Dynamic Property Simulation Research of Hybrid Electric Vehicle based on ADVISOR

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Abstract. Energy conservation and environmental protection are two major themes in today's world. Simulation analysis can save a lot of experimental costs in the production of cars. To improve the dynamic property of hybrid electric vehicles, a vehicle simulation model and battery simulation model were established in the ADVISOR to match and select the engine and motor parameters, and the performance of hybrid electric vehicles such as maximum speed, 0-100km acceleration time and SOC change of battery system was simulated and analyzed. The results show that the improved hybrid performance can meet the requirements, the vehicle's power performance and fuel economy was improved.

1. Introduction
With the rapid development of automobile industry, energy crisis and environmental protection are becoming more and more prominent. From the end of the 20th century to the present, global problems such as insufficient oil and poor environment have not been solved. In the face of growing environmental problems, government agencies around the world have established stricter vehicle emission standards. The development of new cars that can save energy and reduce emissions has become the top priority of car companies in all countries. "Made in China 2025" has made the research and development of new-energy vehicles a national strategy.

Hybrid electric vehicle (HEV) is a perfect combination of traditional internal combustion engine and electric vehicles. The HEV includes the advantages of both traditional internal-combustion and pure electric vehicles: long range of traditional internal-combustion vehicles and energy conservation and environmental protection characteristics of pure electric vehicles. Hybrid electric vehicle (HEV), to a certain extent, can improve energy and environmental degradation.

2. Establishment of Automobile Model
2.1. Establishment of Vehicle Model
Generally speaking, according to the position of automobile power source layout, hybrid electric vehicles can be divided into series hybrid electric system, parallel hybrid electric system and hybrid electric system. Among them, the serial hybrid power system has the simplest structure, but the transmission efficiency is low. In some cases, the engine cannot drive the wheels directly, and it has to go through two losses of the generator and the motor. In addition, a smaller power generator is needed, which costs more; the structure of hybrid power system is too complex and its cost is high. In the long distance high-speed driving process, hybrid power vehicle can hardly save fuel. The parallel hybrid power system is close to the traditional automobile. The parallel configuration only needs one motor,
and the motor does not need to provide all the driving forces for the vehicle. The power of the motor can be relatively small, which can greatly reduce the cost. At the same time, because the motor and internal combustion engine can drive the vehicle together, the ultimate power output is higher. To sum up, this paper takes the parallel hybrid electric vehicle as the research object, and changes its vehicle performance parameters, in order to achieve the purpose of improving the vehicle power.

2.2. Battery Pack Model Establishment
Battery pack is a key part of hybrid electric vehicle. The quality of battery pack directly affects the power performance of the vehicle and play a key role in energy conservation and environmental protection. The battery's internal resistance model calculates State of Charge (SOC) value and effective power output value according to the power required by the power bus, and part of the power lost in the driving process is evaluated according to the law of "Coulomb efficiency" and internal resistance loss, so as to construct all the models. The battery simulation model includes many accounting modules, such as limited power module, internal resistance module, accounting voltage module, SOC module, internal current load module and heat dissipation module.

2.3. Formulation of Control Strategy
The control strategy of hybrid electric vehicle determines the working state of the vehicle. As the main factor of motor power control, the control range of battery SOC value is very important. The SOC value should be kept in a relatively stable range during driving. The peak discharge power of the battery pack must be higher than the maximum power required for the motor; When the SOC drops and the engine starts to charge the battery, the peak of the battery pack must meet the charging power demand of the car. The most ideal SOC value of the battery is between 0.6 and 0.85. When the SOC value approaches the lower limit, the car changes to pure electric mode.

3. Matching of Powertrain Parameters
The principle of powertrain parameter matching is that the engine power needs to meet the requirement of driving at the maximum speed on the flat road. As for the driving process, when the car needs to accelerate or climb, its peak power is supplemented by the electric motor. On this basis, as much as possible to reduce the battery capacity, reduce fuel consumption.

3.1. Engine Parameter Matching
The engine of hybrid electric vehicle is required to have certain driving power and sufficient dynamic performance and maneuverability, which can meet the basic dynamic performance requirements of hybrid electric vehicle, and can provide the maximum power required by hybrid electric vehicle together with the driving motor, so that hybrid electric vehicle can reach or approach the level of dynamic performance of fuel electric vehicle. The maximum output power of the engine should be determined according to the power requirements of the vehicle when driving at a uniform speed, which meets the following formula(1):

\[ P_{e,\text{max}} = \frac{1}{3600\eta_t} \left( mgf + \frac{C_d A v^2}{21.5} \right) * v \]  

(1)

The basic vehicle parameters of hybrid electric vehicle are: transmission efficiency \( \eta_t \) is 0.8, vehicle mass \( m \) is 1400 kg, rolling resistance coefficient \( f \) is 0.02, wind resistance coefficient \( C_d \) is 0.34, windward area \( A \) is 2.5m², and the maximum speed \( v \) is 120 km/h. The basic parameters of the vehicle were substituted into the formula for calculation, and the output power of the engine was calculated as 36 kW. The engine power margin is 12% of the engine output power and takes the value of 4.3kW. The power consumption of each accessory equipment of the car is about 4kW, so the total power of the car under normal working conditions is 44.3kW. In order to ensure the dynamic performance of the whole car driven by the engine, the engine with a power greater than 44.3kW should be selected. Considering the above factors, the engine with maximum power of 63 kW and displacement of 1.0 L is the most suitable one.
3.2. Motor Parameter Matching

Electric motor is the key auxiliary power of hybrid electric vehicle. The speed and power of electric motor are the main parameters to be considered in the matching and selection. According to the actual situation of the motor of hybrid electric vehicle, the motor with an extended constant power coefficient $\beta$ of 4 ~ 6 and a maximum speed of 5 000 r/min is the most appropriate choice. The calculation formula is as follows\cite{1}:

$$P_{e,\text{max}} = \frac{1}{\eta_e} \left( \frac{mgf}{3600} \frac{v}{76140} + \frac{C_dA}{v^3} \right)$$

(2)

According to the above formula, the numerical generation into the formula can get that the motor rated power is 35.5 kW, plus 20% maximum gradability, the motor power is 42.6 kW, the selected motor maximum power needs to be greater than for the actual power, therefore, finally choose the power of 59 kW motor, in ADVISOR, choose models for MC_AC59 motor.

3.3. Battery Pack Parameter Matching

The battery pack needs to be charged and discharged repeatedly during the operation of the vehicle, so for hybrid electric vehicles, the configuration of the battery will take into account the major issues such as input and output power requirements, safety and battery life. In addition, the cost and maintenance issues in the actual application process should be considered. Combined with the above factors, valve-controlled lead-acid battery is a more appropriate choice.

After selecting the type of battery, the size of the battery pack also needs to be considered. If the capacity of the battery pack is too small, it will affect the driving distance of the car, and it is very inconvenient to charge during driving. If the battery capacity is too large, the volume and mass of the car will inevitably increase correspondingly, and the power performance and economy of the car will decrease. To sum up, PB25 (Battery capacity 7.5Ah) lead-acid battery is the most suitable for initial selection.

4. Establish the Dynamic Parameter Optimization Model

PHEV power system mainly refers to the system of engine, motor, power battery, need to optimize the quality of main parameters of engine power, engine, motor power quality, power battery power, power battery capacity, power quality, such as parts of power is the key factors to dynamic performance, and the battery capacity directly decide the size of the travel distance of pure electric.

4.1 The Establishment of the Target Function

Suppose that the engine cost is $C_E$, the motor cost is $C_M$, the power battery cost is $C_B$, and $f(x)$ is the sum of the power system cost, then the objective function is shown in Formula (3)\cite{3}:

$$\min f(x) = C_E + C_M + C_B$$

(3)

$P_E, P_M, P_B$ and $Q_B$ respectively represent engine power, motor power, power battery power and power battery capacity, and are the optimal variables to be optimized. $K_1, K_2, K_3$ and $K_4$ respectively represent the conversion coefficient between engine power, motor power, power battery power, power battery capacity and engine cost, motor cost and power battery cost. The relationship between the cost of each component and the power and power battery capacity of each component is shown in Formula (4)\cite{3}:

$$\begin{align*}
  C_E &= K_1P_E \\
  C_M &= K_2P_M \\
  C_B &= K_3P_B \\
  C_B &= K_4Q_B
\end{align*}$$

(4)

The battery cost can be calculated according to the power and capacity of the power battery, so the cost of the power battery is taken as the average value of the two, and the cost of the power battery is
expressed by formula (5)[4], and the objective function can be converted into formula (6)[4]:

\[ C_B = \frac{k_4 P_B + k_4 Q_B}{2} \]  

(5)

\[
\min f(x) = k_4 P_E + k_2 P_M + \frac{k_4 P_B + k_4 Q_B}{2}
\]  

(6)

4.2 The Establishment of Constraints
Suppose \( m_E, m_M, m_B \) and \( m_C \) respectively represent the engine mass, motor mass, power battery mass and the mass of other parts of the vehicle excluding these three parts, \( l_1, l_2, l_3 \) and \( l_4 \) respectively represent the conversion coefficient between engine power, motor power, power battery power, power battery capacity and engine mass, motor mass and power battery mass, and the relationship between the mass of each component and the power of each component is shown in Formula (7)[6].

\[
\begin{align*}
    m_E &= l_1 P_E \\
    m_M &= l_2 P_M \\
    m_B &= l_3 P_B \\
    m_C &= l_4 Q_B
\end{align*}
\]  

(7)

4.3 Engine Powerability
The engine power must meet the design requirements of the whole vehicle when the engine is driven alone, the maximum speed, the maximum acceleration and the maximum climbing slope, and the limiting conditions are shown in Formula (8)[6].

\[
\begin{align*}
    P_E &\geq \left( m_v gf + \frac{CAV_{max}}{21.15} \right) \frac{V_{max}}{3600\eta} \\
    P_E &\geq \left( m_v g f V_{t_1} + \frac{m_c g f V^2}{1.5} + \frac{CAV^2 V_{t_2}}{52.875} \right) \frac{1}{3600\eta_i} \\
    P_E &\geq \left( m_v g \sin \alpha + m_v g \cos \alpha \right) \frac{V}{3600\eta}
\end{align*}
\]  

(8)

4.4 Power Battery Performance
The power battery mainly adopts lithium ion battery, which is widely used in the electric vehicle market and has mature technology. The power of the power battery must meet the basic speed requirement of pure electric driving, and the capacity of the power battery must meet the requirement of minimum pure electric driving distance. The limiting conditions are shown in Formula (9)[7].

\[
\begin{align*}
    P_B &\geq \left( m_v gf + \frac{CAV_{21.25}}{21.25} \right) \frac{V}{3600\eta} + P_A \\
    E_B &\geq \frac{L}{V_B} \Rightarrow \frac{Q_b U}{1000} \geq \frac{L}{V_B} P_B
\end{align*}
\]  

(9)

5. Simulation Results and Analysis
The ADVISOR software provides a total of more than 50 foreign standard road cycles for simulation testing. Urban Dynamometer Driving Schedule(UDDS) in urban road cycling conditions in the United States are shown in Figure 1: UDDS road cycles are selected to simulate and test the vehicle performance such as the maximum speed, average speed, 100km acceleration time, 100km fuel
consumption and maximum climbing slope of the designed hybrid electric vehicle.

![Figure 1. UDDS road cycle.](image)

Inputting vehicle parameter data into the model, and through ADVISOR simulation analysis, the SOC value change of the battery system is obtained. SOC value of the battery system changes as shown in Figure 2: SOC value of the battery system decreases with driving time. In the first 600 s, SOC value of the battery system decreased significantly and then leveled off. In the 1800 s time from the beginning of the vehicle to the end of the experiment, the battery SOC value remained between 0.6 and 0.8, meeting the experimental requirements.

![Figure 2. Battery SOC value change in the system.](image)

The simulation performance indexes of hybrid electric vehicles are shown in Table 1: According to the simulation, the maximum driving distance of the vehicle is 11.99km, the maximum driving speed is 91.25km/h, the average speed is 31.51km/h, the average acceleration is 0.5km/s2, the 100km acceleration time is 11.62s, the 100km fuel consumption is 5.1L/km, and the maximum climbing slope is 19.8%. The above parameters are basically consistent with the expected vehicle performance, and the parameter selection of each key component of the hybrid electric vehicle is basically reasonable.

| project                        | The simulation results |
|--------------------------------|------------------------|
| Maximum travel distance /km    | 11.99                  |
| Maximum speed/(km/h)           | 91.25                  |
| Average speed/(km/h)           | 31.51                  |
| Average acceleration km/s2     | 0.5                    |
| 100km acceleration time/s      | 11.62                  |
| 100 km fuel consumption/(L/km) | 5.1                    |
| Maximum climbing slope(%)      | 19.8                   |

### 6. Conclusion

In the performance simulation research of hybrid electric vehicle, the whole vehicle model and battery simulation model of parallel hybrid electric vehicle are established, and the relevant parameters of engine and motor are matched, and the corresponding engine and motor models are selected to carry out simulation analysis on the performance of hybrid electric vehicle, such as the maximum speed of hybrid electric vehicle, acceleration time of 100 kilometers, SOC change of battery system and so on. The analysis results show that the related performance of the parallel hybrid electric vehicle can meet...
the standard, and the dynamic performance and fuel economy of the vehicle are improved.

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