Effects of Geometric Changes at the Fan Side of a TEFC on the Flow and Heat Transfer: A Numerical Study

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Abstract. CFD is performed to study the flow and heat transfer features of a TEFC induction motor. Geometry of an end shield and diameter of the fan cover are varied and examined. The modification of the end shield at the fan side can help increase the flow rate at the loading side by 10% due to a reduction in recirculation between the fan and the end shield. The change of cover diameter can lead to a variation of 40% in the external flow rate at the fan side and around 15% at the loading side. A combination of the re-designed end shield and the fan cover with large diameter is proposed in our study which can lower the average winding temperature by 4°C.

1. Introduction

Electric motor manufacturers have been pushing the limits of power density of motors due to the demand for higher efficiency, smaller and lighter electric machines. The same power output can be delivered with the use of less material or in a smaller size, which means the heat generation per unit volume will be higher as a result of being compact. The maximum temperature in the winding is of great concern since an electric machine will deteriorate in its performance or breaks down if the insulation material of the winding exceeds the limit and fails. Obviously heat dissipation plays an essential role in helping develop better performance motors, and more numerical and experimental studies regarding heat transfer performance are required in order to achieve a better design.

Totally Enclosed Fan Cooled (TEFC) induction motor is one of the motor types used most widely in a variety of industrial equipment. Heat resulted from the stator and the rotor is mainly dissipated via conduction to the parts including a finned frame along with end shields and then via convection to the ambient. Self-cooling is achieved by introducing an external fan with a fan cover at the non-drive side (or the fan side). What we can expect is the external flow features will be critical to the cooling performance which requires good designs for a fan, fan cover, end shield and finned-frame.

Micallef et al. [1] numerically and experimentally examined the flow field as well as the heat transfer in the end region of the winding and proposed an alternative configuration employing a fan mounted on the shaft near the end shield and the winding tip, and an increase by 19% in the windage loss along with a decrease by 33% in the thermal resistance was found. Chen et al. [2] adopted Response Surface Methodology with multi-quadratics as basic functions in order to optimize the fins on the frame under specific operating conditions. Results showed a more than 50% reduction in the thermal resistance in some cases. CFD was performed by Valenzuela and Tapia [3] to examine the air flow rate, air velocity and temperature of a motor, and the CFD results were well validated. Andres et al. [4] characterized radial fans used in electrical machines with the application of CFD. Flow-pressure characteristic curve of fans were obtained by CFD. More numerical and experimental works regarding air flow with fans [5] and cooling ducts [6] can be found in the literature.
From the literature survey we know how important the external flow is for cooling motors including TEFC. A lot of researchers have conducted studies to characterize fan, fan cover, finned frame and so on, although not many works regarding the overall effect of combining the components mentioned above on the air flow in axial direction and the winding temperature are available. In the present work we investigate the flow features at the fan side, re-design the geometry of the end shield, modify the fan cover and finally examine the effects of the end shield and the fan cover on the flow rate and the temperature in the winding in order to get a deeper insight into the overall effect of the external flow.

2. Mathematical model and simulation methodology

2.1. Geometric configuration
NEMA F#5810 series is selected in the present work. This motor is suited to wind/ hydraulic power facilities and can be applied in oil refinery, power plants and so no. We want to further improve the cooling performance and consequently CFD is conducted to study the flow and heat transfer features of a 60Hz, 4P-1000HP TEFC induction motor, as shown in figure 1.

2.2. Boundary and volume conditions
6 surfaces enclose the motor. The bottom surface simulates the ground on which the motor is placed and hence an adiabatic wall is introduced as the boundary condition. The rest of the 5 surfaces are set as pressure outlet, with the upstream and downstream surfaces 2.5 times and 8 times the length of the motor away from the motor, while the 3 lateral surfaces 2.5 times the width of the motor away from the motor. Ambient temperature is set 25°C. The motor runs at 1800rpm; a total loss of around 22kW is introduced accordingly to the stator, winding, rotor and rotor conductor as volume heat source.

2.3. Numerical method
The commercial software ANSYS FLUENT™ is used to study the flow and thermal features of the full motor. This conjugate heat transfer problem is assumed to be steady-state and run with an implicit and segregated solver. The rotation of the fan is simulated with the multiple reference frame model (MRF). Unstructured mesh mainly composed of tetrahedral cells is applied for complicated geometries while structural mesh is applied to sweepable parts. Fine grids are deployed where high velocity or temperature gradient takes place, including air gap between the stator and rotor, blades, fins and so on. Y+ is checked to solve for laminar sub-layer.

3. Results and discussion

3.1. Flow features of the original design
From figure 2, a recirculation is clearly observed between the fan and the end shield at the fan side which will lead to a loss in energy and flow rate in the axial direction from the fan side to the loading side. In the present study the fan will be left unchanged due to the higher cost in modification while the fan cover and the end shield are allowed to be re-designed.

Figure 1. 3D CAD of NEMA 5810 induction motor.

Figure 2. Vector distribution of the original version at the rear of the fan.
3.2. Reduction in recirculation
To eliminate this energy loss, we modify the end shield to be more streamlined, as shown in figure 3. Here we take a look at the flow rates in the inter-fin spacing at the 7 sections along the flow direction (z-dir.). From figure 4, an enhancement in flow rate is noticed with the addition of the streamlined end shield by 2 and 10% at the fan side and the loading side, respectively. The improvement is more announced at the downstream to make sure that the air flow is still sufficient to remove the heat at the loading side. Figure 5(a) demonstrates that with a more streamlined air-guiding end shield, the recirculation is reduced significantly and the air flow in the inter-fin spacing is improved as we can see the main flow is extended and hence the separation point at the loading side is shifted further to the downstream as shown in figure 5(b).

Figure 3. Sketch of the air-guiding end shield.

Figure 4. Local flow rate at sections along the flow direction.

Figure 5. Vortex of the original design and the one with a more streamlined end shield at (a) the rear of the fan and (b) the inter-fin spacing.

Figure 6. Three diameters of fan cover.

Figure 7. Flow rates using different fan cover diameters.
3.3. Cover outlet diameter
Here the diameter of the fan cover is varied to investigate the effect on the flow rate. Three diameters are examined, D=765 (original design), 790 and 815mm, where a gap of 5mm between the fan cover and the fins on the frame is remained, as shown in figure 6. Flow rates using different fan cover diameters are demonstrated in figure 7. An increase in flow rate is noted as the diameter increases. One can notice a significant rise in flow rate at section 1 by 22% and 29% with D_med and D_max, respectively. However, the flow rate drops dramatically to a very unnoticeable difference at the loading side (section 7). Winding temperature at the loading side might be much higher than that at the fan side due to the huge flow rate drop. Moreover, 22% increase in flow rate is achieved with D_med compared to D_min while only 7% increase is revealed as the diameter is further increased to D_max, showing that there might be some optimal design in the fan cover diameter and will be studied in the future work. Figure 8 shows the flow vector using different fan cover diameters. Flow rate is increased in the fin region while a recirculation is observed in all three cases.

3.4. A combination of the air-guiding end shield and the fan cover with large diameter
From the above studies, the ‘convex’ design for the end shield at the fan side is noticed to help reduce recirculation at the rear of the fan. In addition, it is found that the flow rate increases as the diameter of the fan cover increases. In this part we combine these two features, that is, the modified end shield at the fan side along with the fan cover having D_max=815mm in our new design, as sketched in figure 9. Figure 10 shows the flow rate with the new design. An increase in the flow rate is noted by 40% and 15% at the fan side and the loading side, respectively, when comparing new to original design. Note in the figure that when comparing D_max+NewES with D_max, the flow rate can increase by 5-10% along the flow direction with the modification of the end shield at the fan side, resulting in a decrease in average winding temperature by 1°C as demonstrated in table 1. The winding temperature is lowered by almost 4°C when comparing new to original design. Figure 11 shows the vector on x-plane across one inter-fin spacing. From figure 11(a), a reduction in recirculation is observed as mentioned previously, while figure 11(b) shows an overall increase in velocity, even at the root of a fin.

Table 1. Temperature rise in the winding.

| Case            | Average temperature rise in winding, K |
|-----------------|----------------------------------------|
| D_min (original)| 103.87                                 |
| D_med           | 102.62                                 |
| D_max           | 101.30                                 |
| D_max+NewES     | 99.98                                  |
4. Conclusions
A 60Hz, 4P-1000HP F#5810 TEFC induction motor is studied with CFD approach. Results of the original design reveal recirculation at the rear of the external fan. In order to reduce the recirculation we modify the geometry of the end shield at the fan side. Making the end shield at the fan side more streamlined enhances the air flow even at the downstream side by 10%, showing less flow energy wasted in a recirculation and higher fan efficiency achieved. In addition, larger fan cover diameter is found to lead to higher air flow rate in the present study although the dramatic drop in flow rate from the fan side to the loading side is observed, showing some flow dissipated to outside of the fin region. The combination of the air-guided end shield at the fan side and the fan cover with larger diameter is proposed and an increase by 40% /15% in the flow rate at the fan/ loading side is noticed. Finally, a full thermo-fluid simulation is performed to confirm a reduction in the winding temperature by 4°C.

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