Pareto Optimization in Terms of Electromagnetic and Thermal Characteristics of Air-Cooled Asynchronous Induction Machines Applied in Railway Traction Drives

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Abstract **– In terms of electromagnetic and thermal parameters, the utilization of asynchronous induction machines applied in railway traction drives is much higher than those used in industrial drives. Therefore, the multi-physics optimization with respect to electromagnetic and thermal behaviour is nowadays one of the most important design task with such machines. The paper discusses a novel optimization approach considering the Pareto optimal design to improve both electromagnetic characteristics and thermal behaviour using a sequential coupling of electromagnetic, thermal as well as fluid dynamics analyses.**

Index Terms **– Pareto optimization, Multi-physics optimization, Induction machine, Finite element analysis.**

I. Introduction

BESIDES of the very high electromagnetic and thermal utilization of induction machines applied in railway traction drives, there is very limited space for all components of the entire drive system, too. In particular with high speed trains, the increased power density asks for improved cooling methods and advanced machine designs respecting additional limitations e.g. on noise.

By using a typical length scale of an induction machine λ such as air-gap diameter or stacking length [1], the power losses P_{Cu} depend on the square of the current density J within the windings while the iron losses P_{Fe} in the iron parts depend on the square of the magnetic flux density B as well as the frequency f of the rotating field scaled by $1 \leq \beta \leq 2$ as

$$P_{Cu} \sim J^2 \, \lambda^3 \quad , \quad P_{Fe} \sim B^2 \, f^\beta \, \lambda^3 \quad . \tag{1}$$

On the other hand, the temperature rise ΔT due to these losses can be assumed as

$$\Delta T \sim \frac{P}{\lambda^2} \quad . \tag{2}$$

Consequently, constant or increased electromagnetic utilization leads to an uprising cooling problem with electrical machines having a very high torque and power density.

The proposed optimization algorithm utilizes a sequential coupling of electromagnetic, thermal and fluid dynamics analyses by using numerical and analytical methods [2]–[6]. The most important optimization lies on geometry and arrangement of the cooling ducts with respect to thermodynamics and electromagnetics.

II. Optimization Algorithm

The objectives of the optimization are a minimized magnetizing current, a minimized rotor temperature as well as a minimized stator temperature. Fig. 1 shows the

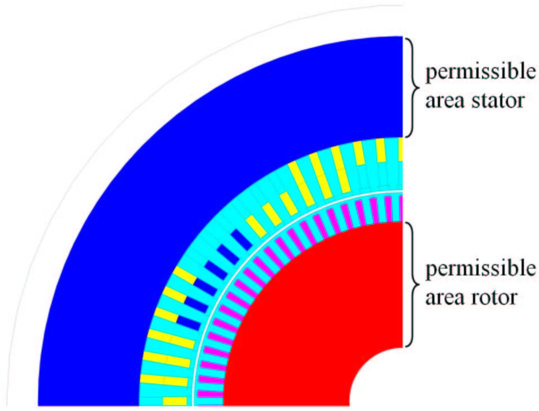

Fig. 1. Permissible areas of the cooling ducts with stator and rotor

permissible areas of the cooling ducts with stator and rotor. However, there are some constraints which have to be considered such as in particular a minimum distance between the cooling ducts and a minimum width of the cooling ducts in order to have a realizable pressure drop with an appropriate heat transfer.

Fig. 2 depicts the effects of an increased cross section due to either increased number and/or geometric size of the cooling ducts on the magnetizing current of the induction machine. Since both objectives counteract against each other, there will be no global optimum of the machine [7], [8]. However, a Pareto optimum can be defined by weigthing magnetization current and temperature rise to obtain an optimal design.

Fig. 3 depicts the sequential optimization loop. Electromagnetic and thermal analyses are carried out by finite element analyses which use fully parametric meshing, solving and postprocessing. With the intent of a fast optimization, the fluid analyses within the optimization loop utilize an analytical model to incorporate the heat transfer with forced convection in the parallel cooling ducts. Thereby, the heat transfer coefficient α depends on Nusselt, Reynolds and Prandtl numbers,

$$\alpha = \alpha(\mathrm{Nu}) \quad , \quad \mathrm{Nu} = \mathrm{Nu}(\mathrm{Re}, \mathrm{Pr}) \quad . \tag{3}$$

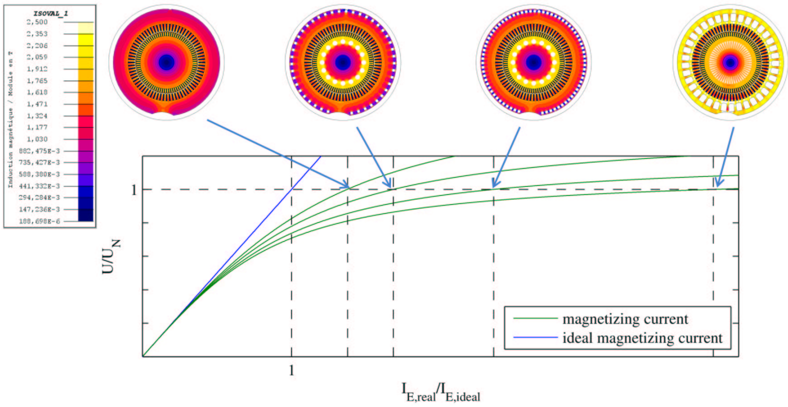

Fig. 2. Increase of magnetizing current due to the cooling ducts

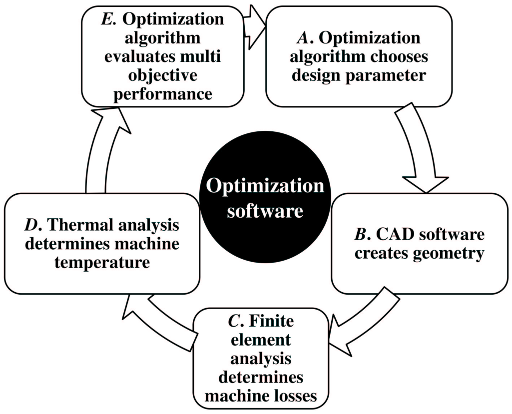

Fig. 3. Optimization loop

Since the same overall pressure loss of all parallel cooling ducts must be fulfilled, the in general different velocity with each cooling duct caused by the arrangement is determined iteratively until the pressure condition is fulfilled. Afterwards, the final design will be analyzed by detailed numerical fluid dynamics analyses.

The full paper will discuss more details about the algorithm, particularly sensitivity tasks with respect to geometric parameters as well as feedback with already built machines in terms of their cooling parameters.

III. Design Improvement

Fig. 4 shows a comparison of the temperature distribution between the initial design and the optimized design. The most important differences are a decreased volume flow although with an increased number of cooling ducts, decreased maximum and average temperatures within the active parts yielding in particular reduced power losses and a decreased magnetizing current, too.

IV. Conclusion

A novel approach for the coupled electromagnetic-thermal optimization of air-cooled induction machines utilized in high power traction drives is presented. The optimization algorithm deals with numerical as well as in particular in the fluid dynamics section analytical methods. However, the optimized design will be analyzed by means of detailed numerical fluid dynamics analyses afterwards.

Since an increasing number or cross section of the cooling ducts enforces a higher magnetizing current and thus increased iron losses, the optimal design is a Pareto optimum with respect to given limits on in particular power factor, temperature rise and heat transfer parameters.

Typical results and design improvements due to the optimization include a reduced air flow, 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, an increased power factor and finally a better efficiency.

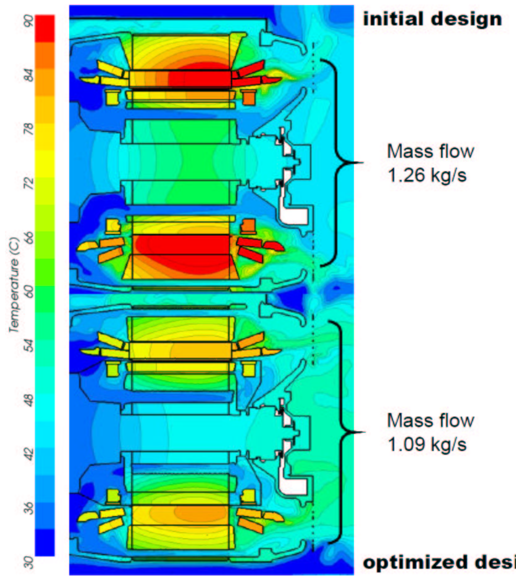

Fig. 4. Comparison between initial and optimized design

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