Thermoefficient traction – energy saving by multi objective traction drives optimization for locomotives

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Motivation

In modern railway traction drive applications the growth of power density (e.g. traction motors) requires over proportional more heat to be discharged. Due to the importance of green energy balance (no/less additional installed cooling power), there is a clear need for more and more advanced cooling techniques. Efficiency improvement of traction motor/enable higher power density & less cooling demand for propulsion system. For example the reduction of fan power, will led to a cooling energy reduction and makes railway traction systems more “green”.

In this paper an optimization and evaluation approach (cf. Fig.1a) for internal air cooled traction machines will be presented. Further investigation results out of this high innovative concept (as fruitful R&D collaboration between TU-Wien/ Institute E370 and Bombardier Transportation) will be shown.

Methodology

A multi-physics optimization considering electromagnetic and thermodynamic performance is performed to increase power density and efficiency of a locomotive traction machine. The method is suitable for being easily extended to consider additional physics e. g. material strength or acoustic objectives, production cost functions or additional limiting constraints. FEA (finite element analysis) is used for obtaining electromagnetic properties whether analytical code is used to rate the amount of heat discharged by the cooling fluid. Fig. 1b visualizes that cooling duct geometry in rotor and stator iron is coupled to electromagnetic behavior of the machine. The aero-/ thermodynamic performance of the optimized solution is finally validated by full CFD (computational fluid dynamics) with conjugate heat transfer.

To model electromagnetics a commercially available finite element software is used. With regard to the rotation of electrical machines with the electromagnetics solutions, it is state of the art to utilize optimized modeling and if possible also solving strategies. They keep fixed meshes of stator as well as rotor and only deal with the air-gap region to represent the rotation. Thus, the numerical accuracy is kept constant for all analyses.[1]

The method shows sufficient agreement with lab test measurements within an error range of 10%.

Optimization Strategy

Different cooling duct geometries are investigated where cooling air passes axially through stator and rotor iron stack. Cooling ducts can be arranged in whole iron yoke areas, see Fig. 2.

The optimization evaluates both the electromagnetic performance as well as the iron stack temperature required for heat removal. The two evaluations are one way coupled; within the electromagnetic calculation the heat sources for the thermal analysis are determined. According to Fig. 3 the workflow is structured in three parts: First, the shape of the ducts is constructed converting the parameters to geometric quantities. Next, the area and circumference of the ducts are calculated.
Then, the duct numbers can be obtained in such a way to fulfill the pressure and flow distribution constraints. Analytical formulae are used to calculate the flow state which is described in detail in [2]. The parameter influence was investigated performing a sensitivity analysis. Parameters without significant impact on the objectives were set to constant to speed up optimization time with reducing the number of required design evaluations by doing so.

Fig. 2: Permissible area for cooling ducts.

**Results**

For the chosen optimized design from the set of solutions all objectives could be improved. The magnetization current could be reduced about -10.2% for constant mechanical output power as well as the rotor iron losses which were reduced about -9.3%. All in all, the reduction of total losses counts -1.5% meaning an increase in efficiency.

For evaluating the cooling performance a full CFD calculations including conjugate heat transfer were realized using commercial CFD code. A significant temperature reduction up to -15K could be achieved, see Fig. 4 for a comparison of the temperature distributions. The temperatures in the iron stack are not distributed rotation symmetrical caused by not symmetrical stator yoke radial length. It is the source of a local temperature peak of about 10K and even continues to the downstream winding head. The cooling flow is directed from left to right and exits there.

![Comparing initial (a) and optimized (b) design temperature distribution.](image)

The reason of rising iron stack temperatures in axial/ downstream direction is decreasing temperature difference caused by increasing fluid temperature. It needs to be taken care of a sufficient temperature difference in the region of downstream winding head to ensure enough cooling. As it can be seen in the temperature plots as well the average fluid outflow temperature is higher for the optimized example design. That is the result of reducing the volume flow rate and allowing higher pressure drop while keeping the fan power constant.

Typical results and design improvements due to the optimization include a reduced air, consequently reduced fan power and noise, reduced winding temperatures, thus decreased power losses and an increased life time of the machines, as well as a reduced magnetizing current yielding enhanced field weakening capabilities, and increased power factor and finally a better efficiency.

**Literature**
