A Chassis Dynamometer Laboratory for Fuel Cell Hybrid Vehicles and the Hydrogen Consumption Measurement System

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Abstract—**To test and evaluate performance, fuel efficiency and emission of fuel cell hybrid vehicles, a laboratory equipped with a heavy duty chassis dynamometer is constructed by CATARC collaborates with Tsinghua University. The framework of the chassis dynamometer laboratory is designed. Then, three hydrogen consumption measurement methods are researched, and a hydrogen energy consumption measurement system for the laboratory is developed. Finally, the application of the chassis dynamometer laboratory is presented, especially several tests for the accuracy and the reliability of the hydrogen energy consumption measurement system is carried out. Certification tests and researches for both heavy duty and light duty fuel cell hybrid vehicles can be carried out in this chassis dynamometer laboratory.**

Keywords-Fuel Cell Hybrid Vehicle; Chassis Dynamometer; Hydrogen Consumption Measurement;

I. INTRODUCTION

Nowadays, with the purpose of countering the energy and environmental crises, more and more automotive manufacturers and research institutes have set researches on new energy vehicles as their major research priorities. Fuel cell vehicles, with the advantage of high efficiency, environmentally friendly, low-noise, etc. have attracted attention of automotive researchers worldwide. To test and evaluate performance, fuel efficiency and emission of fuel cell hybrid vehicles, a certification laboratory, equipped with a heavy-duty chassis dynamometer, was constructed by CATARC collaborated with Department of Automotive Engineering (DAE) of Tsinghua University. Certification experiments for heavy-duty FCVs and Oil-Electric Hybrid Vehicles (HEVs) can be carried out in the laboratory.

Fuel economy is one of the most important indicators for performance evaluation of vehicles. Furthermore, for the FCVs the consumption of hydrogen during the scheduled tests represents the economics of the vehicles. On the other hand, methods of fuel economy measurements for conventional internal combustion engine vehicles, such as the “carbon balance method” etc. cannot be applied to FCVs, because of the special electrochemical properties of the fuel cell engines. So, the research for finding the FCVs economic evaluation method that is highly accurate and can be applied universally at a comparatively low cost, is still in progress worldwide now. DAE developed a hydrogen consumption measurement system for the chassis dynamometer laboratory. The measurement system was based on Pressure & Temperature Method, Flow Method and Weight Method, which are recommended by the SAE J2572 standard for evaluating FCVs fuel economy.

II. STRUCTURE OF THE CHASSIS DYNAMOMETER LABORATORY

A heavy-duty chassis dynamometer provided by MAHA AIP® is equipped for the laboratory. With the chassis dynamometer, certification experiments for performance and emission evaluation of the heavy-duty FCVs can be carried out. Meanwhile, the hydrogen consumption measurement system will supply the vehicle being tested with hydrogen decompressed to the proper pressure for the fuel cell engines. And the measurement system will save the necessary data for calculating the hydrogen consumption and display the result on the host computer screen.

The construction of the chassis dynamometer laboratory is still in progress. The sketch model of the laboratory refers to Figure1.

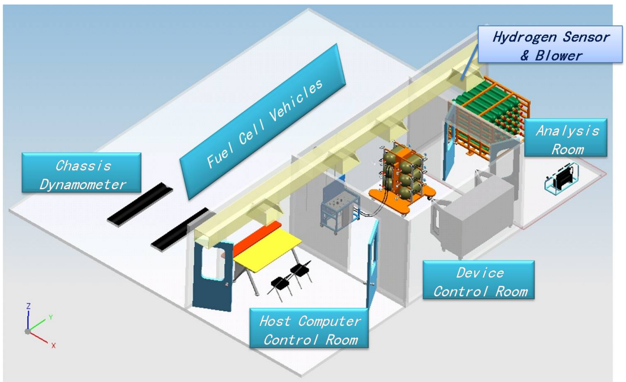

Figure 1. The Chassis Dynamometer Laboratory

Hydrogen is an inflammable and explosive gas, so during the scheduled tests, safety is very important. We recommend that hydrogen sensors and vents with explosion proof blowers should be installed at the necessary position to avoid any hydrogen leakage.

III. HYDROGEN CONSUMPTION MEASUREMENT SYSTEM

Hydrogen consumption measurement system for FCVs is developed for PEM FCVs fueled with compressed hydrogen. Of the three measurement methods recommended by SAE J2572, we took the Pressure & Temperature Method and the Flow Method as the theoretical basis, and set the Weight Method as the accuracy basis. The measurement system consists of three devices: 1) the measurement integrative device, 2) the scale assistant device, 3) the hydrogen supply tank bracket, 4) the data acquisition and host computer management system.

A. Hydrogen Consumption Measurement Method

- The Weight Method

This is a method that directly measures the mass of the pure hydrogen consumed during the test, and this method is used as a accuracy standards of the three methods. Specifically, the weight of the hydrogen tank is measured before and after the tests, and the hydrogen consumption is determined from the difference. Fuel consumption W (g) is calculated using Equation 1 below.

$$W = W_i - W_f \qquad (1)$$

Wi : Weight of the Hydrogen tank before test (g)

Wf: Weight of the hydrogen tank after test (g)

- The Pressure & Temperature Method

Hydrogen consumed during the scheduled test is stored in the tank. If we knew the tank hydraulic test volume, the mass of the hydrogen could be calculated from the modified ideal gas equation with the tank's pressure and temperature measured throughout the test. Hydrogen consumption W(g) is calculated using Equation 2 below.

$$W = \left(\frac{P_i \times V}{R \times T_i} - \frac{P_f \times V}{R \times T_f} \right) \times m \qquad (2)$$

Pi : Hydrogen tank pressure before tests (Pa)

Pf : Hydrogen tank pressure after tests (Pa)

Ti : Hydrogen tank temperature before tests (K)

Tf : Hydrogen tank temperature after tests (K)

V : Hydrogen tank capacity (m3)

R : Gas constant 8.314(J/mol•K)

m : Molecular weight of hydrogen 2.016(g/mol)

Actually, when the hydrogen pressure is more 2 MPa, the ideal gas equation is not proper. So, we use the Van der Waals' equation or the compression ratio to calculate the hydrogen consumption.

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

- The Flow Method

This method measures fuel consumption by continuously measuring fuel supply flow and integrating the flow rate. The Flow Method is adapted for on board using, with little modification to the original pipelines. Specifically, the fuel consumption W(g) is calculated according to Equation 3 below.

$$W = \frac{\sum Q}{22.414} \times m \qquad (3)$$

Q : Hydrogen flow rate (NL/min)

m : Molecular weight of hydrogen 2.016(g/mol)

B. The Measurement Integrative Device

During the scheduled experiments, we may need to move the measurement device to adapt for different vehicles. The shorter the supply pipeline is, the more accurate the hydrogen consumption we will get. So, we integrate the supply pipelines, the regulator valves, the cut off valves, the gas filters, the pressure gauges, etc, into a handcart, which is compact and maneuverable.

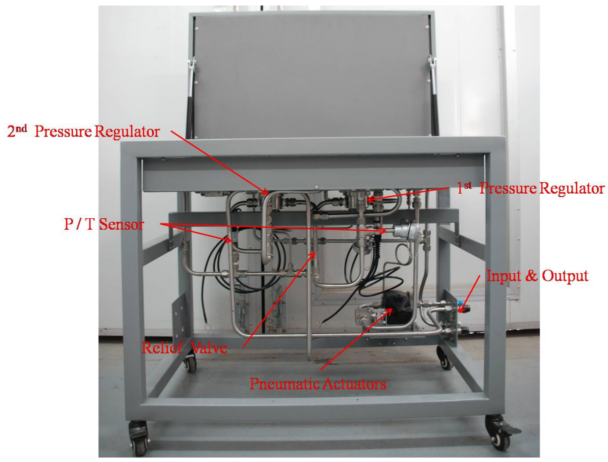

Figure 2. The Measurement Integrative Device

Two gas pressure regulator are placed among the hydrogen supplying pipes, reducing the pressure of the hydrogen from 20MPa in the tanks to about 0.3~0.8MPa at the device outlet. This low pressure hydrogen can be used by the FCVs being tested. This double stage system could keep the output hydrogen at a constant pressure despite the changing tank pressure.

We install a cut-off valve with a pneumatic actuator in the main pipeline of the device, which is controlled by the researcher at the host computer management system. And all the pressure sensors and the temperature sensors installed in the device meet the Ex ib IIC T6 standard. So, the device is quite reliable and safe to be used.

A relief valve is selected to release the high pressure hydrogen through the pipeline when an accident is confirmed. Meanwhile, the hydrogen sensors installed at different positions of the chassis dynamometer laboratory will detect the hydrogen leakage and turn on the blower.

C. The Scale Assistant Device

A Mettler-Toledo® high precision scale is equipped to scale the mass of the hydrogen tank before and after a test if it is necessary. In order to improve the accuracy of the Weight Method, we design a vibration and air blowing prevention device. The vibration conducted through the ground from a running motor or other machines nearby, or the ambient air blowing above the scale may affect its result as much as 1 to 2 grams.

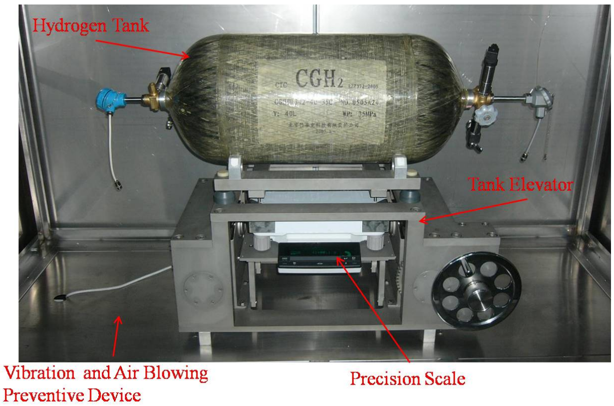

Figure 3. The Scale Assistant Device

We also design a tank elevator to hold the tank being scaled and prevent the scale surface from being broken by accident. The elevator lifts the tank with a Cam-Synchronizing Toothed Belt system.

D. The Hydrogen Supply Tank Bracket

Five Aluminum-Carbon Fiber tanks are selected to serve as the hydrogen supply. Another tank of the same type is filled with nitrogen as the purge tank to blow out the air throughout the pipelines before and after the test. All the tanks have a volume of about 50 liters, which is exactly confirmed by hydraulic tests. And we install a Pt100 temperature sensor and a piezoresistive pressure sensor both at the outlet valve and at the end block of the tank. Meanwhile, a same pressure sensor is fixed at the end block of the nitrogen tank. The temperature and the pressure of the hydrogen stored in the tank will drop continuously as the hydrogen discharging through the tank valve, and the P/T data will be recorded by the data acquisition system.

Figure 4. The Hydrogen Tank

E. The Data Acquisition and Host Computer Management System

The major functions of the system are 1) assisting the researchers in completing the data acquisition process during the test; 2) controlling the hardware equipped device; 3) detecting the security state of the devices; 4) analyzing the recorded data.

- Data Acquisition

The system will collect the useful data during the scheduled tests and record the data to the host computer hard disk for further studies. The data consists of: 1) the scaled data of the pressure sensors and the temperature sensors installed at the hydrogen tank and at the measurement integrative device; 2) instantaneous hydrogen flow data scaled by the Micro-Motion Coriolis mass flowmeter; 3) weight of the hydrogen tank scaled by the high precision scale; 4) atmosphere pressure, temperature and humidity. Refer to TABLE 1.

TABLE I. TEST SYSTEM SIGNALS

Signal	Signal Name	Range	Signal Type
Temperature	Tank Temperature	-20-80℃	4-20mA
	Pipeline Temperature	-20-80℃	4-20mA
	Environment Temperature	0-50℃	0-5V
Pressure	Tank Pressure	0-20 MPa	4-20mA
	Pipeline Pressure	0-20 MPa	4-20mA
	Atmosphere Pressure	0.08-0.11MPa	0-5.1V
Flow	Flow Rate	0-2500NL/min	4-20mA
Humidity	Environment Humidity	0-100%	0-5V

a. NL indicates that the flow rate should be test under normal condition, 1 atm, 0 C

- Hardware Control

The system will control the pneumatic actuators open or cut-off the main pipeline of the integrative device by 100kPa air from an air compression pump

- Construction of the System

The hydrogen consumption measurement test system is based on an industrial personal computer (IPC) manufactured by Advantech®. The host computer management software and the data acquisition software is developed by LabView, which is a virtual instrument development platform published by NI Company. RS485 serial data bus is selected to realize the data exchanging between the IPC and the data acquisition modules or the hardware control modules. The system sampling frequency is 10Hz of the low speed channels, while the sampling frequency of the high speed channels is 20Hz. Refer to Figure 5.

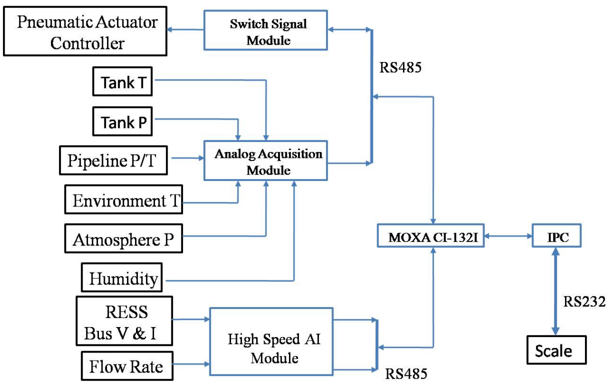

Figure 5. Parallel Dual Fieldbus of the System

- Host Computer Management Software

The host computer management software of the test system is developed by LabVIEW. The major function of the software is building a communication bridge between the IPC and the modules. The system function consists of: 1) Data acquisition, data real-time display, data storage, data recalling and analysis. 2) Data acquisition channel calibration. 3) Control the pneumatic actuator. 4) Detect the process state of the whole system, display alarm on the computer screen when an abnormal state is detected. Refer to Figure 6.

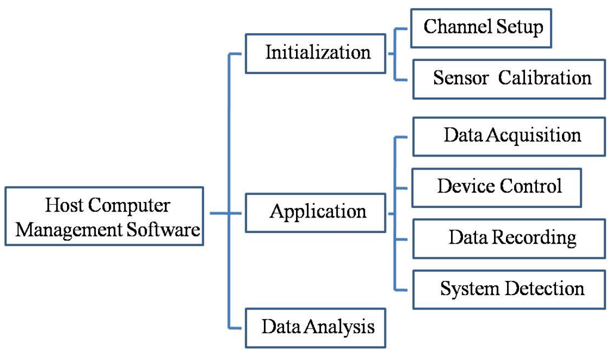

Figure 6. Host Computer Management Software

IV. APPLICATION

Hydrogen discharging tests and Nitrogen discharging tests are scheduled using the hydrogen consumption measurement system. Specifically, the pressure and temperature changing data of the gas in the tank are recorded throughout the tests. Meanwhile, the mass of the used hydrogen tank is scaled and recorded, either. The flow rate is also recorded. But the tests are all carried out without the chassis dynamometer being used. The result with the chassis being used and a FCVs will be mentioned in my full paper.Refer to TABLE 2, Figure 8, Figure 9.

TABLE II. P&T METHOD ERROR

Flow Rate (NL/min)	Weight Method (g)	P&T Method (g)	Error (%)
100	30.2	30.1	-0.3311
300	40.3	40.27	-0.0744
400	72.0	71.8	-0.2777
600	167.9	167.4	-0.2978
800	145.1	145	-0.0689
1000	128.2	127.9	-0.2340

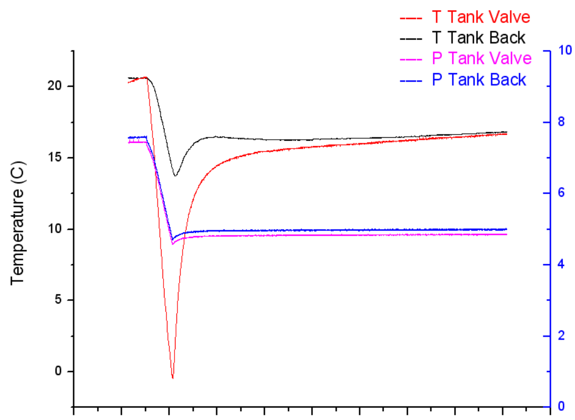

Figure 7. Pressure and Temperature of the Hydrogen

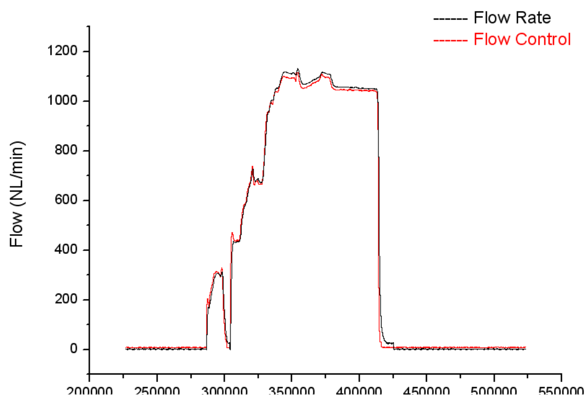

Figure 8. Flow Rate of the Discharging Flow

V. CONCLUSION

The chassis dynamometer laboratory for heavy-duty FCVs is still being constructed by CATARC in Tianjin, China. The hydrogen consumption measurement system is already finished by DAE, Tsinghua University. Scheduled tests will be carried out for heavy-duty FVCs and HEVs when the chassis dynamometer laboratory construction is completed. The tests will deal with the methods of evaluation of performance, fuel efficiency and emission of FCVs and HEVs, meanwhile the methods of evaluating the effect of ΔSOC on the fuel efficiency of FCVs will also be researched.

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