

Effects of the Glass and Body Heat Transfer Characteristics of an Electric Vehicle on its Energy Consumption and Cruising Distance

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ABSTRACT

In order to develop various parts and components of electric vehicles, understanding the effects of their structures and thermal performance on the energy consumption and cruising distance is important. However, such essential and detailed information is generally not always available to suppliers of vehicle parts and components. This paper presents the development of a simple model of the energy consumption by an electric vehicle in order to roughly calculate the cruising performance based only on the published information to give to suppliers, who otherwise cannot obtain the necessary information. The method can calculate the cruising distance within an error of 4% compared to the published information. The effects of the glass and body heat transfer characteristics on the cruising performance in winter were considered as an example application of the proposed model. An anti-fog control method was modeled, where the relative humidity around the front windshield was assumed to be detected and the recirculation ratio of the ventilation was controlled in order to maintain defogging. The effect of the anti-fog control combined with the thermal insulation efficiency of the glass on the cruising performance was examined with the cruising distance estimation method. The results indicated that improving the thermal properties of the glass does not have much effect without the anti-fog control. Hence, anti-fog control enhances the effect of improving the thermal properties of the glass on the cruising distance.

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1. INTRODUCTION

In the winter, the energy consumption and cruising distance of an electric vehicle (EV) can increase and decrease, respectively, by as much as 50% because air heating consumes much of the energy from the battery [1]. In order to increase the cruising distance, the energy load needs to be reduced. When developing parts or components of EVs, the influence of its structure and thermal properties on the electricity cost and cruising distance needs to be considered. However, auto component suppliers are generally not informed of such detailed information and specifications by the automaker for confidentiality reasons. Thus, they cannot develop such parts efficiently and effectively. Clarifying the contribution of each part and component to the overall energy consumption can help suppliers prioritize critical pieces for research and development. Hence, a method for estimating the cruising performance is required that is based only on public information available to suppliers.

In order to increase the widespread use of EVs, improving their convenience for people is important. Providing information on factors that influence the cruising distance and energy consumption is helpful; thus, a method to estimate the electric performance is

required. Iwatsubo et al. developed a simulation method that uses the commercial software AVL CRUISE and validated the cruising distance under the assumption of actual cruising patterns [2].

In the present study, the control principle of energy transmission of the EV was estimated, and a simple calculation method for the cruising distance was developed in order to evaluate the influence of parts and components. The purpose of the present study was to clarify the influence of the glass and body thermal properties on the cruising distance. The combined effect of the glass thermal insulation efficiency and a simplified anti-fog control was also investigated to prevent the reduced cruising distance during winter.

2. SIMPLE CALCULATION MODEL OF ENERGY CONSUMPTION

2.1. Calculation of the Driving Performance

The driving powers of gasoline-engine vehicles and EVs are essentially the same. P_{drv} is the sum of the rolling resistance P_{rr} , air drag P_{ad} , accelerating resistance P_{ac} , and gradient resistance P_{gr} :

$$P_{drv} = P_{rr} + P_{ad} + P_{acl} + P_{gr} \quad (1)$$

The above variables are expressed in the following equations:

$$P_{rr} = \mu_r \cdot m \cdot g \cdot V \quad (2)$$

$$P_{ad} = 1/2 \cdot \rho \cdot C_D \cdot A \cdot V^2 \quad (3)$$

$$P_{acl} = (m + m_p + m_r) \frac{dV}{dt} \cdot V = \frac{m + m_p + m_r}{2} \frac{dV^2}{dt} \quad (4)$$

In this study, P_{acl} was assumed to be the summation of m , m_p , and m_r . The gradient was not considered because a JC08 driving schedule was used that does not include the gradient; thus, $P_{gr} = 0$ [3].

The inverter efficiency η_{iv} needs to be accounted for because of the heat generated when the battery supplies power to the motor. The final reduction gear between the motor and driving shaft requires the power transmission efficiency η_{tm} . Therefore, the energy consumption per unit time of battery L_{drv} can be calculated as follows:

$$L_{drv} = P_{drv} / (\eta_{iv} \cdot \eta_{tm}) \quad (5)$$

However, the exact values of η_{iv} and η_{tm} are not disclosed by manufacturers. The treatment of η_{iv} and η_{tm} is provided in a later section.

If the energy consumption per unit time of the heating, ventilation and air-conditioning (HVAC) system L_{ac} and the energy consumption per unit time of the other devices L_{aux} are also considered, the total energy consumption per unit time during driving L_{cru} is described as follows:

$$L_{cru} = L_{drv} + L_{ac} + L_{aux} \quad (6)$$

EVs feature an energy regeneration system. This can increase efficiency because the motor is treated as an electric generator and the braking energy is recovered. If the ratio of the absorbed braking energy to the total braking energy is represented by ϕ_d , the recovered braking power P_{dcl} can be expressed as follows:

$$P_{dcl} = \phi_d \cdot \left| \frac{m + m_r}{2} \frac{dV^2}{dt} \right| \quad (7)$$

The recovery also needs to account for the final reduction gear and inverter. Overall, L_{cru} is given by

$$L_{cru} = -P_{dcl} \cdot \eta_{iv} \cdot \eta_{tm} + L_{ac} + L_{aux} \quad (8)$$

When L_{cru} is a negative value, the battery is charged. The value of ϕ_d depends on the unique technology of each automaker; thus, it is confidential.

2.2. Evaluation Conditions

The JC08 driving mode was employed as the cruising condition for the evaluation of the cruising performance. This is a well-known Japanese standard [3]. It includes driving in an urban area and on the highway. However, there is no gradient throughout the cruise. The velocity each second was defined as shown in Fig. 1. The cycle time was 1204 s. The cruising distance was calculated under the assumption that this cycle repeated. The HVAC system was not considered during the testing in JC08 mode; thus, $L_{ac} = 0$.

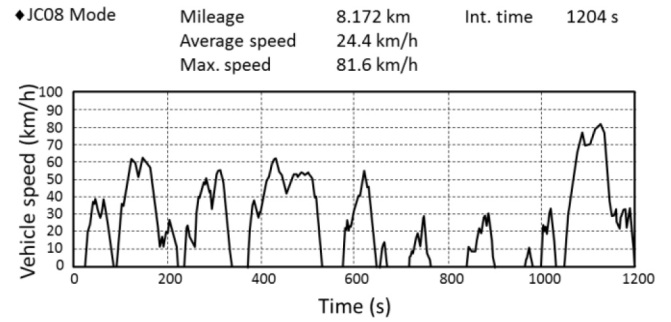


Figure 1. Driving pattern defined as the JC08 mode [3]

2.3. Calculation of Remaining Battery Power and Cruising Distance

The remaining battery power Q_s and cruising distance X_d can be calculated based on the battery capacity Q_c with the time step $\Delta t = 1$ s:

$$Q_s = Q_c - \sum_{i=1}^n (L_{cru} \times \Delta t) \quad (9)$$

The cruising distance X_d is equal to the driven distance when the remaining battery power is zero. X_d was calculated by integrating the vehicle velocity over time.

3. ESTIMATION METHOD BASED ON DISCLOSED DATA

Table 1 presents the disclosed data of Car A, which is an EV compact vehicle. This information was published on the website and in the technical report and open specification sheet of the automaker. The values were converted to SI units for calculations in this study. The unknown variables were A , m_r , η_{iv} , η_{tm} , ϕ_d , and L_{aux} . The frontal projected area A could be roughly estimated based on the catalog, design drawing, and pictures. The average rotational inertia equivalent mass m_r of the gasoline-engine vehicle was $0.08 \cdot m$. The EV has fewer rotating parts in the gearbox than the gasoline-engine vehicle; thus, m_r of the EV was determined to be $0.05 \cdot m$. L_{aux} is the energy consumption by small devices excluding the HVAC system such as the control computer and headlights. It was estimated to be 30 W under the conditions of a low energy consumption and the longest cruising distance. For the severe condition of air-heating during a winter night, L_{aux} was set to 100 W. According to the technical report, the total inverter efficiency η_{iv} of the motor was a maximum of 97%-98% and average of 95%. In the calculation, $\eta_{iv} = 0.95$ was assumed. The power transmission efficiency η_{tm} of the EV may be better than that of the gasoline-engine vehicle; $\eta_{tm} = 0.95$ was employed.