Experimental Study on The Performance of FCV in Standard Test Cycle

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Abstract. The experiments of one FCV (Fuel Cell Vehicle) are conducted in three standard cycle conditions of NEDC (New European Driving Cycle), WLTC (Worldwide Light-duty Test Cycle) and CLTC (China Light-duty vehicle Test Cycle), and the performance of stack power, temperature and system efficiency are compared and analysed. Results show that the variation range of fuel cell system efficiency is ordered as: WLTC > NEDC > CLTC. The efficiency of fuel cell system is highest in CLTC; the fuel cell stack power and temperature are relatively low; the hydrogen consumption is lowest (0.93kg/100km). According to the analysis on experimental data of FCV in NEDC, the output power of stack is proportional to accelerator pedal when the accelerator pedal opening is greater than 25%.

Keywords: Hydrogen Fuel Cell, Performance, CLTC, NEDC.

1. Introduction
The world's famous vehicle companies, such as Toyota, Honda, Hyundai have already launched fuel cell models. As an industry benchmark, Toyota Mirai is the world first mass-produced hydrogen fuel cell vehicle, with a driving range of about 500 kilometers. Toyota plans to achieve an annual sales volume of more than 30000 fuel cell vehicles around 2020. The hydrogen fuel cell vehicle clarity launched by Honda has a maximum driving range of 750km. It is worth noting that the manufacturing platform of this model will take into account the production of clarity Battery electric vehicle and clarity plug-in hybrid vehicle [1]. After the launch of ix35 fuel cell vehicle in 2013, Hyundai launched NEXO fuel cell vehicle in 2018, with a driving range of more than 800km.

The China government supports the development of fuel cell vehicles from a strategic point of view. The energy saving and new energy vehicle technology roadmap issued by the Ministry of industry and information technology clearly states that 5000 fuel cell vehicles will be used as demonstration vehicles in 2020, and one million hydrogen fuel cell vehicles will be used commercially in 2030 [2]. Since 2015, driven by the market of new energy vehicles and sustained favorable policies, fuel cell vehicle market has grown rapidly in China. In 2018, the number of fuel cell vehicle production reached 1619, an increase of 27% year on year. At present, the sales of domestic fuel cell vehicles are mainly trucking and buses. In 2018, the sales of fuel cell buses increased to 421, accounting for 50.5% of the sales of domestic fuel cell vehicles [3].
At present, among domestic automobile enterprises, FAW, SAIC, GAC, great wall and other companies are vigorously promoting the research and development of hydrogen fuel cell vehicles. In order to speed up the independent research and development progress, it is urgent to start the benchmarking research work about the international advanced hydrogen fuel cell vehicle. At the same time, after 2020, the switching of test cycle conditions for the whole vehicle also has an important impact on the design and development of hydrogen fuel cell vehicles. Therefore, under different standard cycle conditions, the comparative analysis of hydrogen fuel cell vehicles has a certain engineering significance.

In this paper, the vehicle power, energy, efficiency and other aspects of one fuel cell vehicle under three standard typical working conditions (NEDC, WLTC and CLTC) are compared and analyzed, and the vehicle performance under NEDC working conditions is analyzed in detail, which is helpful to support technical research of OEM and development of hydrogen fuel cell vehicle.

Compared with electric vehicles, hydrogen fuel cell vehicles have the technical advantages of high energy density, fast hydrogenation, long endurance and environment-friendly, which attract much attention in the research and development process of international automobile enterprises.

2. Experimental method

2.1. Test bench parameters
The model of equipment used in the test bench and the measured parameters are shown in Table 1.

| Device name               | Equipment type           | Measurement parameters                                      |
|---------------------------|--------------------------|------------------------------------------------------------|
| 1 Dynamometer             | AVL Dyno Train 220kW     | Wheel speed                                                |
| 2 Torque meter            | HBM T12                  | Wheel resistance moment                                    |
| 3 weather station         | HMT330                   | Ambient temperature, pressure and humidity                |
| 4 CAN analyzer            | CAN OE                   | Collect can signal data                                    |

2.2. List of CAN signals
Through the installation of external test equipment, the relevant data about the vehicle operation can be obtained, but some parameters on the vehicle are difficult to be measured directly, such as power battery stack voltage, power and water outlet temperature. For such signals, they are obtained by reading the data stream of CAN and the signal list is shown in Table 2.

| Signal                                | Signal                                | Signal                                |
|---------------------------------------|---------------------------------------|---------------------------------------|
| 1 Accelerator pedal opening           | 11 Fuel cell current                   | 21 Fuel cell pump power               |
| 2 Brake pedal opening                 | 12 Stack effluent temperature          | 22 Total power of air conditioner     |
| 3 Gear position                       | 13 Stack air flow                      | 23 Mass air flow of stack             |
| 4 Speed                               | 14 Inlet air pressure                  | 24 Inlet air pressure                 |
| 5 SOC                                 | 15 Inlet air temperature               | 25 Inlet air temperature              |
| 6 Power battery voltage               | 16 Power of hydrogen circulating pump  | 26 Drive motor speed                  |
| 7 Power battery current               | 17 Hydrogen injection request          | 27 Motor temperature                  |
| 8 Single chip voltage average         | 18 Air compressor speed                | 28 Drive motor actual torque          |
| 9 Single chip minimum voltage         | 19 Hydrogen remainder                  | 29 ECO mode                           |
| 10 Total stack voltage                | 20 Radiator outlet temperature         | 30 Vehicle power mode switching       |
2.3. Introduction to experimental conditions
In this paper, the experiments of FCV in NEDC, WLTC and CLTC cycle is conducted. The specific experimental parameters are shown in Table 3.

Table 3. Test parameters

| boundary condition | Conditional parameter |
|--------------------|-----------------------|
| Ambient temperature (℃) | 15.7                  |
| Ambient humidity (%)   | 40%                   |
| Air pressure (kPa)     | 101.5                 |
| Load (kg)             | Half year, 2032        |

2.4. Introduction of three working cycles
Due to the great difference between the working conditions of NEDC and WLTC and the actual road conditions in China, the CLTC working conditions based on 3082 complete vehicles and the operation data of 41 typical cities in China are gradually valued by the R&D personnel of vehicle enterprises because they are more suitable for the actual road conditions in China. During the test, the error between the actual driving speed and the set speed of the standard map shall not exceed 2%.

Table 4. Comparison of characteristic parameters of NEDC, WLTC and CLTC curves

|                | NEDC | WLTC | CLTC |
|----------------|------|------|------|
| Running time (s) | 1180 | 1800 | 1800 |
| Driving distance (km) | 11.03 | 23.21 | 14.94 |
| Average speed (km / h) | 33.64 | 46.62 | 36.35 |
| Maximum speed (km / h) | 120 | 131.3 | 114 |
| Average acceleration (M / S^2) | 0.53 | 0.53 | 0.47 |
| Average deceleration (M / S^2) | -0.75 | -0.58 | -0.52 |
| Acceleration time ratio (%) | 23.22 | 30.94 | 29.14 |
| Deceleration time ratio (%) | 16.61 | 28.56 | 26.4 |
| Cruise proportion (%) | 37.54 | 27.83 | 22.41 |
| Parking percentage (%) | 22.62 | 12.67 | 22.05 |

According to the characteristic parameters shown in Table 4, in the three standard Experimental conditions, the NEDC cycle has the shortest running time (1180s), the shortest driving distance(11.03km) and the lowest average speed(33.64km/h), but the average acceleration and deceleration of the NEDC cycle are relatively high (0.53m/s^2 and -0.75m/S^2), the highest proportion of cruise and parking (37.54% and 22.62%, respectively).In the WLTC cycle, the overall average speed is the highest (46.62km/h), the peak speed is the highest (131.3km/h), the acceleration time ratio (30.94%) and deceleration time ratio (28.56%) are the highest. In CLTC cycle, the amplitude of average acceleration and average deceleration is the smallest, which are 0.47m/s^2 and -0.52m/s^2 respectively. The cruise proportion is the lowest (22.41%) and the peak speed is the lowest (114km / h) [5~ 6].

3. Results and discussion
(1) Power and temperature of fuel cell stack in three cycle conditions
In the performance of the hydrogen fuel cell vehicle, the system power and temperature of the stack are important indicators in the development of the vehicle. In this study, the performance of Toyota was tested in NEDC, WLTC and CLTC cycles respectively. According to the time statistics of stack output power and stack temperature under three cycle conditions, it is found that the stack power is mainly concentrated in 5-30kW, the median value is 17kW, and the maximum power is 68kW under
NEDC cycle condition; in WLTC cycle condition, the stack power is mainly concentrated in 10-35kw, the median value is 21kW, and the maximum power can reach 102KW is the cycle condition with the largest power variation range and the highest median among the three conditions; while in CLTC cycle, the power of the stack is mainly concentrated in 3-25kW, with a median value of 13kW and a maximum power of 60kW, which is the cycle condition with the most concentrated power variation range, the lowest median value and the highest value. From the above analysis results, it can be inferred that the power demand value of fuel cell stack for the actual road cycle in China is lower than that of NEDC and WLTC.

The power of the stack affects the water output of the stack, and then affects the water temperature of the stack. The effluent temperature of the stack can indirectly reflect the efficiency of the fuel cell stack system. As shown in Figure 1, the temperature of stack effluent under three cycle conditions is 57-72℃ and 63℃ respectively under NEDC; 51-79℃ and 65.5℃ respectively under WLTC; 56-69℃ and 62℃ respectively under CLTC. The condition of narrow and lowest temperature mean value indicates that the load of this vehicle is relatively concentrated in actual road operation in China.

(2) Efficiency and hydrogen consumption of fuel cell stack

According to the power interval of the stack under three working conditions and the system efficiency diagram, the system efficiency working points under three working conditions are obtained as shown in Figure 2. The working range of the system efficiency under three working conditions is WLTC > NEDC > CLTC, among which the output power concentration of the stack under CLTC is the highest (with a confidence interval of 80%), and it is mainly distributed near the highest point of the system efficiency. The hydrogen consumption of NEDC, WLTC and CLTC is 0.98 kg/100km, 1.05 kg/100km and 0.93 kg/100km respectively. The hydrogen consumption of CLTC is the lowest. The reason is that the average speed of CLTC in China is low, and idle speed and acceleration and deceleration account for more. While this FCV uses parallel hybrid output, when accelerating/decelerating rapidly, the power battery gives power supplement/recovery to ensure that the stack is maintained in the high efficiency operation area [7]. In China, the power consumption area of fuel cell is near the best efficiency point of the system, which shows that this fuel cell vehicle will have more advantages in CLTC operation.
Figure 2 System efficiency comparison under NEDC, WLTC and CLTC conditions

4. Conclusions
In this paper, the operation data of FCV under NEDC, WLTC and CLTC are collected, and the performance of power, temperature and system efficiency of the stack are analyzed. The conclusions are as follows:

(1) The order of power and temperature range of stack is WLTC > NEDC > CLTC.
(2) Due to the system efficiency of the whole working process: CLTC > NEDC > WLTC, the hydrogen consumption per hundred kilometers is CLTC (0.93kg) < NEDC (0.98kg) < WLTC (1.05kg).
(3) According to the analysis of NEDC working condition, when the opening of accelerator pedal is less than 20%, it is mainly output by power battery. When it is more than 25%, the output power of stack is proportional to the accelerator pedal. With the increase of the output power (0-60kw), the current increases gradually (0-215A), and the voltage of the stack decreases gradually (320-250V).

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