Analysis of Thermal Management of Electric Motors

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Abstract

Electric vehicles (EVs) are important in reaching a sustainable environment. Research shows that their capacity is limited due to temperature rise in the electric motor, which is one of the main components of an EV. Traditionally, the motor is cooled using a cooling jacket to reduce its outer temperature. This project aimed to develop a model of the motor to analyze its thermal characteristics, temperature rise, and explore options for better thermal management. In the thermal analysis of the BMW i3, the maximum temperature was found at the stator windings, with temperatures rising above 300K for power densities of 0.5 x 10^6 W/m^3K through 3 x 10^6 W/m^3K.

Keywords: electric vehicles; motor; thermal model; thermal management; temperature; cooling

Introduction

The roles efficient electric vehicles play to reach a sustainable environment is critical and their demand is increasing rapidly. Research shows that temperature rise in the electric motor, one of the main components of an EV, negatively affects the performance of the EV [1]. It leads to high failure rates and a shortened life span, which reduce the overall efficiency and performance of EVs. However, relatively less research has been dedicated to studying its thermal characteristics compared to its electromagnetic design [1].

Currently, the widespread cooling method of electric motors is through air cooling or a cooling jacket with liquid channels. EVs like the 2016 BMW i3, have spiral cooling channels in its jacket and uses water-ethylene glycol as its coolant. This method cools the outermost surface of the stator.

This project developed a model of an electric motor and simulated a steady-state analysis of the motor at different power densities in ANSYS. We identified the hotspots and explored options for better thermal management. For this project, the electric motor of the 2016 BMW i3 was considered.

The analysis of the thermal profile and thermal management of EVs can provide suggestions for enhancement in the efficiency and performance of electric vehicles.

Method

The BMW i3 is a 125kW NdFe-B- IPM steel motor containing 72 slots. In our thermal analysis, we used a 30^0 model of the motor. The 30^0 geometry was sufficient to generate an accurate thermal profile of the complete motor. It contained six stator winding slots with a thin insulator around each, an air gap between the rotor and stator, and two NDFe-B (neodymium-iron-boron) permanent magnets.

Figure 1. 30-degree model of the BMW i3 motor in ANSYS

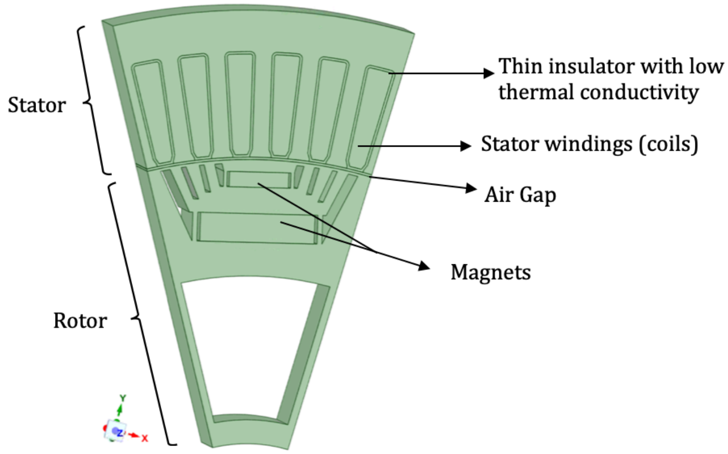


Table 1. Design Specifications of the 2016 BMW i3 motor [2]

Parameter	BMW i3
Stator	
OD	242mm
ID	184.08mm
Stack length	130.02mm
Thickness	22mm
Number of slots	72
Rotor	
OD	178.6mm
ID	59.3mm

We meshed the model in cylindrical coordinates and used the method MultiZone [3]. The total Nodes were 501,127 and Elements, 454,170. Face Sizing was applied to the air gap (thin insulator) between the stator and its windings. The element size was set at 1.e-004m. Edge sizing was then applied to the rest of the model. The No. of Divisions ranged between 4 (vertical sides of the large IPM) and 30 (vertical rotor sides); Element Sizes ranged between 5e-004m (vertical stator sides) and 1e-003 (outer surface of the stator).

Boundary Conditions and Materials

The following conditions were applied to the model in the ANSYS Fluent:

Sidewalls: Symmetry
Outermost surface of stator: h=1000 W/m^2K; T-amb=300K
Other surfaces of stator and rotor: h=10 W/m^2K; T-amb=300K
Surface of magnets: h=10 W/m^2K
Inner surface of rotor: Insulated
Where h = heat transfer coefficient

Power density in stator windings:
Case 1: 3×10^6 W/m^3K
Case 2: 2×10^6 W/m^3K
Case 3: 0.5×10^6 W/m^3K

Convergence criteria (energy): 1e-09

Results

In the steady-state thermal analysis, the maximum temperature recorded was at the stator windings. Meanwhile, the lowest temperature occurred at the outermost surface of the stator.

Figure 2. Case 1: Using 3 ×10⁶ W/m³K; Max. temperature = 352 K; Min. temperature = 322.8

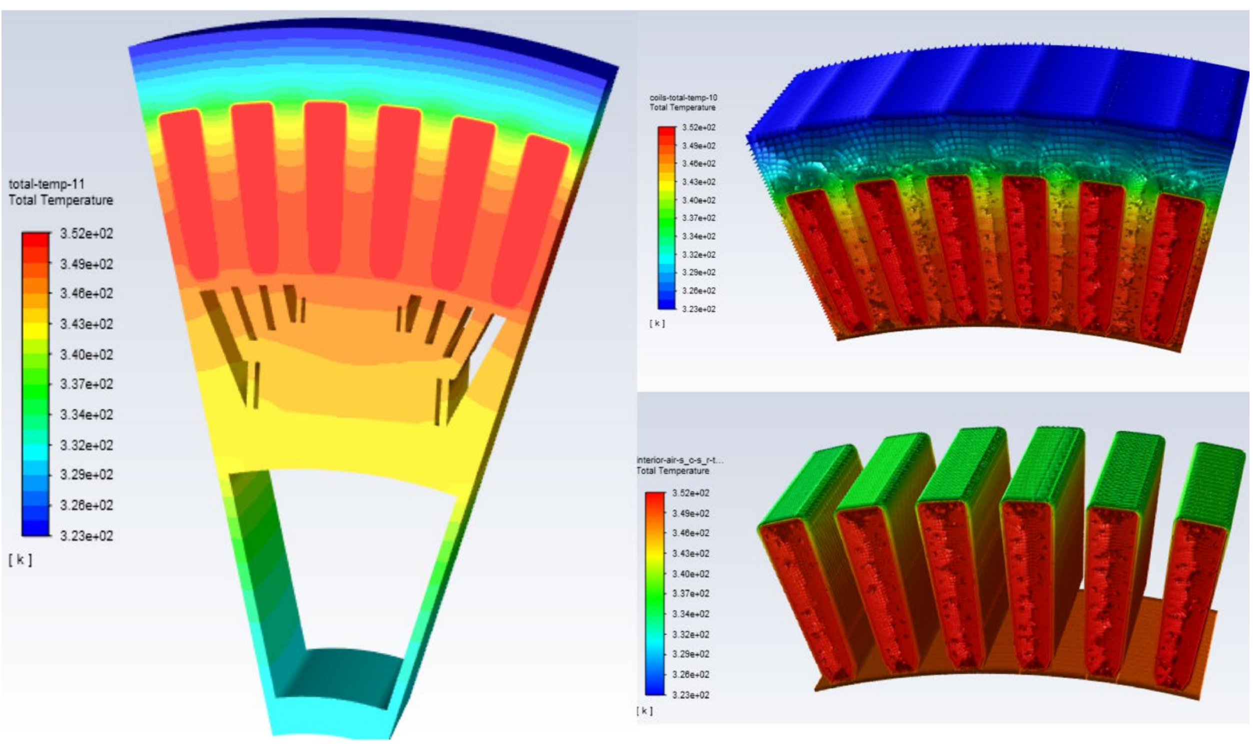


Figure 3. Case 2: Using 2 ×10^{6} W/m^{3}K; Max. temperature = 334.67 K; Min. temperature = 315.21 K

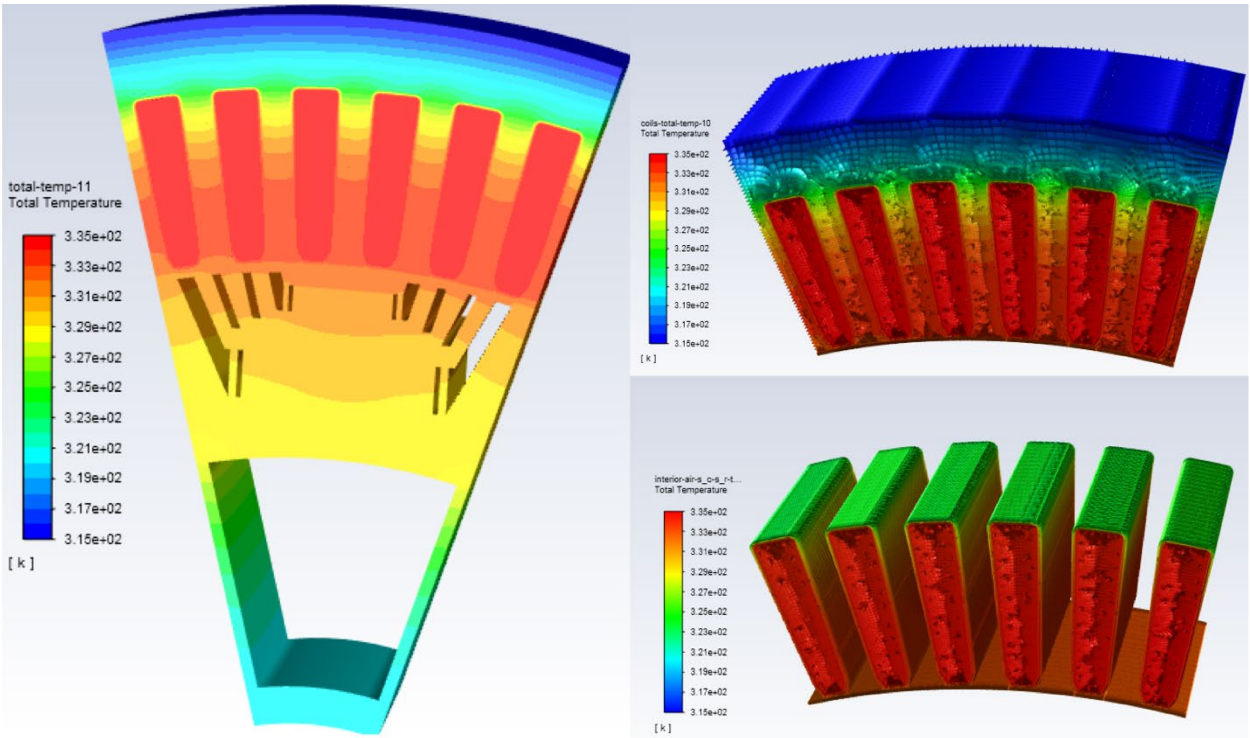
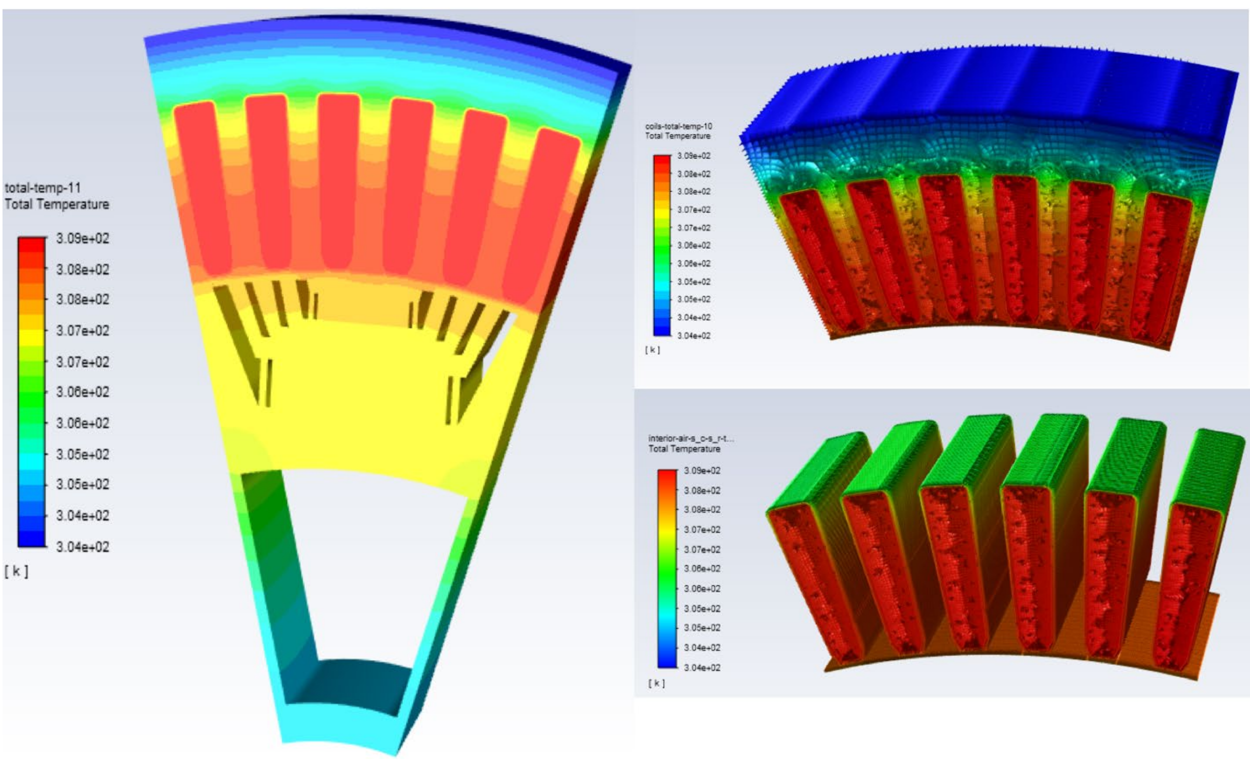


Figure 4. Case 3: Using 0.5 ×10^{6} W/m^{3}K; Max temperature = 308.72 K; Min temperature = 303.82 K



Discussion

We modeled the BMW i3 motor, analyzed its thermal profile, and identified where the maximum temperature occurred. The highest temperature was at the stator windings where most of heat is dissipated. The thin air gap between windings and stator teeth is a source of high thermal resistance. To improve the overall heat dissipation, we need to reduce this thermal resistance. We found that the lowest temperature occurred at the outermost surface of the motor. We suggested an approach where dielectric liquid spray cooling on windings can be used to improve the heat dissipation. This may reduce the temperature of each winding significantly, thereby greatly decreasing the motor's overall temperature. The fluids considered were the Novec 3M 649 and 7300 which have good thermal properties. However, other fluids will also be tested. Moving further, we also intend to compare our method of analysis with other methods such as compact modeling. Also, we plan to test our cooling method on the motors of other electronic vehicles.

Among other things to be considered will be the method of bringing fluids into the air gap and how much alteration will be made to the stator and overall size of the motor.

During the project, we encountered some challenges. A major one was in obtaining the exact dimensions of the BMW i3 motor. Manufacturers do not usually give details of the design of the products, so we estimated the dimensions from the data we could gather from the previous reports.

Another challenge we encountered was while using ANSYS to create the windings and air gap between the stator and rotor. In ANSYS, the base of the windings (a 2.2^0 curve) would not merge with that of the air gap. Both surfaces, curves, were of equal radii and position, yet, ANSYS treated each differently and created a space between the curves. Also, as the distance of the base of each winding is small, the line was considered straight. Meanwhile, the distance between each winding merged with the air gap. This caused problems when meshing and in using Fluent. We tried different techniques and curves, but the problem persisted. We resolved this by eliminating the curve forming the bases of the windings. Then we split that of the air gap to fit the base.

The challenge that was most hindering was the sporadic unresponsiveness of ANSYS and large mesh size. Processes in the meshing and Fluent application that would normally take less than five to ten minutes, took hours, sometimes overnight. I managed this only by committing more time, working through the night and weekends.

Conclusion

Electric vehicles play a significant role in reaching a sustainable planet and their demand is growing. To create more efficient EVs, the heat generation in the motor has to be managed effectively. However, there is relatively less research in this area. Our research was on the thermal analysis of EV motors, specifically the 2016 BMW i3 motor. We modeled the BMW i3 motor in ANSYS and analyzed its thermal profile. We were able to identify where the maximum temperature occurred, which is at the stator's windings. One of the bottlenecks in efficient thermal management was the air gap between winding and stator teeth. We are suggesting liquid spray cooling technique in this zone to improve the heat dissipation. This may significantly affect the motor's temperature as it brings a coolant in direct contact with the hotspots. Further research will be performed to analyze the impact of our solution on the BMW i3's thermal profile.

References:

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