Development of test bed of hybrid electric vehicle based on chassis dynamometer

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Abstract. For verify control strategies in the course of developing hybrid electric vehicle, a kind of test bed was developed. Four removable wheels was used as test best’s supporting, all powertrain and control units of true vehicle were contained in the test bed. At the same time, the test bed was connected with two driving wheels. Chassis dynamometer was used to simulate road surface, was connected and fixed with the test bed. For applying different control strategies, dSPACE system was used as real-time control component. Some characteristics tests can be done using the test bed, such as dynamic, economic, discharge and regenerative braking. Test of regenerative braking was done, the test results showed that the test bed can satisfy requirements.

1. Introduction

The first paragraph after a heading is not indented (Bodytext style). Electric vehicles have become the new energy vehicles which lead the development trend of automobiles due to energy saving, environmental protection, technology and popularization. Hybrid electric vehicle is the most mature and most popularized electric vehicle. With the deepening of research on hybrid electric vehicle, some key technologies still restrict its development, such as parameter matching, control strategy optimization, etc. Whether these technologies can be comprehensively upgraded has become a key factor affecting the overall market of hybrid electric vehicle[1-2].

Experiment is the best way to solve the above problems. There are usually two platforms for hybrid electric vehicle bench test: Vehicle bench test and assembly bench test. At present, the modular powertrain platform has been developed by domestic Jilin University and Chongqing University in the research of hybrid electric vehicles[3-5], but there are few reports abroad. The engine dynamometer is used as the power absorption and loading device. Modular design can flexibly lay out the assembly of each component, but the operating conditions do not conform to the actual vehicle, and can not carry out power performance and economic and emission test based on operating cycle conditions. Bogdan Vulturescu of the French Institute of Transportation Science and Technology and others have set up a vehicle test bench for testing energy management strategies of 3.5t city buses equipped with high-energy Ni-Cd batteries and high-power supercapacitors using chassis dynamometers[6], which is less reported
in China. Such benches are made of chassis dynamos to absorb and load the power, it is possible to test the power performance of the whole vehicle and the economy and emission performance of the vehicle based on the operating cycle condition, but each assembly on the vehicle is compact and not easy to test.

In view of the above reasons, a new hybrid vehicle test bench is developed, which combines the advantages of the two platforms. The test-bed adopts the form of movable four-wheel support. It has all the power assemblies and control units of the real vehicle. Two driving wheels are connected at the output end of the driving half-shaft. The chassis dynamometer is used as the power absorption and loading device to connect the driving wheels of the test-bed with the chassis dynamometer drum. And the test-bed is fixed through a fixed device. The dSPACE system is used as the real-time controller of the test-bed system to load different control strategies. The test bench has the characteristics of simple structure, compactness, simple connection, convenient movement and small occupation.

2. The composition of test-bed system
The structural arrangement of the hybrid vehicle test-bed based on the chassis dynamometer is shown in figure 1. The main function of the test-bed is to be able to easily and realistically test the basic performance (dynamic, economical, emission) and regenerative braking performance of the hybrid powertrain under different control strategies.

![Figure 1. Structure arrangement of test bed](image-url)

The test-bed is an integrated hybrid power system test rig built by TOYOTA Prius powertrain. The planetary gear mechanism is used to connect the power assembly of engine, motor and generator. The power assembly is connected with the driving wheel through the deceleration mechanism, the driving wheel is connected with the chassis dynamometer drum, and the test bench is connected with the ground through a fixed device. The dSPACE system is used as the real-time controller of the test-bed system. The engine, generator, motor, battery pack and brake system are controlled by the control interface. The chassis dynamometer is controlled by the main control computer, and the fuel consumption meter and the emission test system are controlled by their respective control units. The test bench is removed from the chassis dynamometer without testing and can be easily moved to a designated position.
3. Operational principle of Test-bed

The power source of the test bed system includes the engine and the motor, the controllers respectively are the engine ECU and the motor controller; the loading device uses the chassis dynamometer; the data acquisition and control functions of the system are completed by the sensors, the controllers and the dSPACE system. The sensor collects the analog signal and transmits the signal to the controller, and converts it into a digital signal through the controller operation processing, and sends it to the dSPACE main control system through the CAN bus. The control command of the main control system is sent to each controller through the CAN bus, and the control of the actuator is completed by each controller.

The control strategy of hybrid electric vehicle can be validated by controlling the components of the test-bed. Through the collection and analysis of chassis dynamometer, fuel consumption meter, emission test system and battery SOC data, the related performance of hybrid electric vehicle can be known, which meets the predetermined functional requirements of building a hybrid electric vehicle test-bed.

3.1. Basic performance test

Before the test, the road resistance of the chassis dynamometer is set according to the weight of the test-bed, and the position of the test-bed is adjusted, so that the test-bed system and the chassis dynamometer are in good contact and fixed, and the control strategy to be verified is set by the dSPACE system, and then carry out the corresponding test.

The power is tested according to GBT19752-2005 "Hybrid Power Vehicle Performance Test Method" for maximum speed, acceleration time t and maximum grade. For economical tests, the fuel consumption test system needs to be connected to the oil system of the test bed engine, according to GBT19753-2005"Light-type hybrid electric vehicle energy consumption test method" for fuel consumption test; For discharge test, the discharge test system sampling probe needs to be connected to the corresponding position of the test bed exhaust pipe, and emission pollutants CO, HC, NOX should be tested according to GBT 19755-2005"Pollutant Emission Measurement Method for Light Hybrid Electric Vehicles".

Through the above methods, the test-bed can complete the test of the basic performance such as the power, economy and emission of the hybrid vehicle under the control strategy.

3.2. Test of regenerative braking performance

Regenerative braking is a unique braking technology used in electric vehicles. The system principle is shown in figure 2. In the case of deceleration braking, the driving motor runs in the power generation state, and relies on the reverse dragging of the wheels to generate electric energy and wheel braking torque. Thus, while slowing down the speed of the vehicle, part of the kinetic energy is converted into electric energy to be fed back to the battery for charging, and the energy feedback is realized [7].

![Figure 2. Structure principle diagram of regenerative braking system](image)
Start the test-bed system, and set the engine gear in D gear, control the test-bed running at a certain set speed according to the predetermined braking strength of the brake pedal braking, at this time can carry out SOC, braking torque and other indicators of testing.

4. Control and test system

The test-bed not only combines the advantages of the two test platforms, but also adopts the advanced dSPACE system as the real-time control system, as well as the chassis dynamometer test system of AVL Company and the fuel consumption meter emission test system, which guarantees the real-time and accuracy of the test-bed.

4.1. dSPACE system

dSPACE real-time simulation system is a control system development and hardware-in-the-loop simulation software platform based on MATLAB/Simulink, which realizes the seamless connection with MATLAB/Simulink/RTW[8]. dSPACE runs through the whole process of the development and test of the measurement and control system with computer support technology. It has the advantages of strong real-time, high reliability and good extensibility. It can also provide a test environment with strong adaptability and friendly interface for the test in the test phase[9].

The dSPACE system is connected to the control units of each powertrain and brake system through the control interface, receiving test parameters and running control of control strategies set.

4.2. Chassis dynamometer test system

Chassis dynamometer testing system is used to simulate road performance. The measurement accuracy is high, the measuring range is wide, and it can simulate many kinds of actual road conditions. Chassis dynamometer is generally composed of loading device, measuring device, drum assembly and other auxiliary devices. The key to the application of chassis dynamometer is the setting of road resistance[10].

The resistance of the car on the road is:

\[ F = F_f + F_w + F_j + F_i \]  

In the formula: \( F \) is the driving resistance of the car; \( F_f \) is the rolling resistance of the car; \( F_w \) is the air resistance of the car; \( F_j \) is the accelerating resistance; \( F_i \) is the climbing resistance of the car; that is, \( F_w \) is the rolling resistance of the car, that is:

\[ F_w = \frac{2}{21.15} \cos \theta \sin \delta \frac{dv}{dt} + mg \sin \theta \]  

In the formula: \( m \) is the mass of the vehicle; \( g \) is the acceleration of gravity; \( f \) is the rolling resistance coefficient; \( CD \) is the air resistance coefficient; \( A \) is the windward area of the vehicle; \( \theta \) is the climbing angle; \( v \) is the vehicle speed; \( \delta \) is the conversion factor of the vehicle rotating mass.

According to the definition and expression in the formula (2) corresponding to the driving resistance in formula (1), it is known that \( F_f \) and \( F_w \) can be expressed as the primary or quadratic function of the driving speed \( V \), \( F_j \) is independent of the speed, and \( F_i \) is set separately on the chassis dynamometer. According to the meaning of taxiing energy change method in GB18352.3-2005 "Limits and Measurement Methods of Pollutants Emitted by Light Vehicles (China Phases III and IV)", the driving resistance of each vehicle is analyzed by regression method, and another expression of driving resistance simulated on chassis dynamometer is obtained:

\[ F = a + bv + cv^2 \]
In the formula: \( a \) is the resistance independent of velocity, \( N \); \( b \) is the primary velocity influence coefficient, \( N/(km/h) \); \( c \) is the secondary velocity influence coefficient, \( N/(km/h)^2 \).

Road resistance coefficient \( a, b, c \) can be obtained by the method of road skidding test and table lookup method. In this paper, table lookup method is used, that is, GB18352.3-2005 standard is obtained according to the quality of test-bed and other parameters.

After the road resistance coefficient is set, the connection between the test bed system and the chassis dynamometer can be performed. Speed and torque sensors are respectively installed on the drum of the chassis dynamometer and the coaxial motor, and the speed and torque signals are separately collected and provided to the main controller for calculation and analysis.

4.3. Fuel consumption meter and emission test system

The fuel consumption test system adopts AVL PLU 401-108 fuel consumption meter, and its working principle is shown in Figure 3. The box in the figure is shown the inner operational principle diagram of the fuel consumption meter. The inlet and return pipeline interfaces between the fuel tank and the fuel consumption meter are respectively ①, ②, and the inlet and return pipeline interfaces between the fuel consumption meter and the engine are respectively ③, ④.

The emission test system adopts AMA i60 of AVL company to test exhaust pollutants such as CO, HC and NOx.

5. Test and result analysis of regenerative braking process

Before the test, first open the dSPACE system, then replace the control algorithm related to the main program with the control strategy of the brake condition, and compile and download it to dSPACE to run the Control Desk software. According to the test requirements, set the CVT gear position to D gear, step on the accelerator pedal to increase the vehicle speed to 35km/h, release the accelerator pedal, press the brake pedal to keep the brake strength \( z \) at 0.2, and continue to decelerate until the stop. The data, including the speed, SOC and regenerative brake torque, are recorded through by the test-bed measurement and control system.

Taking the vehicle speed of 30km/h as an example, the SOC value of the brake with 0.2 braking strength increased from 68.6% to 68.73%, which can verify the energy recovery. The experimental results were fitted to obtain the parametric curves of speed at \( z=0.2 \), front wheel (driving wheel) braking force, motor torque, battery SOC and the time as shown in Figure 4.
As can be seen from Figure 4, when the brake pedal is pressed, the speed decreases, the brake force of the front wheel decreases rapidly and the torque of the motor increases rapidly, and the SOC value of the battery increases with the regeneration of the brake energy, which indicates the braking energy regeneration test function of the hybrid vehicle of the test bed system.

It can be seen from the test results of the above braking conditions that the test bed can meet the requirements of the hybrid electric vehicle test, and the test of the braking conditions reflects the energy feedback of the hybrid electric vehicle, which can verify the energy recovery under the set control strategy.

6. Conclusion
Compared with the advantages and disadvantages of the whole vehicle bench and the power assembly bench in the current control strategy of hybrid vehicle development, a hybrid vehicle test rig combining the advantages of both is developed. The dSPACE system is used to control the test bed system in real time, which is convenient to load different control strategies. The regenerative braking test verifies that the test bench can realize the recovery of braking energy. The test bench developed has the characteristics of simple structure, compactness, simple connection, convenient movement and less land occupation. It is of great significance for real and efficient verification of hybrid vehicle control strategy.

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