TEMPERATURE ESTIMATION OF A PERMANENT MAGNET ELECTRICAL MOTOR

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Popular science summary of the thesis [1].

Thermal management is an important component for electrical motor performance. This thesis presents an approach to obtaining the magnet temperature, when measurements on a moving rotor is difficult.

Battery and hybrid electrical vehicles have experienced a surge in popularity in recent years. An attractive and prevalent choice for the electrical motor is the permanent magnet synchronous motor, PMSM, which is a highly efficient motor thanks to its lack of magnetization current. A key factor to optimize motor performance is the temperature management of the permanent magnet used in the revolving rotor. Excessive permanent magnet temperatures can inhibit the motor's ability to generate torque and lead to permanent hardware failures. It is, however, both difficult and costly to perform direct temperature measurements using sensors on a moving rotor.

The work presented in this thesis was instead centered around an alternative approach to estimate the temperature of the permanent magnet rotor with a mathematical model of the PMSM, combined with motor currents and voltage controller references. These signals are both much more easily obtainable and are most likely already known quantities used to regulate the motor.

Estimating the rotor temperature or torque with a mathematical model and measured signals, which is more formally known as a state observer, does, however, have its own assortment of issues. To start with, the PMSM model and its characteristics can vary greatly in different operating regions. To achieve a greater estimation accuracy, it was very important to attempt to compensate for these variations. The model also suffered from poor visibility of the states when inferred from the measured signals at low motor velocities that would lead to large estimation inaccuracies. A successful solution was to utilize the information of the motor coolant temperature in an alternative estimation approach at low operating velocities.

The thesis included a variety of different state observer designs that were tested and evaluated. One such category of designs, was developed for circumstances with limited access to information of the inductances. The inductances are important motor parameters to determine the relation between the currents and the magnetic field generated from the permanent magnet. By also including inductance estimation, the observer model became non-linear. The methods for the non-linear observer design were chosen with the purpose to be less computationally demanding, using a technique where different operating regions have their own associated tuning. This did, however, come at the expense of a more laborious and sensitive tuning process. The non-linear observer design was, nonetheless, crucial for obtaining accurate estimation results over the entire operating region, during circumstances with limited or poor inductance information.

Some of the analysis also showed potential numeric computational concerns when operating on hardware with constraints on numerical precision. Techniques to normalize or rescale the system model showed analytic improvements but were not readily apparent in simulations in a high-precision simulation environment.

The analysis was predominantly conducted using simulations with input signals and references generated from a detailed and advanced Motor-CAD model. To help validate the results, some additional evaluations were also conducted using real measurement data from a BorgWarner motor with rotor temperature measurements. The results were mixed; the observer model was sensitive to the accuracy of certain model parameters and the tuning process was very time-consuming. The analysis did, however, show early signs of promise and a continuation of the research work, dedicated to measurement data analysis, appears fruitful.

[1] Mårtensson, D., 2022. *Kalman-Filter Design and Evaluation for PMSM Rotor-Temperature Estimation*. MSc Thesis TFRT-6156. Department of Automatic Control, Lund University, Lund, Sweden. URL: *https://lup.lub.lu.se/student-papers/search*