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Performance Analysis of EV Powertrain system with/without transmission

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Abstract

With the ever rising price of oil, driven by the gradual depletion of global oil deposits, along with the serious global warming issues caused by substantial CO₂ emissions, energy saving and environmental protection awareness are expanding issues of global concern. The trend of green energy industry is prevailing in the industrial design and development of vehicles. Therefore, electric vehicles focusing on low energy consumption and zero pollutant emission have become the development direction of the future, recognized in succession by various global vehicle manufacturing giants. The design methods of the Powertrain System for electric vehicles vary depending on different structures and arrangement methods of the vehicle; there are also two different practices in regard to the Drive System design. On one hand, as the powertrain characteristics of a traction motor differ from those of an engine, in order to make an electric vehicle which possesses the same performance as a traditional vehicle, it is required to match the traction motor with the transmission. On the other hand, being an electric vehicle, the number of traditional vehicle components used should be reduced, while only using a traction motor equipped with a single ratio gearbox. This study conducted an analysis on the performance discrepancy between an electric vehicle with 5-speed transmission and that with a single ratio gearbox, and compared their strengths and weaknesses by observing their performance in overcoming road loads through simulation. *Copyright Form of EVS25.*

Keywords: Electric Vehicle, Powertrain, Transmission, Gearbox

1 Introduction

As the awareness of environmental protection and energy saving continues to rise, only the electric vehicle can realize real zero oil consumption and zero pollution. The gasoline engine and the diesel engine (no matter how much their efficiency is improved) as well as

hybrid vehicles all consume fossil fuel, so there is still some way to go in realizing real zero emissions. Therefore, the electric vehicle with zero emission will undoubtedly become the mainstream means of private transportation in the future. The governments of each country and their societies have outlined large scale plans to promote battery-powered electric vehicles and are vying for

considerable opportunities to change the nature of private vehicles.

The biggest difference between the electric vehicle and the vehicle with a combustion engine lies in the difference in the powertrain system; the traditional vehicle with combustion engine is fueled by fossil fuel which drives the engine system to provide energy for the vehicle to travel; while the energy source of electric vehicle is electric energy, as shown in Figure 1, the drive system structure of the electric vehicle mainly includes a power motor system, control system and battery system. It sends a signal to the battery system through an electric control and management system, instructs the battery system to output sufficient electric power and gives the motor relevant instructions to drive the motor and generate power, providing the energy required for traveling. Through the conversion of mechanical energy of reverse torque into electric energy, regenerative braking of the battery system is realized [1].

Figure1: Drive System Structure of Electric Vehicle

Compared with traditional engine vehicles, the electric vehicle has the following strengths:

1. Zero exhaust gas emissions: no green house gases are emitted, alleviating the greenhouse effect.
2. Energy sources will not be restricted by oil producers: as the oil deposits decrease, the price of oil is bound to rise, while electricity can be generated through wind power, solar power and other green energies.
3. Saving energy cost: with the same traveling distance, the cost of an electric vehicle using electric power is about 1/4 to 1/6 that of an engine vehicle.

2 Introduction of Electric Vehicle Types

Generally speaking, vehicles with electric power as the energy source for driving all fall under the category of electric vehicles; based on different powertrain systems and ways of replenishing energy, electric vehicle can be divided into four categories, namely: Hybrid Electric Vehicle

(HEV), Plug-In Hybrid Electric Vehicle (PHEV), Battery Powered Electric Vehicle (BEV) and Fuel Cell Electric Vehicle (FCEV) [2].

2.1 Hybrid Electric Vehicle (HEV)

Vehicles using two or more different power sources are called hybrid vehicles; based on current practice, power sources are generally a combination of gasoline, diesel or other alternative fuel engine and battery plus motor, so it is generally called a hybrid electric vehicle; see Figure 2 for its structure.

The driving force of a hybrid power system can be acquired by motor and engine, and it can be used separately or in combination according to different driving modes. While driving the vehicle, the battery can be charged with power generated by the motor driven by the engine. The power motor often serves as the generator; regenerative braking can convert energy into electricity stored in the battery via the motor; see Figure 3 for the schematic of hybrid power vehicle operation [3].

Figure2: Structure of Hybrid Electric Vehicle

Figure3: Schematic of Hybrid Power Vehicle Operation

2.2 Plug-In Hybrid Electric Vehicle (PHEV)

The Plug-In Hybrid Electric Vehicle is a hybrid electric vehicle which can be charged by an external source. It includes parallel and serial types, according to the composition mode of the power system; see Figure 4 for its structure. The operating principle of parallel PHEV is closer to that of the traditional HEV. Normally, the motor is the power source; when the battery power is exhausted, it will switch to engine driving. While serial PHEV purely uses the motor as its power source, and the engine mainly plays the role of generator, regenerating the battery with power generated by the engine through fuel oil, it can prolong the driving distance of the electric motor; see Figure 5 for the schematic of PHEV operation [3].

Figure4: Structure of Plug-In Hybrid Electric Vehicle

Figure 5: Schematic of Plug-In Hybrid Power Vehicle Operation

2.3 Battery Powered Electric Vehicle (BEV)

The Battery Powered Electric Vehicle means vehicles simply use the battery and motor as the

power source. As it fully depends on the battery to generate electricity, it has zero or near zero emission, which is eco-friendly; however, the quantity of battery pack used in battery powered electric vehicles is more than that in HEV and PHEV. If the cost of batteries fails to drop significantly, the price will affect the willingness of the public to purchase such vehicles. In addition, BEV mainly uses an external source to regenerate electricity; as it can not use the engine to generate power, it is strongly dependant on the infrastructures, including charging stations or power grid. As the motor is the only power source, the driving system structure of BEV is simpler than that of HEV and PHEV, as shown in Figure 6.

Figure6: Structure of Battery Powered Electric Vehicle

2.4 Fuel Cell Electric Vehicle (FCEV)

The Fuel Cell Electric Vehicle is a kind of electric vehicle where the chemical energy can be directly converted into electric energy through an electrochemical reaction. The electric energy of the typical fuel cell electric vehicle is generated through the reaction of hydrogen and oxygen, and its energy conversion efficiency is 2-3 times of the combustion motor. With hydrogen as the fuel, FCEV only discharges water when traveling, which makes it a rather energy saving and eco-friendly vehicle; see Figure 7 for its structure [4].

Figure 7: Structure of Fuel Cell Electric Vehicle

3 Analysis of Power Drive System

A part from traction motor, another important component related to the power performance in the systems of electric vehicle is the transmission or gearbox in the drive system. Figure 8 shows the power system of an electric vehicle with multi-speed transmission, and Figure 9 shows the power system of an electric vehicle with a single-ratio gearbox. What are their impacts on the power performance of the vehicle? The following is a comparative analysis of this issue.

Figure 8: Traction Motor with Multi-Speed Transmission

Figure 9: Traction Motor with Single-ratio Gearbox
Here is an analysis of the power performance of an electric vehicle with one 5-speed transmission or one single-ratio gearbox. See Table 1 for the vehicle specifications and Table 2 for the specifications of the transmission and gearbox.

Table1: Vehicle specifications

Tire radius (<i>m</i>)	0.3175
Rolling resistance coefficient	0.0173
Air drag coefficient	0.593
Front area (<i>m</i> ²)	2.85
Weight (<i>kg</i>)	620

Table2: Specifications for transmission and gearbox

5-speed transmission		Gearbox
1 st	10.4815	
2 nd	7.5978	
3 rd	5.156	
4 th	4.1617	
5 th	3.6829	

Gear ratio = 7

Traction motors generally select the 10kW BLDC motor, with the performance curve shown in Figure 10. The rated torque of such motor is 48Nm, the peak torque is about 125Nm, and the maximum rotate speed is about 3,000 rpm. The analysis has adopted the rated torque.

Figure10: 10kW BLDC motor T-N curve

When traveling, electric vehicles should have sufficient driving force to overcome road load. The acceleration performance and maximum speed performance of electric vehicles can be observed based on the wheel axle driving force curve and road load curve. Equation (1) shows the calculation of the acceleration performance of an electric vehicle with transmission, and Equation (2) shows the calculation of the acceleration performance of an electric vehicle with a single stage gearbox:

$$Acc_t = \left(\frac{T_m \times R_{1st} \times \eta_{d-t}}{r_w} - \mu_k m_t g \right) / m_t = 2.13 m/s^2 \quad (1)$$

$$Acc_g = \left(\frac{T_m \times GR \times \eta_{d-t}}{r_w} - \mu_k m_g g \right) / m_g = 1.42 m/s^2 \quad (2)$$

where, T_m is the rated torque of the motor (Nm); R_{1st} is the 1st gear ratio; GR is the single stage gear ratio; η_{d-t} is the transmission efficiency (90%); r_w is tire radius (m); μ_k is the rolling resistance coefficient; m_t is the weight of the transmission (620kg); m_g is the weight of the single gearbox (600kg); g is gravity acceleration; A_{cc_t} is the acceleration of an electric vehicle with transmission (m/s^2), and A_{cc_g} is the acceleration of an electric vehicle with a single stage gearbox (m/s^2).

Equations (1) and (2) denote the average acceleration at starting; from the comparison result, it can be seen that the acceleration performance of an electric vehicle with transmission is superior to that with a single stage gearbox. The main reason is that the 1st gear ratio of transmission is larger than that of the single stage gearbox.

Equations (3) and (4) are the calculation of non-load maximum speed performance:

$$v_{speed_t} = \frac{RPM_m r_w}{k \cdot R_{5th}} = 97 km/h \quad (3)$$

$$v_{speed_g} = \frac{RPM_m r_w}{k \cdot GR} = 51 km/h \quad (4)$$

where, RPM_m is the motor speed, k is the conversion coefficient of the motor speed and vehicle speed (2.65); R_{5th} is the 5th gear ratio of the transmission; v_{speed_t} is the non-load maximum speed carrying the transmission (km/h) and v_{speed_g} is the non-load maximum speed carrying the single stage gearbox (km/h).

It can be seen from Equations (3) and (4) that the maximum speed of the electric vehicle with transmission is larger than that with a single stage gearbox, but the speed is not the actual maximum speed; when the vehicle is traveling on the road, the speed will be lower due to the impact of pavement load, so the actual speed should be the intersection of the driving force curve and the road load curve. This intersection signifies a balance between the driving force and the road resistance, as shown in Figure 11 and 12.

Figure 11: Performance of EV with a 5-speed transmission

Figure 12: Performance of EV with a single-ratio gearbox

4 Conclusions

From the above comparison and analysis, it can be seen that as the transmission has different gear-ratio, the performance scope of motor can be expanded (with large torque at low speed and with high rotate speed at high speed). Thus, an electric vehicle with transmission has better road load resistance performance than that with a single ratio gearbox, and it can reduce the power requirements for the motor as well as enhance the performance of the electric vehicle. Therefore, transmission is a better choice to enhance the performance of an electric vehicle.

However, an issue worth discussion accompanies this conclusion, the technology of the gear shift control of the gearbox. For a traditional manual transmission, gear shifting is realized by manually pushing a shift lever behind steering wheel or on the carriage floor to different stalls, thereby pulling a steel cable connected to the shift lever.

Such traditional gear technology is pure manual and mechanical, which fails to satisfy the new and diversified vehicle space design and requirements of advanced and innovative electric control gear shift. The research team has been working on the research and development of an Automatic Manual Transmission system (AMT) that is already patented. By applying the method of electric control instead of traditional cable control, the gear shift action can be completed by the trigger of an electric signal, realizing the flexible gear shift function and satisfying the demand of electric vehicles in the future.

References

- [1] Frost & Sullivan (2009)
- [2] Electric Drive Transportation Association. <http://www.electricdrive.org>

- [3] <http://www.hybridcars.com/top-hybrid-cars-list>
- [4] <http://tech.ddvip.com>

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