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Temperature Analysis of a Custom-Built Electric Vehicle at Two Different Speeds

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Abstract: In this paper, we examined the temperature variations of key constituents during the operational cycle of a custom-built electric vehicle. The vehicle was made employing a motor of 10kW, a KLS7275D controller, and a lithium-ion battery. Temperature sensors for monitoring was affixed to the motor, controller, and battery, facilitating a comprehensive analysis of thermal behaviors. A controlled 20 minute driving tests encompassing both high and low speeds were executed to scrutinize temperature variations. Our findings reveal that the controller exhibited the most substantial temperature fluctuation compared to the battery and motor. Results shows the importance of thermal management strategies for components to ensure optimal driving performance and component reliability in electric vehicles.

Keywords: electric vehicle; battery; motor; controller; temperature

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1. Introduction

Electric vehicles have emerged as a prominent solution in the ongoing global effort to mitigate climate change. The vehicles, powered by electricity stored in high-capacity batteries, offer an effective alternative to traditional internal combustion engine vehicles that rely on fossil fuels. The adoption of electric vehicles represents a profound shift in the transportation paradigm, with the potential to reduce carbon emissions, ameliorate air pollution, and revolutionize the way we transport [1–4].

In the pursuit of advancing electric vehicle technology, custom-built electric vehicles have emerged as a viable method. Custom-built electric vehicles offer a versatile platform for integrating cutting-edge battery technologies, thereby facilitating the development of energy storage solutions characterized by enhanced performance, durability, and cost-effectiveness. This approach serves as a catalyst for innovation within the electric vehicle sector, driving forward progress in sustainable transportation [5,6].

In addition, there has been a growing community of technologists building electric vehicles or converting existing vehicles into electric ones by themselves. These custom-built electric vehicles showcase a range of designs and technologies, contributing to the diversity of the electric vehicles.

For an electric vehicle, especially custom-built electric vehicles, temperature management is crucial for the performance, efficiency, and the safety of electric components of the vehicles [7–9]. Charging efficiency can be influenced by temperature of a battery. Charging a battery at extreme temperatures can lead to slower charging rates and may affect the overall health of the battery. Some electric vehicle manufacturers implement thermal management systems to regulate battery temperature during charging [10–13]. Driving at high temperatures can lead to overheating, which may reduce the motor's efficiency and potentially cause damage. Proper cooling systems or heat dissipation mechanisms are often necessary to maintain optimal motor performance.

Components such as inverters and power converters are crucial for converting and managing electrical power in an electric vehicle [14]. These components generate heat during operation, and temperature control is necessary to prevent overheating and ensure their proper functioning. Regenerative braking systems, which capture and convert kinetic energy back into electrical energy during braking, can generate heat. Temperature control is important to manage the heat generated during regenerative braking to prevent overheating and maintain system efficiency [15].

Various electronic components and sensors throughout the vehicle may have temperature limits for optimal operation. Ensuring that these components are within their specified temperature range is

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crucial for reliable and safe operation. Extreme temperatures can pose safety risks. High temperatures may lead to thermal runaway in batteries, causing fires or other hazardous conditions [16]. On the other hand, low temperatures can affect the fluidity of lubricants and impact the overall performance of the vehicle [17].

For temperatures, most critical component in an electric vehicle is its battery. The performance and lifespan of lithium-ion batteries, commonly used in electric vehicles, are sensitive to temperature. Operating the battery within a specific temperature range is essential for optimal efficiency and longevity. High temperatures can accelerate chemical reactions and degrade the battery, while low temperatures can reduce its efficiency and capacity [18,19].

In this paper, we investigate temperature variations in a custom-built vehicle to enhance safety of the vehicle focusing on the motor, the controller, and the battery of the our electric vehicle, because self-made vehicles may not generally undergo the same rigorous safety testing and certification processes as commercially produced vehicles.

2. Electric Vehicle

For zero CO_2 emission transportation, the utilization of electric vehicles and hydrogen fuel cell vehicles emerges as a viable strategy, owing to their minimal emission profiles during operational phases. There exist differences between these vehicular technologies with regard to their underlying power sources, as well as the methodologies employed for energy generation and storage. Since most custom-built vehicles employ electric batteries, we focus on components of electric vehicles.

2.1. Motor

Electric vehicles (EVs) use various types of electric motors for propulsion. Among them, three types of electric motors are primarily used in electric vehicles, brushless DC (BLDC) motors, AC induction motors, permanent magnet synchronous motors, etc. [20,21].

Some electric vehicles use AC induction motors. AC induction motors do not require permanent magnets and are generally simpler and cheaper to manufacture than BLDC motors. They are, however, slightly less efficient than BLDC motors.

Permanent magnet synchronous motors use permanent magnets on the rotor and are synchronized with the frequency of the supply current to the stator windings. Since permanent magnet synchronous motors offer high efficiency and power density, they are commonly used in high-performance electric vehicles.

BLDC motors are commonly used in electric vehicles due to their high efficiency and reliability. An electronic controller is required to switch the current in the stator windings and control the speed and direction of the motor.

The choice of a vehicle motor depends on various factors including the specific application, cost, and desired performance characteristics. For our electric vehicle, we employed a BLDC motor of which power capacity is about 10 kW.

2.2. Battery

Main source of power for custom-built electric vehicles is batteries. Electric vehicles use several kinds of batteries such as lithium-ion batteries, lithium iron phosphate ($LiFePO_4$) batteries, lithium nickel cobalt manganese oxide batteries, lithium nickel cobalt aluminum oxide batteries, solid-state batteries, etc. [10,22,23]

Lithium-ion batteries employed in our vehicle have primarily been used due to their high energy density and performance characteristics. For lithium-ion batteries, graphite is used as anode material and cathode is made of lithium cobalt oxide ($LiCoO_2$), lithium iron phosphate ($LiFePO_4$), lithium nickel cobalt manganese oxide ($LiNiCoMnO_2$), and lithium nickel cobalt aluminum oxide ($LiNiCoAlO_2$).

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2.3. Heat Flow in a Battery

Heat generation in a cell can be described for the case where the battery cell is operating within it's normal limits. The following expression gives the heat generation rate ($\dot{Q}$).

$$\dot{Q} = I(V - V_{oc} - T_{ref}\frac{dV_{oc}}{dT}), \tag{1}$$

where I, V_{oc}, T, T_{ref} are the battery operating current, the battery open circuit voltage, the battery cell temperature, and the reference temperature [12,13,24–26].

In eq. 1, the first term, $I(V - V_{oc})$, is the irreversible Joule heating term and the second part, $IT_{ref}\frac{dV_{oc}}{dT}$, is the reversible entropy term or Reaction heat term. While the second part is significant in a charging phase, the first Joule heating part is dominant in a discharging phase.

3. Custom-Built Electric Vehicle

We made a custom-built electric vehicle which has a Golden Motor of 10kW, a lithium-ion battery, and a KLS7275D controller. The golden motor employed in this experiment is a 10 kW BLDC motor in which air cooling is adopted for lowering the temperature of the motor. The advantage of using KLS7275D microprocessor is that it could reduce the noise of BLDC motor, extending the fault detection and protection. In our vehicle, temperature sensors are attached to the motor, controller, and battery of the electric vehicle.

The block diagram of the electric vehicle is shown in Figure 1. The throttle in the electric vehicle works similarly to that in traditional internal combustion engine vehicles by controlling the amount of current flow to regulate electric motor's speed. When a driver put pressure on the accelerator pedal, the throttle system sends a signal to the car's controller. Based on the received signal with the information of the amount of acceleration, the controller adjusts the amount of current needed from the electric motor, which lead to resulting in an increase or decrease in speed.

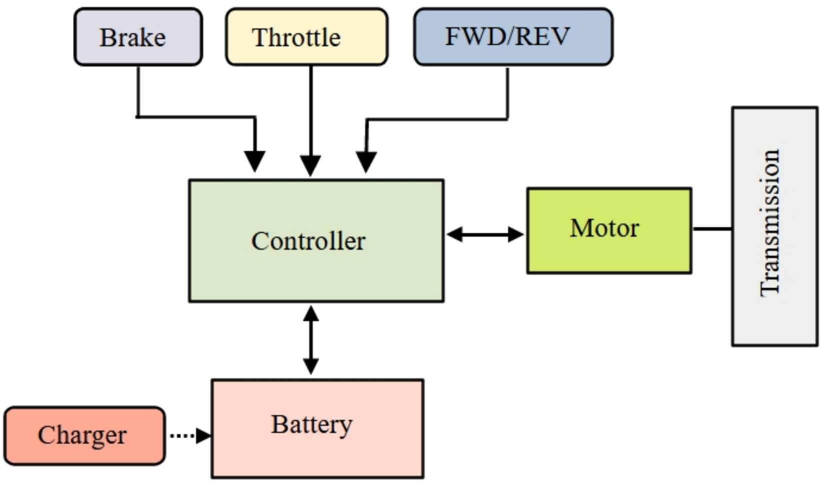

Figure 1. Block diagram for an electric vehicle structure.

Since the electric vehicles are not equipped with gears, the forward/reverse switch dictates the direction of the motor's direction. For backward driving, reverse switch sets the motor spin backward.

The charger connected to battery by a dash line in Figure 1 is only used for battery charging. Electric vehicle charger pulls an electrical current and delivers the electricity to the battery of the vehicle.

Figure 2 is the custom-built electric vehicle used for a race competition and for temperature measurements of key components of the vehicle.

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Figure 2. Custom-built electric vehicle used for experiment.

4. Temperature Variations for Different Speeds

We investigated temperature changes of major components of the custom-built electric vehicle during driving of 20 minutes. In the driving experiment for temperature measurement, temperature sensors were used to monitor the temperature changes of controller, motor and battery. The control unit also took a GPS signal for vehicle's speed estimation. The driving test for temperature measurements were conducted for the speeds of 10 km/h and 30 km/h. Temperature measurement experiment was conducted according to the flowchart of Figure 3 for each speed.

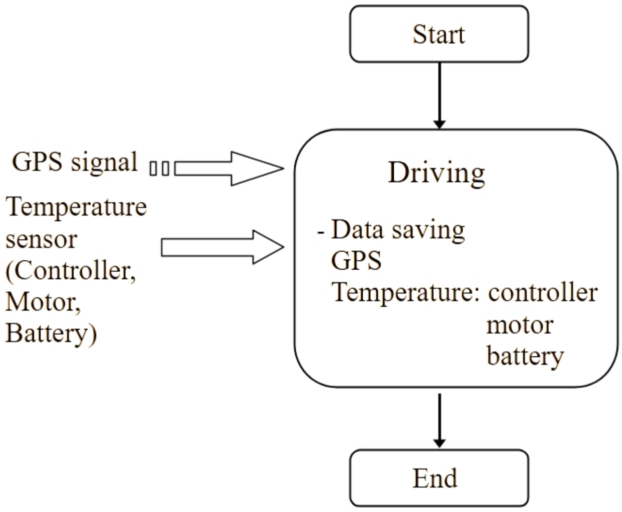

Figure 3. flowchart of the temperature measurement experiment of electric vehicle.

Measured data show that the overall temperatures of controller, motor and battery increased in both speeds of 10km/h and 30 km/h with ambient temperature of 5°C. During the driving, the motor temperature increased by about 5°C and 6°C for the speeds of 10 km/h and 30 km/h, respectively.

The battery temperature graph showed a temperature increase in the early phase followed by a slow decrease in both low and large speed driving. We believe that, after the vehicle reached a target speed and obtained inertia to keep the vehicle moving with an almost constant speed, the motor required smaller torque and power to spin the wheels than the early phase of driving. Since the battery provides less power to motor, the temperature of the battery decreased about 3 $\sim$ 4 °C.

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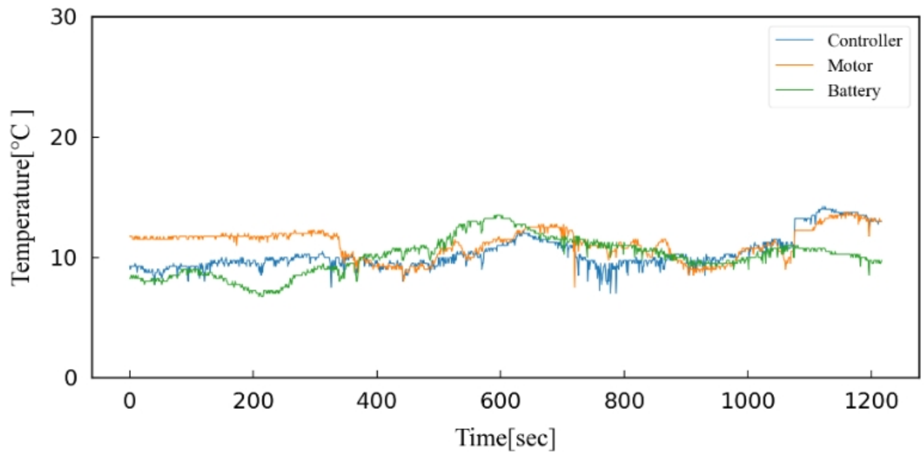
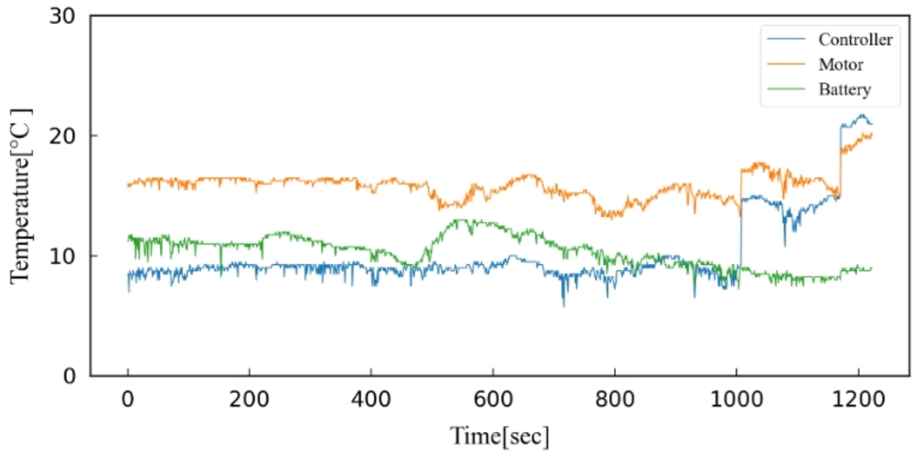
The temperature of the controller exhibited increments of approximately 7°C and 15°C at speeds of 10 km/h and 30 km/h, respectively, as illustrated in Figure 4. These increments represented the most substantial variations observed among the three components under investigation. Despite these fluctuations, it is noteworthy that the maximum temperature change recorded for the controller remained within the prescribed tolerable operating temperature range of -15°C to 70°C throughout the duration of our experiment.



(a)



(b)

Figure 4. Temperature changes of controller, motor and battery for the speeds of (a) 10km/h and (b) 30km/h.

5. Conclusions

In this study, we investigated the temperature variations of motor, controller and battery of a custom-built electric vehicle during driving. Temperature measurements were conducted over a 20 minute duration while the vehicle operated at speeds of 10 km/h and 30 km/h. Temperature monitoring was made by sensors positioned within the motor, controller, and battery assembly. Analysis of temperature variations revealed distinct thermal profiles for the lithium-ion battery, BLDC motor, and controller during driving operations. In the experiment, the controller exhibited the most significant temperature fluctuation, with deviations of approximately 15°C observed across the tested speed ranges. Conversely, the temperature variations within the lithium-ion battery and BLDC motor were comparatively moderate, suggesting relatively stable thermal behavior under the given experimental conditions. The experiment result showed that, even though a large battery temperature

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has been an issue for an electric vehicle, other components such as motor and controller should be monitored for stable driving performance.

Future research should explore component temperature dynamics under varied operating conditions, thus advancing our understanding of thermal behavior in electric vehicle systems.

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Abbreviations

The following abbreviations are used in this manuscript:

EV	Electric vehicle
BLDC	Brushless direct current
GPS	Global positioning system

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