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An Analytical Method of EV Velocity Profile Determination from the Power Consumption of Electric Vehicles

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Abstract

Concerning a car's performance, acceleration and deceleration are the most important features in performance assessments. Fuel consumption has been a key issue in the performance of cars in recent years. Electric vehicles (EV) with high energy-efficiency have been developed for such a reason. Due to the lower capability of electric energy storage in the car, problems related to the running distance per charging, the charging time, and so on have remained because of the smaller battery that energy is stored in. Under these circumstances, it is more important to analyze the running state of EV. To obtain longer running distance and good mileage, a theoretical equation to determine the EV performance to the input electric power is deduced. As to an EV, deriving the accelerated velocity, a, from a situation when electric input power, P, is given to an EV, driving at a velocity, v, is extremely important in order to find out the acceleration performance of a car. This paper analytically describes a method to obtain the performance of the EV from equations between the measured acceleration, a, and the input or regenerated electric power, P. It is shown that this method can demonstrate possibilities to predict the performance of electric vehicles using stored electric energy and the driving root.

Keywords: electric vehicle, input power, acceleration, velocity profile

1 Introduction

Predicting the velocity actually obtained from the applied power to vehicles is a very important factor in design. However, it is not easy to get the generated output power as a measured value in the case of internal-combustion engine vehicles. In the case of electric vehicles, on the other hand, it is possible to know the generated power by simply measuring the voltage and current of the electric power and the velocity profile of electric vehicles. Furthermore, it is also shown that, with the results, accelerated velocity is calculated by the time variation of the applied electric power, P, in the case of an EV, and then the velocity variation of the EV is obtained. Needless to say, a running-resistance parameter for electric vehicles is needed. [Chan et al., 2001; Nasukawa et al., 1993]

2 Proceeded Approach

2.1 EV Acceleration theory

When an EV is running with a velocity, v [m/s], and an acceleration, a [m/s^2], the running resistance of the vehicle is the acceleration resistance, Fa, the rolling resistance, Fr, the air resistance, Fk, and the inclination resistance, Fg. Therefore, the force, F [N], to the vehicle running with velocity, v, is expressed using the vehicle weight, m [kg], rolling resistance constant, μ, and air resistance constant, k [kg/m].

$$F = Fa + Fr + Fk + Ft\,[N] \qquad (1)$$

$$Fa = ma$$

$$Fr = mg\mu$$

$$Fk = kv^2$$

$$Ft = mg\sin\theta$$

Therefore, an automotive with a velocity, v, is expressed by the following equation:

$$p = F \cdot v \qquad (2)$$

A relationship input power, P, and output power, p, is shown in the following equation with motor efficiency, η:

$$\eta P = p = F \cdot v \qquad (3)$$

In the case of a DC motor, most of losses are copper loss for the high current region. Therefore, motor efficiency, η, is shown following equation:

$$\eta = (P - I^2 r)/P \qquad (4)$$

Here, I [A], represents the current and, r [Ω], represents coil resistance. When this equation is assigned to (3), it becomes:

$$P = I^2 r + Fv \qquad (5)$$

The following equations show the relationship of a DC motor's back-electromotive force, E, current, I, velocity of vehicle, v, and force, F:

$$F = \frac{Ka\phi N}{R} \cdot I = KI \qquad (6)$$

$$E = \frac{Ka\phi N}{R} \cdot v = Kv$$

Here, Ka, represents the DC motor innate armature-constant, ϕ, is the magnetic flux on the armature, R, is the radius of the tire and, N, is the reduction ratio caused by gears and others. Thus, a current is shown in the following equation:

$$I = \frac{F}{K} \qquad (7)$$

When this is assigned, (5), it becomes:

$$P = \frac{r}{K^2} F^2 + Fv \qquad (8)$$

And (1), is assigned, it becomes:

$$P = \frac{r}{K^2}(ma + kv^2 + mg\mu)^2 + v(ma + kv^2 + mg\mu) \qquad (9)$$

Here, we assumed that grade resistance is zero. This equation shows that input power which needs to run with velocity, v, and acceleration, a.

Equation (12) can be changed to the following equation:

$$a = \frac{-2r(kv^2 + mgu) - vK^2 \pm K\sqrt{v^2K^2 + 4\,\mathrm{Pr}}}{2mr} \qquad (10)$$

This equation is used to calculate the accelerated velocity from the input power to the motor. And, the velocity, v, is expressed in the following equation:

2.2 Limit of regenerative power

Equation (10) allows a condition of input power, P < 0. This negative electricity is a regenerating energy towards a power-supply unit. According to the condition whereby an inside radical sign is positive, the following equation is obtained:

$$P > \frac{v^2K^2}{4r} \qquad (11)$$

This equation indicates minimum regenerating energy.

In short, the energy range, in which regenerating is possible at a velocity, v, $0 > P > -\frac{v^2K^2}{4r}$, and the accelerated velocity is minimum under the condition of (11).

Equation (10) is transformed as,

$$P = \frac{rm^2}{K^2}[a + \frac{1}{2m}(2kv^2 + 2mgu + \frac{vK^2}{r})]^2 - \frac{v^2K^2}{4r} \qquad (12)$$

The electricity, P, needed an acceleration velocity, a, can be calculated from this equation. According to Equation (13), the necessary electricity, P, is convex to downward in relation to the acceleration velocity, a. And in the case of (12), it becomes minimum.

$$a = -\frac{1}{2m}(2kv^2 + 2mgu + \frac{vK^2}{r}) \qquad (13)$$

In other words, the regenerating energy becomes maximum.

$$P = \frac{r}{K^2}(kv^2 + mgu + mav) + v(kv^2 + mgu) + mav$$
$$= \mathrm{Pr} + Pv + Pg \qquad (14)$$

According to (10), in the case of the following, the acceleration and deceleration efficiencies can be calculated.

Loss by motor

$$Pr = \frac{r}{K^2}(kv^2 + mgu + mav)$$

Loss by travel resistance $Pv = v(kv^2 + mgu)$

Energy obtained $Pg = mav = Pg$

Acceleration efficiency, ηa, and deceleration, ηd, can be calculated.

$$\eta a = \frac{Pg}{P} \quad (15)$$

$$\eta d = \frac{P}{Pg} \quad (16)$$

Acceleration efficiency, ηa, indicates how much it is possible to obtain the energy from input energy, P, at the time of acceleration. Deceleration efficiency, ηd, indicates how much it is possible to regenerate from lost energy at the time of deceleration.

2.3 Velocity profiles measurement and calculation

If (12) is used, the relationship of the velocity profile which is predicted by the input electric power can be calculated. The comparisons with actual measurement values become possible. We examined, and compared measured velocity with calculated velocity.

Figure 1 shows pictures of the EV used for the evaluation. Two electric vehicles were used. COMS is the marketed one. The other is the electric vehicle which is made for a project to achieve a velocity of 100 km/h with a car powered by size-AA dry-cell batteries with a person on board [Ashida and Minami, 2007].

a) EV 1 COMS

b) EV 2 electric vehicle for project

Figure 1. A photograph of EV's used for the evaluation of the theory

Table 1 shows EV's parameters to calculate an acceleration velocity from (12).

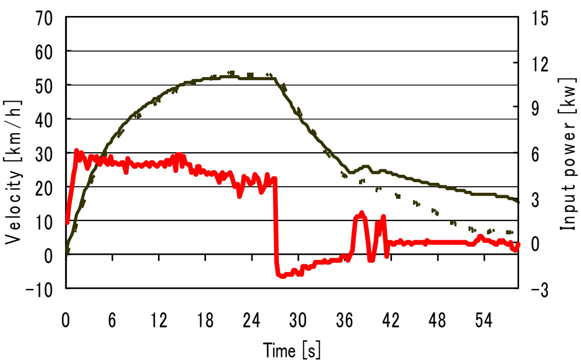
TABLE 1.

EV's Parameters to calculate the acceleration velocity

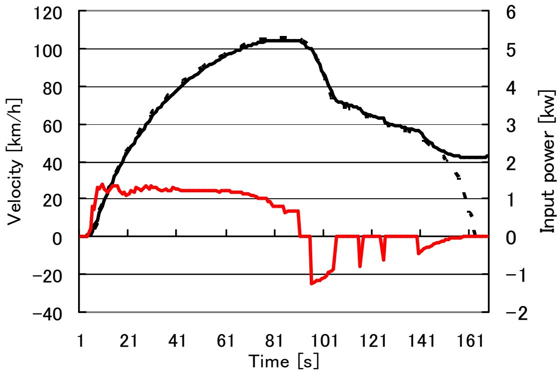
Parameters	EV 1	EV2
Vehicle weight (include a driver) m [kg]	350	100
Rolling resistance coefficient u	0.006	0.003
Air-resistance co efficiency k [kg/m]	1.26	0.027
Product of armature constant and flux of magnetic induction $K a \phi$ [V・s]	1.05	0.13
Resistance of motor r' [Ω]	0.16	0.11
Radios of tire R [m]	0.23	0.17
Axle ratio N	1	1
Transmission efficiency η [%]	100	100

The feature of two electric vehicles is to adopt direct drive motor rear 2-tire. Then, drive train transmission efficiency is 100 % and axle ratio is 1. Further, two motors in the rear tire are connected in parallel, so the resistance of motors is calculated as a parallel circuit. Coefficient of transformation at electromotive force and speed, K, and resistance of motors, r, is obtained from Table 1.

Figure 2 shows the input power, P [kW], and the results of velocity plot which is measured and calculated from (10) and (11). In Figure 2, the solid line shows calculated velocity and the dot line shows measured velocity. There is a great difference in the velocity measured and calculated at a time of 42 s in (a) and 150 s in (b), because in these times, a mechanical brake was done.



(a) Result from EV1



(b) Result from EV2

Figure 2. The velocity profile measured (dots) and calculated (solid). The red line shows the electric input power, P.

3 Conclusion

In conclusion, general equations for obtaining a velocity profile are formulated by giving those changes of electricity input, *P*, in a vehicle. By applying the equations to actual data and by showing that the theoretical predicted values and the actual measurement values of the velocity profile conform well, it can be shown that the equations formulated in this paper have validity. This method is considered useful in order to obtain performance assessments of electric vehicles in the future.

References

[1] C. C. Chan, and K. T., Chau, "Modern Electric Vehicle Technology, Oxford Science Publications," 2001.

[2] K. Nasukawa, Y. Miyashita, and M. Shiokawa, "Cruising Performance and the Testing Method of Automobiles (in Japanese)," Sankaido, 1993.

[3] Ashida, T., S. Minami, H. Fujita, A. Saihara, E. Uchiyama, M. Otani, "Designing Engines of Compact Battery-Cars for the Target Velocity of 100 km/h using Nickel-cells (Oxyride Dry-cell batteries) Part 1 : Optimization of the body," Journal of Asian Electric Vehicles, 5, 2, 2007.

[4] T. Ashida, S. Minami, "Designing Compact Battery-car for which the Target Velocity is 100 km/h Using Nickel-system Primary-cells (Oxyride Dry-cell Batteries) Part 2: Battery System Optimization," Journal of Asian Electric Vehicle, Vol. 5, 2, 2007.

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