On-line calibration facility of compressed hydrogen dispenser based on weighing method and master meter method

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Abstract. This paper introduces a kind of on-line calibration facility based on weighing method and master meter method, which can carry out the on-site and laboratory calibration of 35MPa/70MPa hydrogen dispenser. At first, the working principle and technical specifications of the hydrogen dispenser is explained. Then the working principle and design structure of the calibration facility is depicted. Finally, the calibration facility is used to perform the real flow calibration test on hydrogen dispenser. According to the test results, the expanded uncertainty of the calibration facility of master meter method is about 0.7% (k=2), and the expanded uncertainty of the calibration result is 0.96% (k=2); and the expanded uncertainty of calibration facility of weighing method is about 0.097% (k=2), and the expanded uncertainty of calibration result is 0.48% (k=2). The real flow test shows that the two method calibration facilities both can be used for actual calibration of 2.5-level hydrogen dispenser. The calibration facility of weighing method is suitable for the occasions with high accuracy requirements because of its short traceability chain, while the calibration facility of master meter method can be used for flexible on-line calibration because of its simple structure.

1. Introduction
Under the background of China's commitment to peak carbon emissions by 2030, frequent occurrence of El Nino and La Nina phenomena caused by greenhouse effect and accelerated melting of Antarctic glaciers, the energy conservation and environmental protection have been paid more and more attention by governments and worldwide environmental protection organizations. As the product of combustion exothermic process is only water, the hydrogen energy is becoming a popular clean energy under the condition that the safety use is fully guaranteed and the difficulty of obtaining is greatly reduced. The hydrogen vehicle is a kind of vehicle using hydrogen as energy, which converts chemical energy produced by hydrogen combustion reaction into mechanical energy to drive the vehicle. At present, hydrogen fuel cell vehicles occupy a dominant position in the market due to their high safety and energy efficiency.

However, in the process of popularization of hydrogen fuel cell vehicles (FCEV), a problem that cannot be ignored is the design and manufacture of hydrogen filling facilities. The compressed hydrogen dispenser emerges as the times require. In 2014, the Chinese national standard GB/T 31138-2014"Compressed Hydrogen Dispenser for Vehicles" was issued, which standardized the design principle, production procedure and technical indicators of the hydrogen dispenser. However, the
method and specification of calibrating the measurement performance of the hydrogen dispenser has not been mentioned. Therefore, this paper will focus on the calibration of measurement performance of hydrogen dispenser.

2. Working principle of the hydrogen dispenser

2.1. Working principle of the hydrogen dispenser
Like all filling measuring instruments, compressed hydrogen dispenser is a flow measurement system for measuring the accumulative mass or volume flow of compressed hydrogen, whose components mainly include high accuracy Coriolis mass flowmeter, electronic signal acquisition and control system, fast cut-off valve, nozzle, etc.

The working principle of compressed hydrogen dispenser is as follows: Firstly, the compressed hydrogen enters into the pipeline system of the dispenser, successively passes through the pressure-regulating valve, gas filter, mass flowmeter, quick shut-off valve, pull off valve, high-pressure hose, etc., and finally injects into the high-pressure storage container carried by the hydrogen fuel cell vehicle [1-2]. The electronic signal acquisition collects the cumulative mass flow, instantaneous mass flow, temperature, pressure and other signals of the mass flowmeter, and also controls the relevant parameter setting, start and stop of the hydrogen dispenser. The working principle and appearance of the hydrogen dispenser are shown in Figure 1.

![Figure 1. The working principle and appearance of the compressed hydrogen dispenser](image)

2.2. Main technical specifications of hydrogen dispenser
The main technical specifications of the hydrogen dispenser include working pressure range, measurement accuracy, flow range, etc. According to the type of hydrogen storage cylinder (vehicle type), the hydrogen system of compressed hydrogen dispenser is generally divided into commercial-vehicle hydrogen system, of which rated working pressure is 35MPa, and the mass of on-board hydrogen is about (20-40) kg, and passenger-vehicle hydrogen system, of which rated working pressure is 70MPa, and the mass of on-board hydrogen is no more than 5kg. To the measurement performance part, the maximum allowable error of both the above compressed hydrogen dispenser is ± 2.5%, the measurement repeatability is ± 1%, and the hydrogen flow rate shall not exceed 3.6 kg / min.

3. Introduction of on-line calibration method and principle of hydrogen dispenser
The calibration of all filling metering instruments is essentially aimed at the calibration of its internal flowmeter. Different from the liquid volumetric flowmeter used for oil filling metering instruments, the
small diameter Coriolis mass flowmeter is used for hydrogen dispenser and CNG or LNG dispenser as the measurement instrument.

3.1. Principle of calibration facility for hydrogen dispenser

For the above reasons, the calibration of hydrogen dispenser can be transformed into the calibration of Coriolis mass flowmeter working under high pressure [3-5]. So, the master meter method and weighing method can be included in the measurement method of compressed hydrogen dispenser. The gas flow standard facility of the master meter method is the facility which uses the master meter as measurement standard. The method is to let the working flow medium continuously pass through the master meter and the flowmeter to be measured at the same time, and then determine the measurement performance of the flowmeter or the flow metering device to be measured by comparing the difference of their cumulative mass flow. In addition, the master meter selected by the flow standard facility and the meter to be measured are generally of the same type. The gas flow standard facility of weighing method is generally positive pressure air inlet type, which is mainly composed of gas source, hydrogen storage cylinder, precision electronic balance, pipeline system and indicating flowmeter. When the facility works, the working flow medium successively pass through the flow meter to be measured and the hydrogen storage cylinder. Then by weighing and recording the weight increase of the hydrogen storage cylinder, the actual mass of the working flow medium passing through the pipeline in the measurement process can be obtained. Then the measurement performance of the flowmeter can be examined by comparing the difference between the cumulative mass flow and the weight increase of the precision electronic balance.

3.2. Main technical specifications of hydrogen dispenser

Based on the contents mentioned above, an on-line calibration standard facility of hydrogen dispenser is built, which integrates master meter method and weighing method. The structural schematic diagram is shown in the figure2.

![Figure 2. The structural schematic diagram of the on-line calibration standard facility](image)

The standard facility is mainly composed of master meter, pressure sensor, quick shut-off valve, hydrogen storage cylinder and valve group for storage cylinder, precision electronic balance, data acquisition and control system. When on-line calibration is carried out, the precision electronic balance can be omitted, only master flowmeter act as the measurement standard. However, the precision electronic balance shall be used as the measurement standard for laboratory calibration. To the on-line calibration, the master meter belongs to the category of transfer standard, while to the laboratory calibration, the electronic balance can be regarded as secondary standard for the reason that the master meter used as the transfer standard needs to be traceable to the weighing method standard facility. The flow range of the standard facility is (0.2~4) kg/min, the expanded uncertainty of the master meter
method standard facility is better than 0.3%, while the expanded uncertainty of the weighing method standard facility is better than 0.15%. It is a universal calibration facility for 35MPa and 70MPa hydrogen dispenser. In the standard facility, the master meter is the high-pressure Coriolis mass flowmeter produced by Tatsuno, which flow range is (0.16~6) kg/min and maximum working pressure is 100MPa; the type of precision electronic balance is FD300IGG produced by Sartorius, which weighing range is (60 ~ 300) kg and the calibration index value is 10g, and the gross weight of the hydrogen storage cylinder before inflation is 100kg.

3.3. Pressure range partition and flow point selection of the calibration

Because the filling flow rate of hydrogen dispenser will change with the internal pressure of the hydrogen storage cylinder, it is impossible to specify the calibration flow point as the method of calibration the normal pressure flowmeter. Due to the characteristics of high working pressure, small molecular weight of hydrogen and small mass flow during hydrogen filling, the whole hydrogenation process is divided into three pressure ranges for calibration. The pressure range partition and calibration flow point selection of the hydrogen dispenser with the maximum working pressure of 35MPa are shown in Table 1, while the pressure range partition and calibration flow point selection of the hydrogen dispenser with the maximum working pressure of 70MPa are shown in Table 2.

Table 1. The pressure range partition and calibration flow point selection of the hydrogen dispenser with the maximum working pressure of 35MPa.

| Flow point | Start pressure of the storage cylinder | Stop pressure of the storage cylinder |
|------------|----------------------------------------|---------------------------------------|
| R (1)      | (1~2) MPa                              | (34~35) MPa                           |
| R (2)      | (11~12) MPa                            | (34~35) MPa                           |
| R (3)      | (23~24) MPa                            | (34~35) MPa                           |

Table 2. The pressure range partition and calibration flow point selection of the hydrogen dispenser with the maximum working pressure of 35MPa.

| Flow point | Start pressure of the storage cylinder | Stop pressure of the storage cylinder |
|------------|----------------------------------------|---------------------------------------|
| R(1)       | (1~2)MPa                               | (69~70)MPa                            |
| R(2)       | (22~23)MPa                             | (69~70)MPa                            |
| R(3)       | (45~46)MPa                             | (69~70)MPa                            |

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4. Real flow test and uncertainty analysis of measurement

The 35MPa hydrogen dispenser produced by a company in Shanghai was taken as the test object. First, the standard facility, the hydrogen dispenser, and other temperature and pressure sensors were connect by pipeline, according to the figure 2. Then open all valves of the test pipeline, make the compressed hydrogen fill the whole test system, then continue to inflate until the pressure of the hydrogen storage cylinder reaches 35MPa, and then close the gas source valve, maintain the pressure of the system for 5min, and observe whether the pressure drop of each part exceeds 0.2MPa. After the sealing test, the real flow test was carried out by master meter method and weighing method.
4.1. Real flow test with master meter method

4.1.1. Real flow test with master meter method. The real flow test result with master meter method is shown in the table 2.

| Flow point / Start pressure of the storage cylinder | Reading of hydrogen dispenser (kg) | Reading of master meter (kg) | Single measurement error (%) | Relative error (%) | Repeatability (%) |
|---------------------------------------------------|-----------------------------------|----------------------------|-------------------------------|-------------------|-------------------|
| R (1)/1.35Mpa                                     | 22.712                            | 22.731                      | 0.15                          | 0.06              | 0.23              |
| R (1)/1.42Mpa                                     | 22.687                            | 22.716                      | 0.22                          |                   |                   |
| R (1)/1.55Mpa                                     | 22.667                            | 22.643                      | -0.17                         |                   |                   |
| R (2)/11.45Mpa                                    | 10.961                            | 10.937                      | 0.31                          |                   |                   |
| R (2)/11.67Mpa                                    | 10.996                            | 10.981                      | 0.67                          | 0.59              | 0.29              |
| R (2)/11.50Mpa                                    | 10.981                            | 10.956                      | 0.80                          |                   |                   |
| R (3)/22.23Mpa                                    | 5.513                             | 5.552                       | 1.14                          |                   |                   |
| R (3)/22.37Mpa                                    | 5.434                             | 5.498                       | 1.07                          | 1.28              | 0.33              |
| R (3)/22.08Mpa                                    | 5.601                             | 5.591                       | 1.64                          |                   |                   |

4.1.2. Evaluation of uncertainty of test result with master meter method. The uncertainty of test result with master meter method mainly stems from the type B uncertainty of the master meter used in the facility and the type A uncertainty caused by repeated measurements.

The relative expanded uncertainty of the standard Coriolis mass flowmeter given by the calibration certificate is $U_{m}=0.7\%$, ($k=2$), so its standard uncertainty is $u_{ms}=0.7\%/2=0.35\%$. And the type A uncertainty is 0.33\%, of which is the maximum repeatability of three flow points.

Therefore, the relative standard uncertainty of the measurement result ($u_m$) with master method can be calculated by the following formula:

$$u_m = \sqrt{0.35^2 + 0.33^2} = 0.48\%$$

(1)

Taking the inclusion factor $k=2$, the relative expanded uncertainty of the measurement result with master method is $U_m=k*u_m=0.48\%*2=0.96\%$.

4.2. Real flow test with weighing method

4.2.1. Real flow test with weighing method. The real flow test result with weighing method is shown in the table 4.

| Flow point / Start pressure of the storage cylinder | Reading of hydrogen dispenser (kg) | Reading of master meter (kg) | Single measurement error (%) | Relative error (%) | Repeatability (%) |
|---------------------------------------------------|-----------------------------------|----------------------------|-------------------------------|-------------------|-------------------|
| R (1)/1.35Mpa                                     | 22.153                            | 22.212                      | 0.26                          | 0.18              | 0.10              |
| R (1)/1.42Mpa                                     | 22.128                            | 22.148                      | 0.09                          |                   |                   |
| R (1)/1.55Mpa                                     | 22.574                            | 22.614                      | 0.17                          |                   |                   |
| R (2)/11.45Mpa                                    | 11.324                            | 11.383                      | 0.52                          |                   |                   |
| R (2)/11.67Mpa                                    | 11.285                            | 11.353                      | 0.60                          | 0.45              | 0.23              |
| R (2)/11.50Mpa                                    | 11.113                            | 11.138                      | 0.22                          |                   |                   |
| R (3)/22.23Mpa                                    | 5.826                             | 5.895                       | 1.16                          |                   |                   |
| R (3)/22.37Mpa                                    | 5.669                             | 5.728                       | 1.03                          | 1.17              | 0.17              |
| R (3)/22.08Mpa                                    | 5.517                             | 5.591                       | 1.31                          |                   |                   |
4.2.2. Evaluation of uncertainty of test result with master meter method. The uncertainty of test result with weighing method mainly stems from the type B uncertainty of the precision electronic balance used in the facility and the type A uncertainty caused by repeated measurements. The maximum weight of the precision electronic balance used in the calibration facility is 300kg, and the initial weight of the hydrogen storage cylinder is 100kg, so the actual range of the electronic balance is (0~200) kg. According to the calibration certificate, in the weighing range of (0~5) kg, the expanded uncertainty of the reading of the balance is the largest of is 4g, so the type B relative standard uncertainty introduced by the electronic balance is $u_{mb} = 4/5000/1.732*100 = 0.046\%$. And the type A uncertainty is 0.23%, of which is the maximum repeatability of three flow points. It is assumed that there is 2g frost on the wall of the gas cylinder and other pipelines of the weighing platform, which the estimated quality value of frost obeys triangular distribution, due to heat absorption during the measurement. The maximum relative standard uncertainty in the whole flow area caused by the frosting of storage cylinder and pipelines of the weighing platform is $u_{mk} = 2/5000/\sqrt{6}*100 = 0.016\%$.

Therefore, the relative standard uncertainty of the measurement result ($u_m$) with weighing method can be calculated by the following formula:

$$u_{m2} = \sqrt{u_{mb}^2 + u_{mk}^2} = \sqrt{0.046^2 + 0.016^2} = 0.24\%$$

Taking the inclusion factor $k=2$, the relative expanded uncertainty of the measurement result with weighing method is $U_{m2}=k*u_{m2}=0.24\%*2=0.48\%$.

5. Conclusion
With the rapid development of international carbon emission reduction and hydrogen dispenser industry, the calibration of hydrogen dispenser production industry, the research on measurement performance verification method and calibration standard facility design of hydrogen dispenser has become a hot topic for engineers in related fields. Under this background, the weighing method and master meter method standard facility for on-line calibration of hydrogen dispenser is introduced in this paper. Then standard facility is used to calibrate the measurement performance of the hydrogen dispenser in real flow test. Finally, the uncertainty of the test results with the two calibration methods is analyzed. The results show that both the two methods all can be used for calibration of the hydrogen dispenser. For the on-line calibration, considering the simple structure and convenient operation, the standard facility of master method is preferred, while for the cases of high accuracy requirements, the standard facility of weighing method may be the optical choice.

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References
[1] Galassi M C, Papanikolaou E, Heitsch M, et al. Assessment of CFD models for hydrogen fast filling simulations [J]. International Journal of Hydrogen Energy, 2014, 39(11):6252-6260.
[2] Maus S, Hapke J, Ranong C N, et al. Filling procedure for vehicles with compressed hydrogen tanks [J]. International Journal of Hydrogen Energy, 2008, 33(17):4612-4621.
[3] Furio Cascetta, Giuseppe Rotondo. Measuring of compressed natural gas in automotive application:A comparative analysis of mass versus volumetric metering methods [J]. Flow Measurement and Instrumentation, 19(2008): 338-341.
[4] C.Clark. The performance characteristics of a micro-machined Coriolis flow meter:An evaluation by simulation[J]. Flow Measurement and Instrumentation, 17(2006): 325-333.
[5] G.Bobovik, J.Kutin, I.Baaisic. The effect of flow conditions on the sensitivity of the Coriolis flowmete[J]. Flow Measurement and Instrumentation, 15(2004): 69-76.