Proton exchange membrane fuel cell multi-stack parallel gas supply and load-up experiment

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Abstract: Given the current situation that there is no parallel experiment of multiple stacks in China, this paper uses a fuel cell test platform independently designed and produced by a company to study the performance of three fuel cells. This article describes the construction of the experimental test platform and the multi-stack load-up experiment. The experimental results show that the power generation of the three fuel cells is almost the same, which are 9475W, 9385W, and 9512W. When carrying out multi-stack load-up experiments, it was found that as the number of stacks increased, the voltage efficiency continued to decrease. The Analysis revealed that the parallel gas supply method caused uneven gas distribution, which caused some fuel cells to be in a state of hydrogen deficiency. This article proposes amendments to this problem.

1. Introduction

Proton exchange membrane fuel cell has the advantages of high energy conversion efficiency, high power density, good cold-start performance, fast start-up, and zero pollution\cite{1-4}. It is valued by various countries and is considered the most promising future high-efficiency energy conversion\cite{5}. And it has a long service life, so it is very useful in propulsion systems\cite{6}. The test platform can test the performance and life of the stack under different simulated conditions, and obtain accurate experimental data. The data is important to study fuel cell stack and system operating mechanism, battery destruction mechanism, improvement of core components, and optimization of fuel cell performance\cite{7}. The PowerStation-Compuce20 commercial test platform of TesSolInc, Germany, can accurately control fluid flow, pressure, temperature, and relative humidity\cite{8}. At present, there is almost no domestic gas supply test of multiple stacks in parallel. Therefore, this research designed and built a proton exchange membrane fuel cell test platform, and carried out an up-load experiment on three proton exchange membrane fuel cells with a rated power of 10KW. And the power generation performance of single, double, and three fuel cells is obtained, which can provide some data reference for fuel cell researchers.

2. The overall design of the test system

2.1. Proton exchange membrane fuel cell

This experiment uses a fuel cell product of a company. The rated power of the stack is 10KW, and the voltage value of the stack is not allowed to exceed 75V. It has 75 cells, and the effective area of each cell is 225cm². The working voltage of each cell should be maintained at 0.5-1.0V, and the minimum should not be less than 0.3V. The current setting value should be 0-230A. The heat generation should be
4-16KW, the water generation speed should be 1.2-5.8L/h, and the highest exhaust temperature should be 70°C.

2.2. Fuel cell test platform
The current commercial fuel cell stack test platform is difficult to meet the requirements of R&D and testing. For example, the air and hydrogen supply system cannot realize the functions of active regulation of the humidity and voltage of the fuel cell stack for vehicles\textsuperscript{[9]}. The test platform used in this experiment can achieve these functions. The humidity of the gas entering the stack can be adjusted by changing the temperature of the gas heater at the front and back of the humidifier of the test platform. Besides, after connecting the electronic load, the test platform has a variety of experimental modes: constant voltage output, constant current output, constant power output, voltage/current scanning, and open-circuit voltage measurement. Also, it has the function of quickly switching the dew point. The following figure shows the anode end control flow chart of the test platform:

![Flow chart of anode end control of test platform](image)

Fig 1. Flow chart of anode end control of test platform

3. Load-up experiment

3.1. Single stack Load-up experiment
The Load-up experiment is carried out on a single stack, the open-circuit voltage of the stack is 70.66V, and the experimental mode is set to the set current output mode. Starting from 0, continuously increase the output current value of the stack, with an interval of 5A each time. The stoichiometric ratio of anode gas flow rate in the single-stack experiment is 1.4, and the cathode gas flow stoichiometric ratio is 2.0. The cathode flow and anode flow is automatically supplied according to the stoichiometric ratio. The experimental data of three type stack is shown in Figure 2, Figure 3, Figure 4:

![Load-up experiment of type I](image)

Fig 2. Load-up experiment of type I

![Load-up experiment of type II](image)

Fig 3. Load-up experiment of type II
The experimental data of type I is shown in Table 1. The measured maximum output power of the stack is 9475W. At this time, the fuel cell output current is 220A, the cell voltage is 0.57V, which is higher than the safety standard of 0.3V, the anode gas flow rate is 145L/min, and the cathode gas flow rate is 841L/min.

When the output power of the stack is 7189W, the voltage across the stack is 51.32V, the output current of the stack is 140A, the flow rate of hydrogen is 110L/min, and the temperature is room temperature. The voltage efficiency of the fuel cell can be calculated by Formula (1):

$$\varepsilon_{\text{voltage}} = \frac{V}{E}$$  \hspace{1cm} (Formula 1)

Among them, V is the actual working voltage of the fuel cell, in V, and E is the thermodynamically reversible voltage of the fuel cell, in V. Therefore, the voltage efficiency of type I fuel cell can be calculated by Formula (1):

$$\varepsilon_{\text{voltage}} = \frac{51.32}{1.23 \times 75} = 55.63\%$$

The experimental data of type II shows that the maximum output power of the fuel cell measured for type II is 9385W, the output current set at this time is 220A, the measured cell voltage is 0.57V, the anode gas flow rate is 140L/min, and the anode gas flow rate is 826L/min.

The experimental data of type III shows that the highest output power of the fuel cell type III measured is 9512W, the output current set at this time is 220A, the measured cell voltage is 0.58V, the anode gas flow rate is 142L/min, and the anode gas flow rate is 834L/min.

Table 1. Experimental data of type I, type II, and type III fuel cell

| parameter | I Type | II Type | III Type |
|-----------|--------|---------|---------|
| H₂ Flow/L·min⁻¹ | AIR Flow/L·min⁻¹ | P/W | H₂ Flow/L·min⁻¹ | AIR Flow/L·min⁻¹ | P/W | H₂ Flow/L·min⁻¹ | AIR Flow/L·min⁻¹ | P/W |
| 50 | 31 | 187 | 2597 | 28 | 168 | 2544 | 30 | 171 | 2617 |
| 100 | 63 | 375 | 4974 | 57 | 356 | 4840 | 61 | 372 | 4990 |
| 150 | 95 | 563 | 7245 | 91 | 544 | 7189 | 92 | 560 | 7295 |
| 200 | 126 | 750 | 8872 | 123 | 732 | 8752 | 124 | 747 | 8963 |

The analysis shows that the cathode and anode gas flows into the three fuel cells are almost the same, and their power generation performance when the output current is 220A is almost the same, all around 9450W.

3.2. Type I and II double-stack series load-up experiment

Connecting two stacks in series and supplying gas in parallel, the cathode and anode gas flow rate is increased to twice that in the single stack experiment, the anode gas flow stoichiometric ratio is 1.4, and
the cathode gas stoichiometric ratio is 2.0. The experimental model is a constant current output mode. When the output current of the stack is changed, the increase is 10A each time. Since the amount of hydrogen obtained by the stack when gas is supplied in parallel may not be uniform, to protect the stack, the load does not rise very high. The measured experimental results are shown in the Figure 5:

![Figure 5. Type I and II double stack series load-up experiment](image)

The data measured in the test are shown in Table 2:

| Parameter | Current (A) | H₂ Flow/L·min⁻¹ | AIR Flow/L·min⁻¹ | P/W |
|-----------|------------|------------------|------------------|-----|
|           | 50         | 200              | 598              | 5702|
|           | 70         | 200              | 598              | 7675|
|           | 100        | 200              | 598              | 10496|
|           | 130        | 204              | 654              | 12983|
|           | 150        | 235              | 752              | 14383|

The maximum output current set in the experiment is 150A. The maximum stack output power measured in this experiment is 14383W. At this time, the cell electricity is both 0.64V, and the output power is twice that of a single stack. The power is 7065W. The measured power generation of the type II stack is 7318W. The output power of the two stacks is somewhat different. According to the display of the flow meter, the amount of hydrogen passing through the type I stack is 87L/min, which is less than the amount of hydrogen supplied during single-stack measurement. And the amount of hydrogen passing through the type II stack is 148L/min, which is more than the amount of hydrogen supplied during single-stack measurement. The amount. The voltage efficiency at this time can be based on Formula (1). Calculate:

\[ \epsilon_{\text{voltage}} = \frac{V}{E} = \frac{95.89}{1.23 \times 75 \times 2} = 51.97\% \]

3.3. Load-up experiment of type I type II type III three-cell stack
Connect three stacks in series and supply gas in parallel. Set the output voltage and current of the stack to three times that of the single stack. The other given conditions are the same as when the single stack is loaded. The measured experimental results are shown in Figure 6:

![Figure 6](image)
Fig 6. Three-cell stack Load-up experiment

When changing the output current of the stack, each increase of 10A, the anode gas stoichiometric ratio is set to 1.4, and the cathode gas stoichiometric ratio is set to 2.0. The test data is shown in Table 3:

| Current (A) | H₂ Flow/L·min⁻¹ | AIR Flow/L·min⁻¹ | P/W |
|------------|-----------------|------------------|-----|
| 50         | 129             | 396              | 8431 |
| 70         | 166             | 525              | 11411 |
| 100        | 231             | 715              | 15560 |
| 130        | 310             | 978              | 19405 |
| 150        | 349             | 1097             | 21191 |

It can be known that the highest output power of the stack measured in the experiment is 21191W, the cell voltage is about 0.64V. The power generation power of the type I stack is 6947W, the power generation power of the type II stack is 7306W, and the power generation power of the type III stack is 6938W. It can be seen that the power generation performance of the type II stack is better than that of the type I and type III stacks at this time. Compared with the single-stack measurement, the power generation performance of the type I and type III stacks is slightly worse, and the type II stack is relatively better. According to the display of the flowmeter, the amount of hydrogen passing through the type I stack is 89L/min, which is less than the amount of hydrogen supplied during single-stack measurement. The amount of hydrogen passing through the type II stack is 176L/min, which is more than the amount supplied during single-stack measurement. The amount of hydrogen passing through the Type III stack is 84L/min, which is less than the amount of hydrogen supplied during single-stack measurement. The voltage efficiency at this time can be calculated according to Formula (1):

\[
\varepsilon_{\text{voltage}} = \frac{V}{E} = \frac{141.27}{1.23 \times 75 \times 3} = 51.05\%
\]

4. Conclusion

From the data, it can be concluded that the voltage efficiency of the stack decreases when the number of stacks increases. But the power generation performance of the three stacks is almost the same when tested separately. The reason is that the parallel gas supply is used when the stacks are connected in series. And there is only one hydrogen port for parallel gas supply. After the pipe is split, the amount of hydrogen obtained by the three fuel cells is different. Therefore, when multiple stacks are connected in series, the stacks far away from the hydrogen port can obtain less hydrogen and have poor power generation performance.

To make the amount of hydrogen obtained by the three stacks uniform, we can appropriately increase the diameter of the pipeline to the stack that is far from the hydrogen port. And we can also reduce the diameter of the pipeline to the stack near the hydrogen port to make the hydrogen better-distributed. Alternatively, three electronic flow control valves can be set on the three channels, and the valve
opening can be adjusted by the program to divide the hydrogen evenly. This method is more accurate and convenient.

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