Research on Automatic Manual Transmission of Pure Electric Vehicle

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Abstract. In recent years, the electric vehicle industry has developed rapidly. Compared with traditional internal combustion engine vehicles, pure electric vehicles have the advantages of less pollution, less noise, and simple structure. At the same time, the problem of short range has become an important factor restricting the development of pure electric vehicles. This paper proposes to mount a four-speed mechanical automatic transmission in a pure electric vehicle to improve the working efficiency of the motor, thereby improving the vehicle's cruising range. CRUISE simulation software was used to build a vehicle model of a pure electric vehicle equipped with this transmission. A vehicle equipped with a fixed gear ratio reducer is used as a comparative experiment to study the impact of a mechanical automatic transmission on the economy and power of the vehicle.

1. Introduction

Cars have provided us with convenience, and at the same time brought environmental problems that cannot be underestimated. Compared with traditional fuel vehicles, electric vehicles are powered by batteries and driven by electric motors, with little or no pollution [1]. However, since the launch of pure electric vehicles, the distribution points of charging piles for electric vehicles are currently scattered, causing drivers to be unable to charge their vehicles in time at their destination. On the other hand, because the charging speed of pure electric vehicles is slower than the rate of refueling of traditional internal combustion engine vehicles, the range problem has restricted the development of pure electric vehicles to some extent [2]. Pure electric vehicles are often equipped with a fixed ratio reducer. Although the fixed ratio reducer can meet some urban road conditions, when the vehicle is driving on a relatively steep slope and more complicated road conditions, the motor cannot continue to work in the high efficiency range that conduct to loss of power [3]. The purpose of this article is to propose a transmission with multiple gears for a pure electric vehicle, so that when the motor operates under different operating conditions, it can well be more opportunities to operate in a high efficiency range, reduce power loss, and improve vehicle economics. On the other hand, the multi-stage transmission can reduce the speed and increase the torque, which improves the vehicle's power performance [4]. The introduction of automatic transmission technology for pure electric vehicles can effectively improve the comfort of the ride, improve the efficiency of shifting, and improve the overall performance of the vehicle [5]. The automatic transmission is a torque converter that replaces the clutch. It is used by most passenger vehicles because it has a small sense of frustration during gear shifting and smooth gear shifting without the need for frequent driver operations. Large, high quality, high cost, not suitable for pure electric vehicles. Combining the characteristics of high transmission
efficiency, low cost, simple structure, small size, and low failure rate of mechanical transmissions, as well as the advantages of automatic transmissions, Automatic Manual Transmissions (AMT) are widely used in pure electric vehicles [6].

2. Vehicle parameters
The parameters of the vehicle are usually defined from three aspects, the external dimensions, mass, and air resistance coefficient [7]. This paper selects the Model 3 of the American Tesla company as the research object. The parameters that need to be determined when determining the research object are shown in Table 1. The dynamic index is a key index to measure the performance of the car. The specific parameters are shown in Table 2.

| Vehicle parameters                  | Parameters value |
|-------------------------------------|------------------|
| Total mass/kg                       | 2105             |
| Readiness quality/kg                | 1611             |
| Shape size (length * width * height)/mm | 4694×1850×1443   |
| Tyre Specification and Type         | 235/45 R18       |
| Wheelbase /mm                       | 2875             |
| Tread /mm                           | 1580             |
| Windward area/m²                    | 2.28             |
| Wheel rolling radius/m              | 0.334            |

| Dynamic Indicators                  | Parameters value |
|-------------------------------------|------------------|
| Acceleration time (t/s)             | 0-50km/h < 5     |
| Maximum Speed (km/h)                | 120              |
| Maximum gradient (%)                | 25,20km/h        |

3. Transmission structure design
The structure of the AMT power transmission system is shown in Figure 1. The main components of a vehicle power transmission system are the engine, AMT, main reducer, differential, and wheels [8]. In this section, the 3D modeling of the transmission is done by SOLIDWORKS, as shown in Figure 2.

![AMT power transmission structure](image)

1-Unidirectional Clutch; 2-Long Planetary Gear; 3-Planet carrier; 4- Ring gear; 5-Meshing gear; 6-Small Sun Gear; 7-Short Planetary Gear; 8-large sun gear; B1, B2-Brake; C1, C2, C3-Clutch.

**Figure 1.** AMT power transmission structure

The structure is based on the design of double planetary gear train. It consists of two planetary wheels, small sun gear and large sun gear, long planetary gear and short planetary gear. Short
planetary gear 7 meshes with small sun gear 6, long planetary gear 2 meshes with large sun gear 8, short planetary gear 7 and ring gear 4, respectively. Ring gear as the only power output gear engages with gear 5 to ensure power output. The shift action of gearbox is completed by the cooperation of clutch C1, C2, C3 and brake B1, B2. The Planet carrier is used as input power and keeps the position of the planetary wheel. The function of unidirectional clutch is to ensure that the planetary carrier will not reverse during the operation of planetary gear train. Following is a description of the working process of four forward, reverse and neutral gears.

First gear: C1 clutch combined, small sun gear input power, B1 brake work, at same time, planetary carrier is locked, power output from the ring gear.
Second gear: C1 clutch combined, small sun gear input power, B2 brake work, large sun gear is locked, ring gear output power.
Third gears: C1 clutch and C3 clutch work at the same time, any two components of planetary gear train work in the same speed and direction, the whole mechanism is locked, and the ring gear both the input and output of power to produce direct gear.
Fourth gears: C2 clutch combined, planetary carrier input power, B2 brake working, large sun gear locked, ring gear output power.
Reverse gear: Since the electric vehicle is powered by the motor, depending on the characteristics of the motor, the motor can be reversed to achieve reverse gear.
The structural shifting feature is that the C1 clutch is always in the combined state during the shifting of the first to third gears, and the first and second gears are controlled by the B1 and B2 brakes. The C3 clutch can be combined to complete the third gear shift. Therefore, the smoothness of shifting is increased and the loss of power is reduced.

Figure 2. 3D modeling of transmission

4. Transmission ratio calculation
Reasonable transmission ratio distribution can make the drive motor have more chances to work in the high-efficiency range, so that the cooperation between the motor and the transmission can be optimized, thereby improving the performance of the entire vehicle [9]. The transmission structure is based on the design of the double planetary gears. Using the characteristic equations of the double planetary gears, the transmission ratio formula of each gear can be obtained [10] to achieve a reasonable distribution of the transmission ratios.
(1) First gear.
The characteristic equation of the rear planetary row is:
\[ n_{24} - \alpha_2 n_{22} + (\alpha_2 - 1)n_{23} = 0 \]  \( (1) \)
The small sun gear speed is equal to the input speed \( n_i \); 

\[ n_{21} \]

Ring gear speed, equal to the output speed \( n_0 \); 

\[ n_{22} \]

Planet carrier speed, this time is 0; 

\[ n_{23} \]

The ratio of the number of teeth of the ring gear to the number of teeth of the small sun gear. 

Therefore, the transmission ratio can be obtained from the equation (1).

\[
i = \frac{n_i}{n_0} = \alpha_2
\]

(2) Second gear.

Front planetary gears meet 
\[ \alpha_i n_0 - (1 + \alpha_i) n_c = 0 \]  
(2)

Rear planetary gears meet 
\[ n_i - \alpha_2 n_0 + (\alpha_2 - 1) n_c = 0 \]  
(3)

The transmission ratio obtained by the equation (2), (3) is 
\[
i = \frac{n_i}{n_0} = \frac{\alpha_i + \alpha_2}{1 + \alpha_i}
\]

(3) The third gear is the direct gear. So, transmission ratio is 1.

(4) Fourth gear.

According to the characteristic equation (2) of the front planetary row, the transmission ratio can be obtained as 
\[
i = \frac{n_i}{n_0} = \frac{\alpha_i}{1 + \alpha_1}
\]

Finally, the transmission ratio calculation results are shown in Table 3.

Table 3. Transmission ratio

| Transmission gear | Main reducer | First gear | Second gear | Third gear | Fourth gear |
|-------------------|--------------|------------|-------------|------------|-------------|
| Ratio             | 4.3          | 3.18       | 1.84        | 1          | 0.61        |

5. Simulation model establishment and result analysis

The CRUISE developed by AVL includes simulations of fuel economy, vehicle dynamics, braking performance and emissions performance. It uses a comprehensive solution to increase the accuracy and speed of calculations. CRUISE software includes various components of the vehicle and vehicle model modules and is easy to operate [11]. Therefore, the entire vehicle model is built in CRUISE.

5.1. Building a vehicle simulation model

The vehicle simulation model mainly includes: vehicle module, motor module, power battery module, clutch module, transmission module, reducer module, differential module, brake module, wheel module, and cab module [12]. For the input of the vehicle parameters, refer to Table 1. The motor parameters are matched by the dynamic index, as shown in Table 2. The design range of the target vehicle is 300km, so the battery module is matched with the design range. After the vehicle model is set up, the signals are first connected to each part, and then the calculation tasks are set, that is, the maximum speed, gradient, and acceleration. The complete vehicle simulation model is shown in Figure 3.
5.2 Analysis of simulation results
In order to discuss the impact of AMT on the vehicle's economy and power, a pure electric vehicle model equipped with a fixed ratio reducer was selected for comparison. Figure 4 is the gradient curve of two different transmission vehicles. The blue curve is the gradient curve of the AMT vehicle, and the red curve is the gradient curve of the fixed ratio reducer vehicle. When the vehicle is traveling at 25km / h, the highest gradient of a pure electric vehicle using a fixed ratio reducer is 22.3%, and the highest gradient of an AMT vehicle can reach 26.2%, which can meet the performance requirements of the entire vehicle.

Figure 5 shows the acceleration curves of two different transmission vehicles. The blue curve is the simulation result of the AMT vehicle, and the red curve is the simulation result of the vehicle with a fixed ratio reducer. The acceleration time of the AMT vehicle from the start to 50km / h is 4.26s, which meets the acceleration performance requirements of the entire vehicle.

This paper uses the energy consumption of the two vehicles under NEDC conditions to evaluate the economic performance of the two models. Figure 6 shows the state of charge (SOC) of the vehicle under NEDC conditions. The blue curve is the SOC change curve of the AMT vehicle during driving, and the red curve is the SOC curve of the fixed ratio reducer vehicle. From the data in Figure 6 and Table 4, it can be seen that the fixed ratio reducer vehicle is in the NEDC operating state, and the battery SOC has dropped from 80% to 69.7929%. AMT vehicle battery SOC dropped from 80% to 71.1163%. In the matching scheme, the battery pack capacity is 48 kW • h, and under complete NEDC cycle conditions, the battery energy consumption of AMT vehicles is reduced from 8.883 kW • h to 7.7674 kW • h compared to fixed ratio reducer vehicles.
**Figure 4.** The climbing performance curve of the vehicle

**Figure 5.** The acceleration performance curve of the vehicle

**Figure 6.** The contrast curve of SOC on NEDC condition

**Table 4.** The parameters contrast of the dynamic and economic performance index

| Performance index                  | AMT vehicle | fixed ratio reducer vehicle |
|-----------------------------------|-------------|-----------------------------|
| **Dynamic performance**           |             |                             |
| Maximum speed (km/h)              | 120         | 114                         |
| Maximum gradient (%)              | 26.2        | 22.3                        |
| Acceleration time 0–50 km/h (s)   | 4.26        | 4.85                        |
| **Economic performance**          |             |                             |
| SOC consumption of NEDC conditions (%) | 8.8837      | 10.2071                     |

It is concluded from the simulation results that matching the four-speed AMT of the pure electric vehicle improves the acceleration performance and climbing performance of the whole vehicle, and reduces the power consumption of the pure electric vehicle.

6. **Conclusion**

In this paper, the transmission structure and transmission ratio of the pure electric vehicle transmission
are designed to achieve the matching between AMT and pure electric vehicles. The CRUISE software was taken as the simulation platform, and the AMT pure electric vehicle model was established. In this simulation, a pure electric vehicle model which matching a fixed ratio reducer was established as a comparison. The simulation is performed by setting related calculation tasks, and the performance of two different vehicles is compared and analyzed through the simulation results. The feasibility of matching the four-speed AMT for pure electric vehicles proposed in this paper is verified, and the economic and dynamic simulation results of two types of transmission vehicles are compared and analyzed. The results shows that the economy and power of the pure electric vehicle have improved when the vehicle matching the four-speed AMT.

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