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HEAT TRANSFER PERFORMANCE ENHANCEMENT ON WHEEL HUB MOTOR WITH FIN ADJOINT OPTIMIZATION

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1. ABSTRACT

An effective thermal management system for motors can improve the efficiency, stability, and lifespan, so it is important to study and evaluate different modes of cooling. Hub-motors generally rely upon aerodynamic cooling because the geometry of the wheel naturally limits packaging space, and can preclude the introduction of more complex, efficient (and expensive) cooling systems. When the heat load is high the aerodynamic cooling alone may not be sufficiently enough to cool down the motor to the safe temperature range, in such situations surface modification or topology enhancement with fins become relevant. In this study, three-dimensional (3D) approaches for cooling a commercially available 500W scooter wheel hub motor (BLDC-Brushless Direct Current) are simulated under various driving conditions using the StarCCM+, a computational fluid dynamics (CFD) package. The results show that aerodynamic cooling alone without any surface modification is not sufficient for lowering the temperature of the stator to safe range (<135˚C), when the heat load is more than 5% of rated power. To improve the heat transfer surface features, the internal and external convective thermal resistance has been determined numerically with simulations to introduce cooling fins. The internal convective thermal reisistane on the rotor cover is higher than that of rotor by a factor of 10. Introduction of fin on internal surface of rotor and rotor cover resulted in a marginal heat transfer improvement. It is expected that, pertinent design and optimization of the fins can further bring down the maximum temperature rise.

2. INTRODUCTION

The purpose of the motor cooling system is to limit the temperature of critical components such as the coils, permanent magnets, and bearings; the cooling system should provide sufficient heat dissipation from these components [1]. Deterioration and accelerated insulation ageing of components such as the coil winding are caused by an excessive temperature increase [2]. The heat from the inner side of the motor is conducted to the surfaces and then subjected to convective heat transfer by the surrounding ambient air. Appropriate design of the fins can enhance the convective heat transfer. The heat transfer rate from the fin to the surroundings can be improved by increasing the heat transfer coefficient, or by increasing the surface area of the fins. Increasing the surface area is the most common approach but it leads to an increase in drag. To achieve an improvement, the fin pitch, fin extension, and number of fins need to be optimised. This mode of natural cooling is suitable for small, medium, and large inner-rotor-motors with sufficient outer surface area for fins [2]. Efficient stator cooling for inner-rotor motors has broadly been achieved, however there remains opportunity for the improvement of rotor cooling, and it becomes relevant as the temperature of the magnets increases with load [3]. In the case of wheel hub motors, which has outer rotor and inner stator, both the rotor and stator cooling technologies remain in an early stage of development as the available surface area for fin or any other cooling technologyis limited. So, in this study numerical simulation approach has been used to simulate various heat load and rotational speed conditions to identify the thermal issues on the motor. The results show that the maximum temperature is on the stator and the internal thermal resistance is higher than the external thermal resistance. Also, it has been identified the provision of fins play a vital role in reduction of temperature but need further study in design and optimization of fins. If optimized fins are unable to

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bring down the temperature to safe range for higher heat load conditions then combination of heat pipe (HP) and phase change materials (PCM) as shown in Figure 1(d) could be considered for further studies.

3. METHODOLOGY

For the baseline study, two geometries of motor CAD is used one with bearing (closed system-no interaction between external and interal fluid) and other without bearing (open system-direct interaction between external and internal fluid). The motor CAD was imported into the commercially available CFD software StarCCM+ to examine the fluid flow around the motor and its effect on heat transfer. The general motor CAD design and meshing is shown in Figure 1(a) with ambient air, rotational region and other motor components. Both these systems were separately simulated under steady-state conditions in an external flow domain, under various rotational speed and heat loss, the average external wind speed was assumed to be 6m/s. The model was finely meshed with polyhedral prism layer meshing, conformal meshing is maintained between the motor components, axle, bearings and tyre for conjugate heat transfer between solid and fluid domains Figure 1(a). To reduce the computational cost and the number of cells, the coil was not considered and assumed that the stator is generating a constant heat of 20W, 50W, 75W, 100W, 125W and 250W for each simulation. For each case the speed of the motor was varied from 350RPM to 900RPM in steps of 300RPM. Materials physical and thermal properties for the motor components were assigned, using StarCCM+'s material properties library, and a steady-state k-ε turbulence model with coupled solid energy physics was used to simulate the turbulent convective flow and heat transfer within the motor. The conjugate heat transfer model was used to transfer the heat from solid to fluid by solving the flow and energy equations in the fluid and solid domain. Air was used as the cooling medium for the passively cooled baseline study.

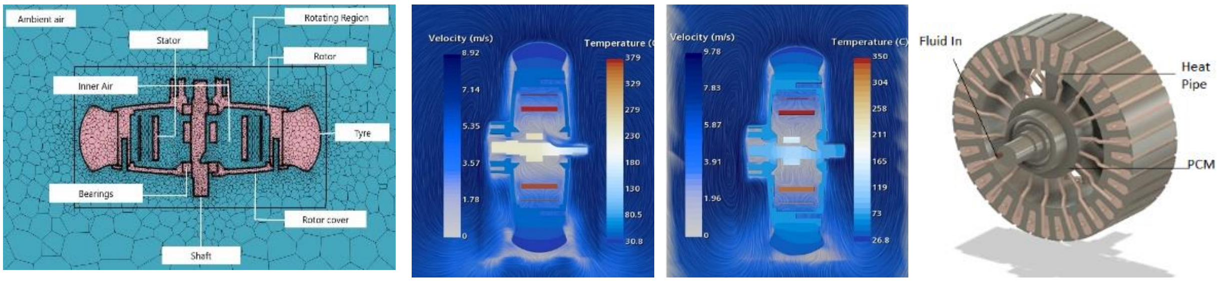

Figure 1. The motor CAD design and meshing of the motor (a) Motor meshing with all solid and fluid regions(b-c) open and closed system temperature and velocity profile for 125W power loss and 600 RPM respectively (c) Novel HP cooling approach.

4. INITIAL RESULTS AND DISCUSSION

During the steady state thermal analysis, the maximum temperature is located on the stator of the motor, and there is a significant temperature difference between the maximum and average temperature on the stator (ΔT) as shown in Table 1. It has been observed that the temperature uniformity represented by $\Delta T = Tmax - Tavg$ has decreased with the increase in the speed of the motor, along with an overall decrease in the maximum temperature. This could be attributed to the enhancement in the convective heat transfer coefficient. The convective thermal resistance at the inner and outer surfaces of the rotor and rotor plates is analytically calculated using equation 1. The variation of the internal and external convective thermal resistance ($R_{th\ Con}$) with the motor speed is shown in the Figure 2. The thermal resistance increases non-linearly with the increase in power losses and for a constant speed. There are discrepencies in the nature of graph which need to be investigated further. It can be seen that the $R_{th\ Con}$ decreases with the increase in speed of the motor for power losses less than 100W eventhough the speed do not have any direct effect on thermal resistance but indirectly it decreases the ΔT with heat transfer improvement. For closed and open system , the motor surface temperature has increased to ˜80˚C from ˜50˚C when heat load is 125W (efficiency 75%).

$$R_{th\ Con} = \frac{\Delta T}{Q}\ K/W \tag{1}$$

Where $R_{th\ Con}$ is the convective thermal resistance, K/W; Q is the heat transfer rate, W; and ΔT is the temperature difference between the average surface and surrounding air.

Table 1. Shows the maximum temperature and average temperature on motor stator components at different speeds and power loss (open system)

Power loss W (Efficiency)	**350 RPM**		**600RPM**		**900RPM**	
	Max Temperature(˚C)	Avg. Temperature(˚C)	Max Temperature(˚C)	Avg. temperature(˚C)	Max Temperature(˚C)	Avg. temperature(˚C)
20 (96%)	106	47.5	99.4	93.7	93.3	89.2
50 (90%)	212	75.5	193	178	174	167
75 (85%)	297	97.1	266	245	235	227
100 (80%)	382	119	338	310.4	294	285
125 (75%)	417	141.6	400	376	354	343.5

The thermal resistance value remains almost consistent for a constant speed irrespective of the power loss. Maximum thermal resistance occurs at low motor speeds, and internal thermal resistance on the rotor plate is as high as multiple of factor 10 in comparison with the internal thermal resistance of the rotor. Providing fins on the internal surface of the rotor cover will clearly improve the heat transfer rate, optimisation of the fin size and shape and also the introduction of the heat pipe to extract heat will be the focus of the next stage of this research.

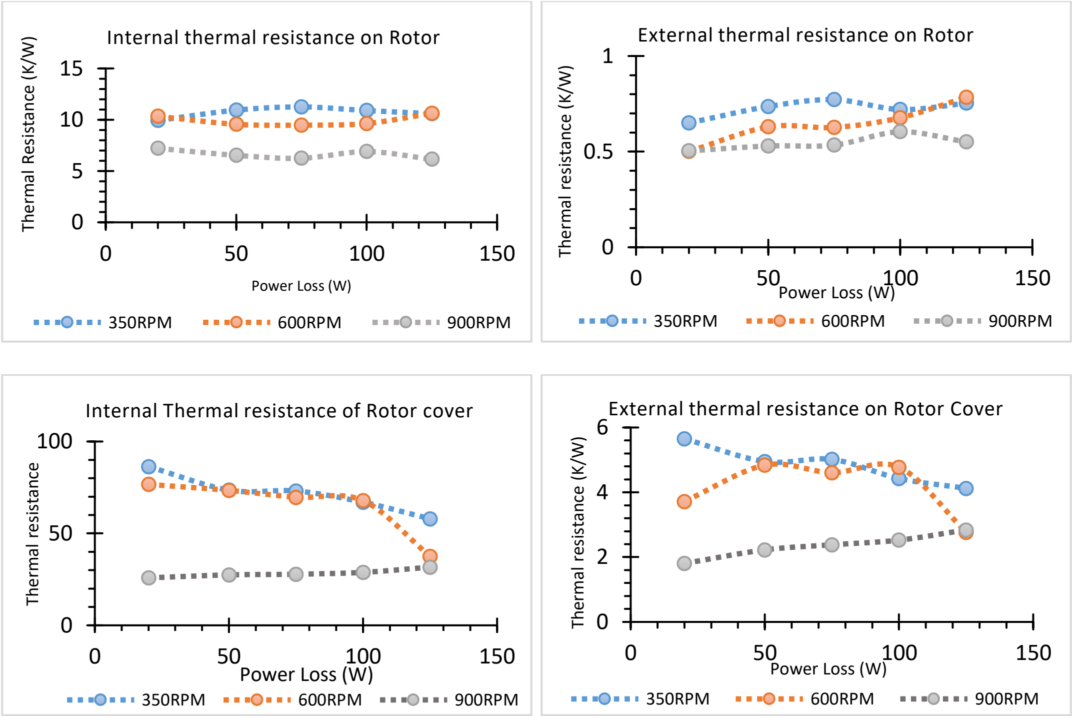

Figure 2. Shows the thermal resistance of the rotor and rotor cover of the motor with power loss and speed of the motor. (a) Internal thermal resistance of the Rotor (b) External thermal resistance of the Rotor (c) Internal thermal resistance of the rotor cover (d) External thermal resistance of the rotor cover.

A preliminary study of closed system analysis with fins has been carried out and for a constant power loss of 125W and rotational speed 350RPM and 600RPM, the results are shown in Table 2, Figure 1(b-c). For a closed system analysis the maximum temperature is expected to be higher than the open system but the provision of fins has reduced the maximum temperature for a constant heat load.

Table 2. Shows the maximum temperature comparison for the open and closed case with fins and without fins.

Phase	Max T (˚C) 350RPM	Max T (˚C) 600RPM	Power loss (W)
Phase 1 (No Fin, Open)	417	379	125
Phase 11(Fins, Closed)	404	350	125

5. SUMMARY

A preliminary study hub motor has been conducted for steady state aerodynamic cooling in the commercially available StarCCM+ software package. The internal and external thermal resistance has been estimated for the external and internal rotor and rotor cover surfaces, the thermal resistance on the internal surface of the rotor cover is higher than the thermal resistanc on the internal surface of the rotor by a factor of 10, and the provision of fins on the internal surface has reduced the temperaturerise. The optimisation of the fins for maximum heat transfer may further lower the temperature which would be a prime consideration in next stage of this study.

6. REFERENCES

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