9898/3220/41131 written by Muhd Syawal Mat Jahak, Mohd Azri Hizami Rasid, Ismayuzri Ishak and Suhaimi Puteh in January 2024.

**Summary of the article:**

The article reports on the different possibilities to control the temperatures of electric machines. Two main ideas are separated: thermal monitoring and computational simulation. These techniques should guarantee that critical temperatures are not exceeded to ensure good machine's performance and a long lifespan.

To regulate the temperature in electric machines one method is to measure the temperature. These measurements can be conducted with thermocouple instruments indicating the temperature at their located place. Another possibility are thermal images made by infrared cameras. These cameras measure the infrared radiation an object emits. One disadvantage is that the radiation is shielded by a non-transparent medium making it impossible to look behind them. Nevertheless, these measurement techniques provide the real machine's temperature while the experiment.

The second approach performs computational simulations using thermal models to calculate the expected temperatures for various operating points. Two prominent techniques are the *Finite Element Method (FEM)* and *Lumped Parameter Thermal Networks (LPTN)*. The first one disassembles the machine's geometry in small geometric forms called elements. On each element the temperature can be calculated incorporating physical laws. The second one introduces (typically a small) number of compartments between which energy can be exchanged or stored inside. To sum up, these virtual models

can predict the temperature of the electric machines always as good as the thermal model fits the reality.
In conclusion, measurements and simulations are essential to prohibit overheating which can cause motor failure or power loss, and both are used to enhance the thermal behaviour of electric machines. At the conclusion of my talk, I give a brief overview of the work I have completed on the project so far.

**My contributions in the project:**

Already in my Bachelor Studies of Technical Mathematics I started investigating efficient methods to calculate the heat distribution in rotating electric machines. I explored the construction of *Lumped Parameter Thermal Networks*. Using Kirchhoff's laws, a system of ordinary differential equations of the form

$$C\,T'(t) + G\,T(t) = P(t)$$

with initial values

$$T(0) = T_0$$

is derived. The structure of the matrices C and G depends on the network structure. The entries of the diagonal matrix C are capacitances describing how much energy can be stored in one apartment when the temperature is increased. The values in the conductance matrix G depend on the geometry of the interface of two compartments and describe how well energy is transferred between the neighbouring cells. Because these values cannot be calculated precisely using geometrical considerations, they are estimated using temperature data from the electric machine that is investigated. Therefore, I used temperatures measurements for calibration. The results from the parameter estimation process can be found in my Bachelor thesis. (Haslhofer, 2023)

For my Master thesis I am implementing a different approach now: the reduced basis method. The idea of this method is to start from high fidelity FEM solutions that were calculated by solving the linear heat equation problem for selected parameters. Then by conducting a singular value decomposition good representatives called reduced basis elements are used to project the matrices onto a low dimensional space. The advantage in this space is the fast computation of solutions for different parameters. Especially for multi-query problems in optimization it pays off to do the costly steps like the construction of the reduced basis elements in the offline phase once. Then the solving procedure for different problems is conducted in a fast way in the online phase. The advantage in comparison to the LPTN is that the accuracy of the approximation can be adopted easily by using more reduced basis elements. In the LPTN approach one would need to extend the network by including a new node and calculate the new conductance and capacitances.

Summarizing both these approaches are used to calculate the heat distribution inside an electric machine. Moreover, after my master I would like to continue doing a PhD in this research field exploring even further techniques.

To conclude the talk, I want to highlight once again with the answers from the introductory questions the importance of optimizing electric machines and would like to have some suggestions how to make people aware of the importance of optimizing electric machines to motivate more students researching in this field.

## Bibliography

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