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## Testing and Modelling of Electrical Traction Machines

### Performance Characterisation with Measurements from Transient Operation

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## Popular summary

Testing, characterisation and modelling of electrical machines might sound like a dry and unsexy subject; however, after a scratch on the surface one can find a quite hot content. Well, hot (as well as cool) might be a bit misleading, and the word relevant probably describes the topic better. In either case, due to the increased interest in applications with a highly dynamic loading pattern, one can expect an increasing need for extensive evaluation of machines that fit such applications well in the next-coming years. Unfortunately, the testing and evaluation methods that are used today generally demand quite a lot of equipment. Furthermore, the durations of these tests tend to be long. Therefore, it makes sense to investigate alternative approaches that obtain as much information about the characteristics of the test object as possible with as small means as possible. And abracadabra, an empty space opens up in the jungle of research.

The purpose of the testing and evaluation is to obtain information about how the electrical machine under test reacts to a certain input. If one for instance excites the stator windings of the machine with specific currents, a torque that creates rotation arises. In addition, the currents and the rotation generate heat. If the torque and the heat can be quantified for many different currents and rotational speeds, one can obtain a good picture of the performance of the machine, which in turn can be used as base for e.g. performance validation, modelling and optimisation of the machine operation. Furthermore, knowledge about the thermal characteristics makes it possible to foresee when the temperature of the machine approaches levels where it might cause damage. Consequently, this knowledge can be used to predict the maximum machine power. In summary, the most important machine characteristics to have information about can be divided up into three categories:

1. The torque (that results in rotation) as a function of the stator currents.
2. The power losses (that generate heat) as functions of the currents and the speed.
3. The temperature distribution in the machine as a function of the stator currents and the speed.

**The torque** of a machine can be measured with a torque sensor on the rotating axis, but it can also be calculated if the electromagnetic properties of the test object are known. This thesis presents a method that estimates the electromagnetic properties based on measurements from when the machine accelerates and brakes, and it therefore does not require a load to keep the machine speed constant (which is otherwise common in this type of machine characterisation). Furthermore, the tests are quick, which means that the temperature does not have time to rise significantly during the procedure. Therefore, the characterisation

can be performed quickly at different temperatures to see if the electromagnetic properties, and consequently also the torque, change.

**The power** of a machine is generally measured in a setup where the shaft of the test object is connected to a second machine that keeps the rotational speed constant. A sensor in between the test object and the second machine measures the relevant parameters to obtain the mechanical power (the torque and the speed). At the same time, a so called power analyser measures the electrical power. When the mechanical and electrical powers are known, the power losses can be estimated by calculating the difference between them. Even though this procedure gives accurate results, it demands long testing times and expensive setups. Therefore, this thesis presents an alternative approach that estimates the mechanical power from accelerations and retardations. In addition, relatively cheap industrial sensors measure the electrical power. Consequently, one obtains a good estimate of the loss characteristics of the machine with very small means.

**The temperature** profile of a machine depends on the aforementioned power losses, but also on its geometry, material characteristics and cooling strategies. A common way to model the temperature behaviour of a machine is to design a so called lumped-parameter circuit. If the circuit has a sufficient design and accurate parameters, one can obtain a good estimate of the temperature in the machine as a function of the power losses and the cooling. This thesis presents a method to obtain parameter values that result in good simulations of the temperature. The method estimates the parameters based on measurement data during transient power loading, and it can therefore foresee the thermal behaviour even when the machine reaches very high temperatures.

In summary, this thesis presents methods that estimate the most fundamental characteristics of electrical traction machines with alternative approaches. Hopefully, the content gives inspiration to engineers and other interested people to keep evaluating machines in new innovative manners. As the great Churchill said: *Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.* For these test methods, that is.