Analysis of Rotor Ventilation System of Air Cooled Synchronous Machine Through Computational Fluid Dynamics

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Abstract. This paper describes design changes on rotor ventilation system of the air-cooled synchronous machine. There are several variants for the analysis. This research is performed to find possible ways for increase of the power output of the machine. The rotor cooling system uses an under winding cooling channel to distribute the cooling air in the axial direction into the rotor and then through the radial rotor channels into the air gap. The presented optimization of the rotor cooling system is in the angle pitch of the radial channels. These changes had to be verified, before it could be implemented to the actual machine. Computational Fluid Dynamics tool Ansys Fluent is used for the simulations. The changes have positive effect on pressure drop, airflow and air temperature.

Keywords: Synchronous machine · Computational fluid dynamics · Cooling · Ansys fluent · Ventilation analysis · Rotor winding

1 Introduction

Optimization of the ventilation system of the air-cooled turbo generator is crucial part of the development and leads to higher power output with the same dimensions. This goes hand by hand with the implementation of FEM software, which can be used for evaluations of the concepts and prototypes before production [1–4]. The alterations proposed in this article should cause reduction of pressure drop, better airflow distribution.

1.1 Turbo Generator Cooling System

Stator of the analyze turbo generator uses multi-compartment cooling system, see Fig. 1. The principle of this cooling system is based on over-pressure and under-pressure. The end-winding area is pressurized by axial ventilator. This pressure drives the airflow through three different branches. First branch is cooling stator. From the end-winding area, the air flows through transfer ducts to so called "cold" compartment from where

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it goes through the stator core to the airgap [5, 6]. Second branch represents airflow through rotor. Air flows under the end cap, where it is divided to cooled end-winding and rotor winding. Rotor winding is cooled via radial ducts, which are subject of the analysis. Last, the third branch is cooling first stator packets and join both stator and rotor branch in the air gap, from where it flows through stator core to the so called “hot” compartment and to the cooler.

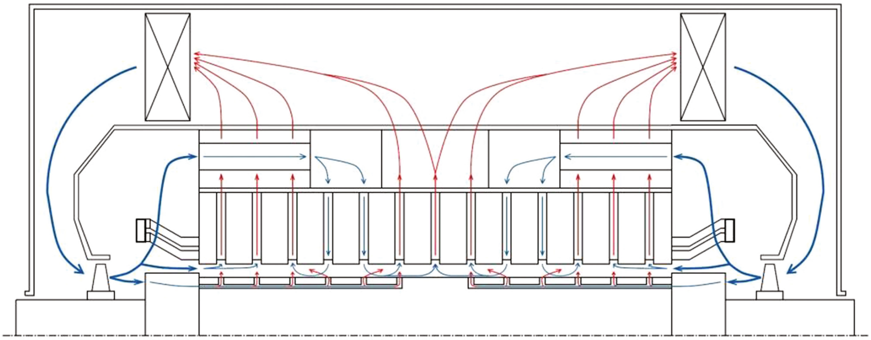

Fig. 1. Cooling system of the turbo generator

1.2 Branch Effect

The velocity of the air which enters the rotor sub slot is very high, so the air cannot turn to the first radial ducts properly. Results is that there is non-uniform distribution of the

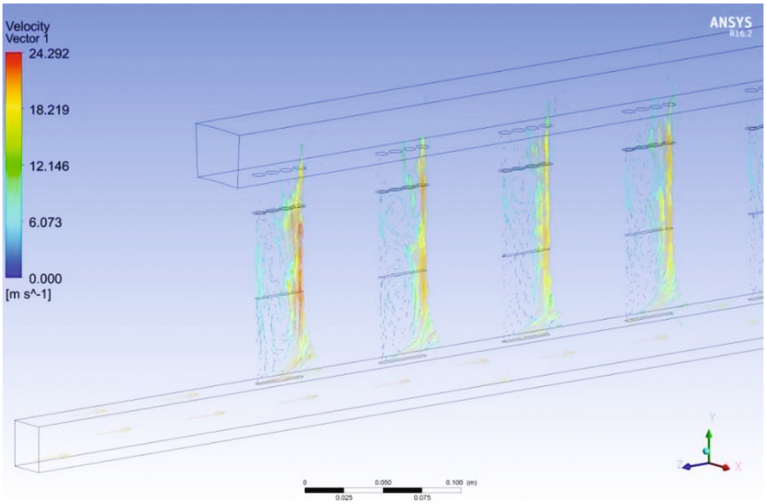

Fig. 2. Example of air vortexes

airflow in radial ducts caused by air-vortexes, see Fig. 2. Those vortexes greatly reduce the usable cross-section.

The branch effect can be calculated using empiric equation described in [7]. This equation gives us relative values of the airflow which can be multiplied by total airflow to get airflow in individual radial duct.

2 Analysis

All analyses are performed using Ansys Fluent and other Ansys tools. There are three different CAD geometries which are analyzed, see Figs. 3, 4 and 5. Angles in all three options are set according to some additional calculations, experience and technological possibilities.

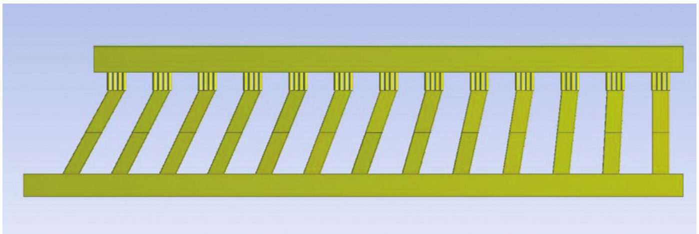

Fig. 3. Geometry option A

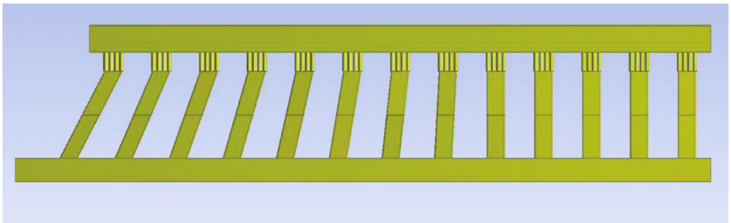

Fig. 4. Geometry option B

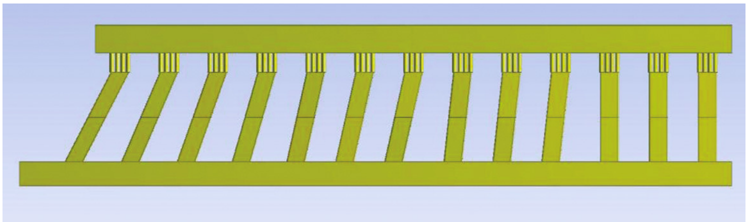

Fig. 5. Geometry option C

It should be point out that walls of the radial ducts are perfectly smooth. This simplification has been done so we could create good quality mesh. Parameters of the mesh for each option are summed up in Table 1 and example of the mesh is in the Fig. 6.

Table 1. Mesh parameters

Option	Num. of elements	Skewness – max	Ortho. – min
A	1 037 876	0.77	0.42
B	813 452	0.77	0.35
C	831 012	0.77	0.35
Original	626 359	0.77	0.35

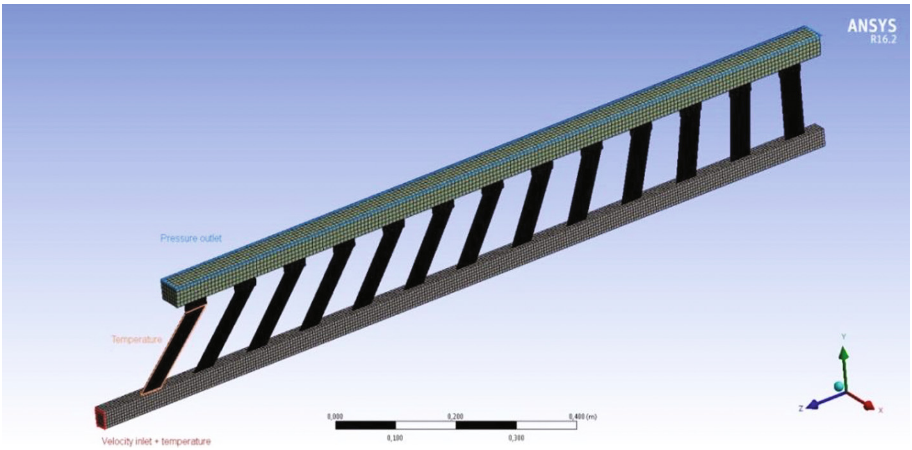

Fig. 6. Computational mesh and boundary conditions

Boundary conditions are set as velocity inlet, pressure outlet and static temperature. Velocity is set to 20 m s^{-1} and pressure to 0 Pa. Constant temperature is applied on radial duct walls (see Fig. 6) The Coupled solver is used to solve all options. Because of good quality mesh, it took only 200 iterations to converge.

3 Results

All analyzed variants proved to be effective in case of airflow distribution and pressure drop. It is also found that tilted radial ducts have positive effect in case of reduction of air temperature hotspots. Following Figs. 7 and 8 show the main differences in air temperature of the original and A option.

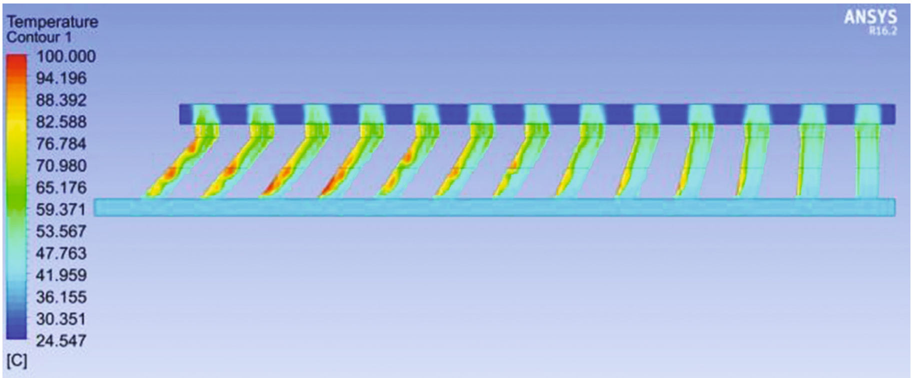

Fig. 7. Air temperature – option A

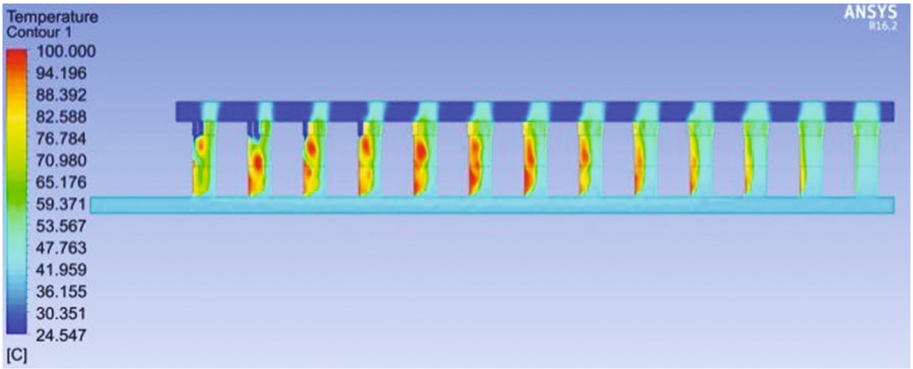

Fig. 8. Air temperature – original option

Next two Figs. 9 and 10 compare airflow distribution in option A and original option. There is major reduction of the described vortexes in first half of the radial ducts. This is backed up by a fact, that all four holes in wedge are used instead of two in case of the original option.

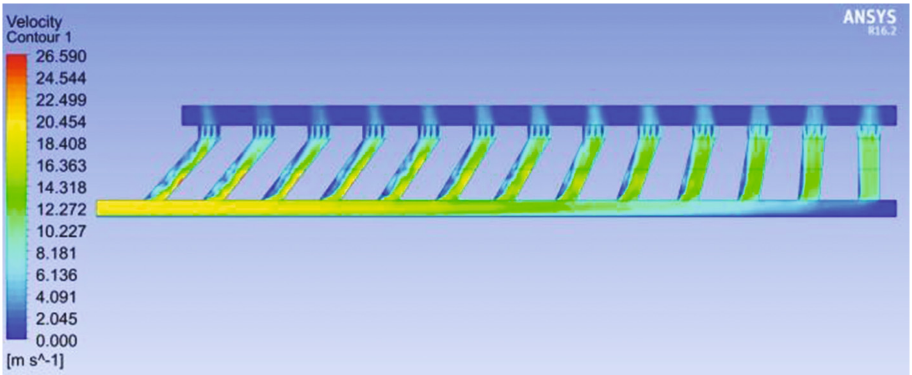

Fig. 9. Air velocity – option A

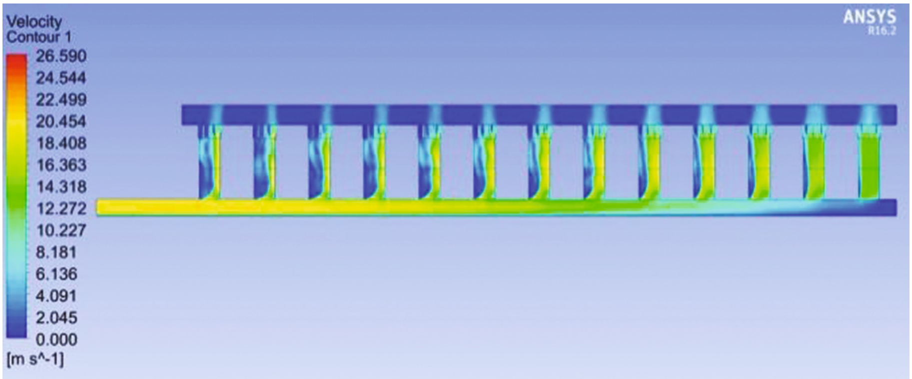

Fig. 10. Air velocity – original option

It has been calculated that because of the overlaps between each conductor, the cooling area is increased by 5% in case of option A, 2.5% for option B and 3% for option C. Figures 11 and 12 support previous statements and clearly show that pressure drop has been lowered and airflow is much more uniform.

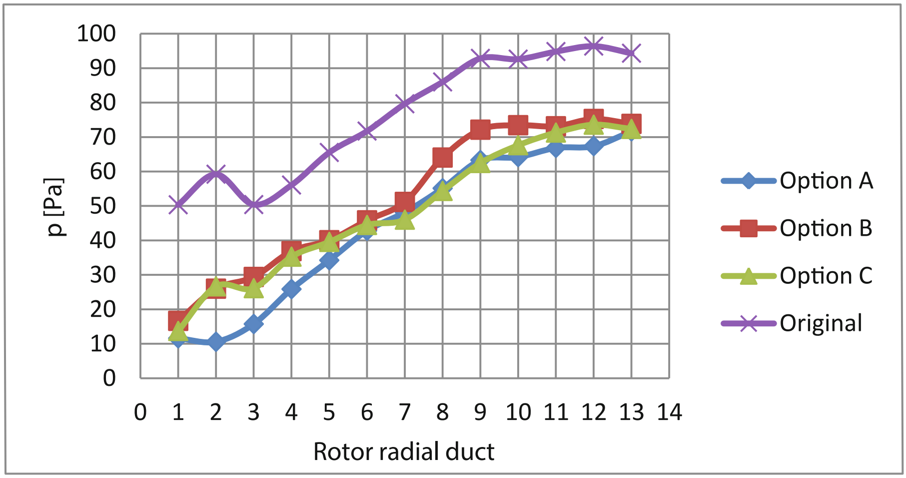

Fig. 11. Pressure drop for each radial duct (all options)

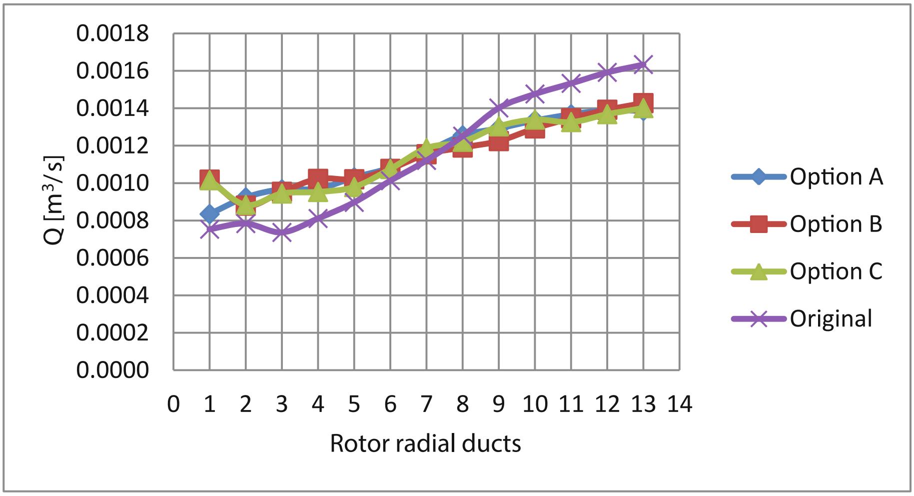

Fig. 12. Airflow for each radial ducts (all options)

4 Conclusion

There are three geometry options prepared for the analyses; each option with different angle of the radial ducts. Based on presented results, the option A seems to be best choice for realization because of its lowest pressure drop.

There will have to be some additional testing of geometry option A, particularly the influence of the mentioned overlaps, which is neglected during first analyses.

The test samples will have to be produced and of course the technological process will have to be specified.

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References

1. Yiping, L., Wenhao, Y., Pengfei, C., Weili, L.: Mechanism research on air mass flow rate distribution in rotor radial ducts of turbo generator with sub-slot ventilation. In: 2008 World Automation Congress, Hawaii, HI, pp. 1–5 (2008)
2. Wang, Z., Han, J.: Numerical simulation of air flow distribution in large air-cooled turbo generator rotor at different rotation speed and inlet pressure. In: 17th International Conference on Electrical Machines and Systems (ICEMS), Hangzhou, pp. 2352–2355 (2014). doi:10.1109/ICEMS.2014.701389
3. Weili, L., Feng, Z., Liming, C.: Calculation of rotor ventilation and heat for turbo-generator radial and tangential air-cooling system. In: Proceedings of the International Conference on Power System Technology, POWERCON 1998, Beijing, vol 2. pp. 1030–1033 (1998). doi:10.1109/ICPST.1998.72924
4. Vlach, R., Huzlik, R.: Thermal model of high speed asynchronous machine. In: 17th International Conference on Mechatronics - Mechatronika (ME), Prague, pp. 1–5 (2016)
5. Franc, J., Pechanek, R., Kindl, V.: Optimisation of ventilation system of the air-cooled turbo generator. In: 2016 17th International Conference on Mechatronics - Mechatronika (ME), Prague, pp. 1–5 (2016)
6. Ancik, Z., Toman, J., Vlach, R., Hubik, V.: Modeling of thermal phenomena in liquid cooling system for aircraft electric unit. IEEE Trans. Ind. Electron. **59**, 3572–3578 (2012). doi:10.1109/TIE.2011.2166232
7. Hak, J., Ošlejšek, O.: Výpočet chlazení elektrických strojů. Výzkumný a vývojový ústav elektrických strojů točivých, Brno (1973)