Repeatability of the master meter method in calibrating compressed hydrogen dispenser

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Abstract

Hydrogen fuel cell technology is an important development direction of clean energy vehicles, which has the characteristics of zero pollution and renewability. As a key role in the commercial operation of hydrogen energy vehicles, the accuracy of the hydrogen filling quantity directly affects trade fairness and market promotion. The master meter method is generally used for the flow calibration of the existing compressed hydrogen dispenser, tin other words, high-precision Coriolis mass flowmeter is connected in series to the hydrogen filling pipeline on site, and the calibration is completed in the actual hydrogen filling process. In practice, it was found that compared with CNG, the compressed hydrogen filling process was added with a pre-charging and pressure maintaining procedure. If the model of the master meter and flowmeter in the compressed hydrogen filling dispenser to be calibrated are different, the repeatability of the calibration result will be poor. It is preliminarily concluded by experiments and analysis that the error is caused by the response of Coriolis mass flowmeter of different types to the single pulse flow during pre-charging and pressure maintaining procedure, which affects the repeatability of calibration of master meter method. Finally, it is suggested that the mass accumulated in the stage of the pre-charging pressure maintaining should not be included in the error calculation when the master meter method is used to calibrate compressed hydrogen dispenser.

1. Introduction

Hydrogen, the most abundant element in the universe, is a unique and renewable energy source. Hydrogen fuel cell technology is superior to coal, natural gas and nuclear power in that its by-products are heat and water and thus have no adverse impact on the environment. Moreover, hydrogen fuel cell technology provides high density energy with good energy efficiency. The weight energy density of compressed gaseous and liquid hydrogen is about three times that of diesel and liquified natural gas (about 120MJ/kg), and the volume energy density is similar to that of natural gas, and the charging time of hydrogen fuel cell power unit is very fast. Based on the above advantages, hydrogen fuel cell technology is an important development direction of new energy vehicles.

Among many hydrogen energy storage methods, compressed hydrogen has become the preferred hydrogen storage and transportation method for hydrogen energy vehicles due to its high maturity, domestic industrial chain and rich application experience. However, due to the pressure of hydrogen production cost and the requirement of range, end-users are very sensitive to the accuracy of hydrogen filling quantity, which calls for the ensurance of measurement accuracy of compressed hydrogen dispenser.

2. Problems

Referring to the verification of compressed natural gas dispenser, the type approval and the flow calibration of compressed hydrogen dispenser can be carried out by means of gravimetric method and master meter method. Considering the dangerous chemical characteristics of hydrogen and the complexity and uncertainty of the site, it is generally recommended to use the compressed gas flow standard device of gravimetric method as the primary standard in order to ensure safety, reduce pipeline leakage and the weighing error caused by the temperature imbalance of hydrogen storage tank after hydrogen charging and discharging. The master meter of Coriolis mass flowmeter as the secondary standard was calibrated with air medium and used for the field calibration (Figure 1).

Figure 1: The photo of the field calibration.

In recent years, with the increasing number of field calibration, we found that if the type of the master meter is not the same as the under tested meter in hydrogen filling dispenser, the repeatability of the calibration results is poor, which affects the evaluation of the measurement performance of the tested dispenser. In order to clarify the causes of this problem, the hydrogen filling process and the characteristics of flowmeter were studied in this paper.

3. Experiments

3.1 Calibration by gravimetric method

It is necessary to verify whether the repeatability of the flowmeter will be affected by different measured medium when the gravimetric compressed gas flow standard device with air as the measured medium calibrates the master meter with hydrogen as the working medium.

Generally, the Π and Ω shaped Coriolis mass flowmeter are adopted by the mainstream hydrogen dispenser. Therefore, before the field test, this paper takes the above mentioned two flow meters as the research object and uses the gas flow standard device of the gravimetric method to calibrate with air at 20MPa and hydrogen at 30MPa respectively. The flow rate curve during calibration is shown in Figure 2.

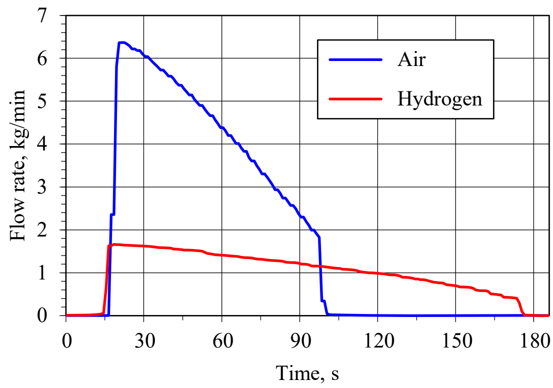

Figure 2: The flow curve of the calibration by gravimetric method.

Table 1: The calibration of the Π shaped sensor by gravimetric method.

Medium	The total mass of the meter (kg)	The total mass of balance (kg)	The average error (%)	Repeatability (%)
Air	5.400	5.413	-0.253	0.012
	5.273	5.287		
	5.114	5.127		
H_2	1.332	1.326	0.488	0.039
	1.328	1.321		
	1.251	1.245		

Table 2: The calibration of the Ω shaped sensor by gravimetric method.

Medium	The total mass of the meter (kg)	The total mass of balance (kg)	The average error (%)	Repeatability (%)
Air	5.135	5.123	0.202	0.061
	5.329	5.322		
	5.444	5.431		
H_2	1.317	1.326	-0.641	0.068
	1.312	1.321		
	1.238	1.245		

The results show that the repeatability of the flowmeter in two calibration medium is consistent, both lower than 0.1% as shown in Table 1 and Table 2. It means that the repeatability of above two Coriolis mass flowmeter will not be worse due to the difference between the properties of hydrogen and air in the filling process.

3.2 Field test by the master meter method

The Ω shaped Coriolis mass flowmeter was installed in the hydrogen dispenser as the under tested meter at the test site. The Π shaped Coriolis mass flowmeter is used as the master meter, which is connected in series between the hydrogen dispenser and the hydrogen storage tank of the vehicle to be filled.

After making sure of no leakage in the connecting pipeline, the test started according to the master meter method. Each group contains three tests with the filling pressure of 35MPa. The key parameters of the filling process of the master meter were recorded, such as flow, temperature, zero point, etc. Since the residual pressure in the hydrogen storage tank of the filled vehicle is random, it hard to ensure consistency of the total mass in three consecutive times, which is significantly different from the gravimetric method.

A typical calibration results are shown in Table 3. It can be seen that the repeatability of the measurement error is 0.916%, which is much larger than that of the previous calibration by the gravimetric method.

Table 3: The result of the calibration by master meter method.

The total mass of the hydrogen dispenser (kg)	The total mass of the master meter (kg)	Error (%)	The average error (%)	Repeatability (%)
3.165	3.209	-1.371	-0.424	0.916
2.413	2.402	0.458		
2.768	2.778	-0.360		

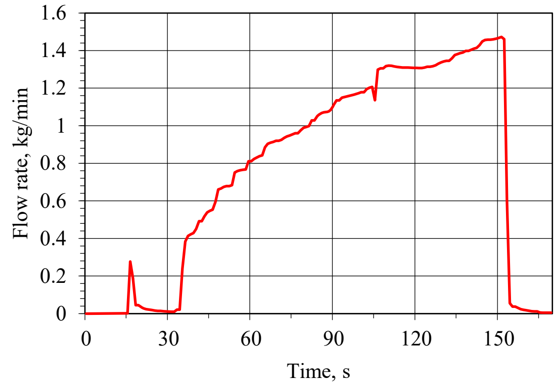

Figure 3: The flow curve of the calibration by master meter method.

Figure 3 is the flow curve of Π sensor in the process of calibration, from which three features can be seen:

1. In contrast to the CNG filling process, the temperature increments and the velocity of hydrogen were limited to ensure the safety of the hydrogen storage tank. Furthermore, due to hydrogen in this test was not pre-cooling before filling, the flow rate increased slowly.

2. During the filling process, the flow increased gradually, but at the end of the filling the flow rate didn’t gradually decrease to 0, but jumped to 0. The main reason is that the filling is stopped manually according to the requirements of some vehicles being filled.

3. There was a pre-charging and pressure maintaining process procedure in the filling process to detect whether there was hydrogen leakage in the pipeline connected to the filled vehicle. The maximum flow rate during pre-charging and pressure maintaining procedure was about 1kg/min, and the duration is about 10s.

Compared to Figure 2, it can be seen that the above three characteristics do not exist in the gravimetric method. In order to clarify how these characteristics affect the calibration results, two tests were carried out.

First, under the condition that the flow in the stage of pre-charging and pressure maintaining is relatively consistent, a group of experiments were completed, which included at least one test in which the flow slowly falls to 0. The test results and the corresponding flow curve are shown in Figure 4. From the repeatability of the test results of this group, it can be seen that the artificial termination of filling is not the main factor affecting the repeatability of calibration.

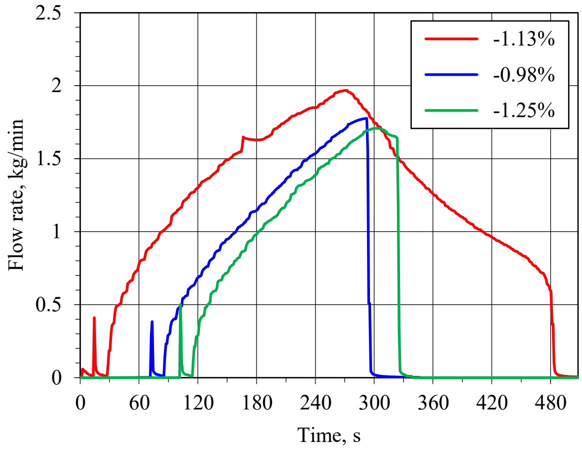

Figure 4: The flow curve and the results of the slow ending test.

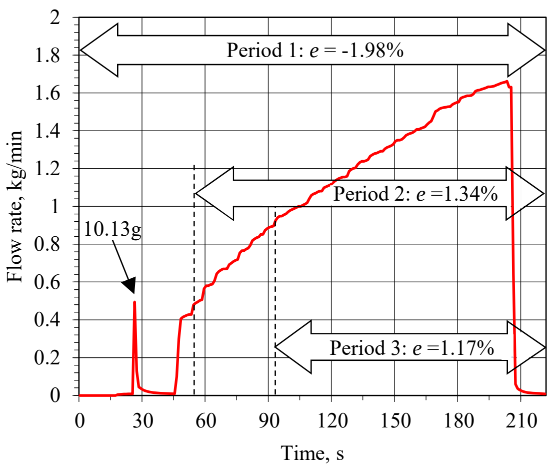

Figure 5: The flow curve and the results of the slow ending test.

Then, while testing with the master meter method, the dynamic flow measurement was carried out by image acquisition, the total mass of filling after the completion of pre-filling and pressure maintaining was recorded, and the flow errors including and excluding the stage of the pre-filling and pressure maintaining are calculated respectively. A set of test results and flow curves are shown in Figure 5.

Period 1 means that the total mass was accumulated from the beginning to the end and the error was -1.98%. Period 2 means that the total mass was accumulated from 55s and the error was 1.34%. Period 3 means that the total mass was accumulated from 92s and the error was 1.17%.

Obviously, when the error calculation does not take into account the mass in stage of the pre-charging and pressure maintaining, the repeatability of the test results is significantly improved, which indicates that the stage of pre-charging and pressure maintaining has a significant impact on the repeatability of the calibration results of the master meter method.

In addition, it was also observed during the experiment that there was occasionally a secondary pressure maintaining test with a lower flow rate during the stage of pre-charging and pressure maintaining. In order to further understand the influence of the mode of the pre-charging and pressure maintaining, the tests of single large and double small pulse flow were carried out respectively, and the test results are shown in Figure 6.

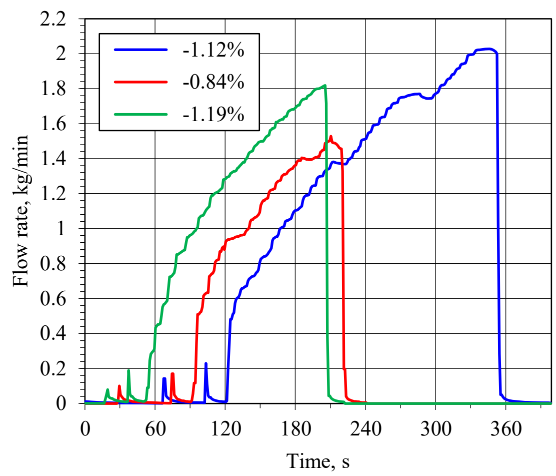

Figure 6: The flow curve and the results of double small pulse test.

According to Figure 6, conclusions can be made as the following:

1. The greater the flow rate in the stage of pre-charging and pressure maintaining, the greater the negative error;

2. The repeatability of the calibration results is in direct proportion to the repeatability of the flow rate in the stage of pre-charging and pressure maintaining;

3. The mode of secondary pressure maintaining with small flow rate has little influence on the calibration results;

4. Analysis

First of all, from the above experiments, we can see that although the flow rate in the stage of pre-charging and pressure maintaining is greater than the cut-off value of the flowmeter, it is still in the low-flow section of the Coriolis mass flowmeter, so its measurement error may increase.

Secondly, the flow characteristics in the stage of pre-charging and maintaining pressure is a pulse mode. According to the structure of Coriolis mass flowmeter, different shape and working frequencies of sensor respond differently to the sudden flow, resulting in different errors.

Thirdly, the cut-off values of different Coriolis mass flow meters are different. For example, the cut-off values of Π shaped and Ω shaped sensor are 0.01kg/min and 0.04kg/min respectively. Therefore, the error may be caused by the difference of cut-out value in the stage of pre-charging and pressure maintaining.

Fourthly, in the previous experiments on compressed natural gas (CNG), we found that there was a temperature gradient in the upstream and downstream of the sensor caused by "Thomson Joule effect", and then the phenomenon of zero drift occurred. Compared to CNG, compressed hydrogen has the characteristics of small nominal diameter, high gas flow rate, complex filling temperature change and "inverse Thomson Joule effect". Therefore, the zero point of Coriolis mass flowmeter may have more serious drift under single pulse flow, resulting in measurement error.

5. Conclusion and suggestions

Based on the above experiments and analysis, this paper proposes an improved master meter method for the calibration of the compressed hydrogen dispenser. In order to reduce the errors caused by different types of flowmeters during pre-charging and pressure maintaining, improve the repeatability of calibration results and achieve more accurate evaluation of the measurement performance, the start of accumulating mass should set after the stage of pre-charging and pressure maintaining.

In practice, it is recommended to use image acquisition to read the total mass of the master meter and the compressed hydrogen dispenser being calibrated, so that the improved master meter method can be directly applied without reforming the existing compressed hydrogen dispenser. The response and behaviour of different Coriolis mass flowmeters to single pulse flow with compressed hydrogen will be further studied in the future.