Study on hot and cold starting characteristics of fuel cell system

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Abstract. In this paper, the starting characteristics of fuel cell system are studied firstly. The hot and cold starting characteristics of fuel cell system are measured by the starting time of fuel cell system, the energy consumption during the starting process and the hydrogen consumption during the starting process. Secondly, the cold and hot starting test of the fuel cell system is designed, and the experimental process is designed by using the orthogonal experimental method. 30kW, 60kW and 90kW fuel cell engines are selected for the test and the experimental data are recorded. Finally, the data obtained from the test are compared and analyzed comprehensively to show the relationship among the time, energy consumption and hydrogen consumption required to start the fuel cell engine at the same power and different temperature.

1 Start-up characteristic analysis of fuel cell system

1.1. Operating characteristics of fuel cell system

The operating characteristics of fuel cell system include starting characteristics, steady-state operating characteristics, dynamic response characteristics, air tightness and insulation, etc. This paper focuses on the starting characteristics of fuel cell system.

1.2. Starting operating characteristics of fuel cell system

The starting of fuel cell system is divided into cold starting and hot starting. At present, cold starting is one of the most difficult technologies in China and even the world. In the national standard, a cold start is defined as starting a fuel cell engine from a cold start (the internal temperature of the engine corresponding to the cold start time is usually defined as the time the fuel cell engine runs from standby to idle)[1]. In order to evaluate the cold start performance of fuel cell engines, test manufacturers may need to test the starting characteristics of their products at low temperatures. When the fuel cell engine is below -10 °C, the starting time increases significantly with the decrease in temperature.

Different from traditional internal combustion engines, the effect of low temperature on the starting of fuel cell engines is more obvious than that of traditional internal combustion engines. Since proton exchange membrane fuel cells (PEMFC) are used in fuel cell engines at present, the starting characteristics of PEMFC are mainly studied in this thesis.

Fuel cell system at low temperature (below 0 °C) is difficult to start, and can't even start. The reason is that in low temperature, fuel cells have internal moisture, and starting current and voltage of battery has certain requirements. As for how to improve the fuel cell cold starting speed, and reduce the energy consumption in the process of starting, manufacturing enterprises are facing a big problem. There must be a certain amount of water in the membrane, otherwise the electrochemical reaction will be affected; The water content in the membrane or the fuel cell should not be too high, otherwise excessive water will freeze before cold starting at low temperature, affecting the performance of the battery, leading to cold starting difficulties.

Cold start means that the fuel cell starts the fuel cell engine from the normal operating temperature range (as specified by the manufacturer) according to the manufacturer's operating procedures. Hot start refers to starting the fuel cell engine from the normal operating temperature range (the normal operating temperature is specified by the manufacturer) according to the operating procedures specified by the manufacturer. The purpose of studying the hot start of fuel cell is to provide certain technical support for the cold start process.

1.3. Analysis of cold starting process of fuel cell system

The factors affecting cold starting performance include starting temperature, working current and undercooling.

1.3.1. Starting temperature

The freezing of water below normal temperature is the main reason for the failure of cold start-up of PEMFC. PEMFC can be divided into three forms of freezing:

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cathode, gas diffusion layer and flow channel. When the cathode temperature of PEMFC is lower than zero degrees Celsius, water will freeze in the cathode pores. When the temperature of the cathode is higher than zero degrees Celsius, and the temperature of the gas diffusion layer is lower than zero degrees Celsius, the water in the cathode will exist in the form of liquid and flow to the gas diffusion layer to freeze. When the temperature of the cathode and the gas diffusion layer is above zero degrees Celsius, the internal temperature of the runner is below zero degrees Celsius.

1.3.2. Working current

The current density is also one of the factors affecting the cold starting of the fuel cell. Reducing the current density can effectively alleviate the formation of water and make the water evenly distributed in the gap of the cathode hole, so as to ensure the full use of the cathode water storage hole. At high current density, the distribution of reaction current is not uniform, and the magnitude of current depends on the proton conduction capacity of ionization meter and oxygen transport in the cathode pore. As the reaction continues, large amounts of water will be produced, which will lead to an increase in proton conductivity of the ionization meter on the side of the PEMFC[2], while the formation of ice will lead to a decrease in oxygen transport on the side of the diffusion layer. In order to obtain enough oxygen to generate a high current, the peak area of the reaction current will be located near the critical surface between the cathode and the gas diffusion layer. In addition to water, more ice will be formed in this area. The gradual absorption of PEMFC near the critical surface between PEMFC and cathode slows down the formation of ice in this area, which leads to the increase of water concentration at the interface between cathode and gas diffusion layer, forming ice cap, impeding the transfer of oxygen, and prematurely closing the water storage hole which makes full use of cathode.

1.3.3. Supercooling phenomenon

The influence of water below normal temperature on cold start performance is mainly shown in: if you repeat the last cold start test, the duration of each time before starting will have significant change, which is because the liquid under certain conditions from the cathode and the gas diffusion layers, formation water, through a combination of cooling water distribution depends on many factors[3]. If a crystal nucleus is not formed, the supercooled water will remain liquid. If the fiber is damaged, cracked, ice caps or vibrated, crystal ice will immediately form in the flow channel, blocking the area in which it is located and causing the fuel cell system to stop working suddenly.

1.4. Evaluation of fuel cell system starting characteristics

There are three performance evaluation indexes to evaluate the hot and cold starting characteristics of fuel cell system. The first is the fuel cell system starting time T, that is, the time required by the vehicle from the cold start to the normal idle condition; The second is the energy consumption of the fuel cell system E, namely the electricity consumed from starting to idling; The third is hydrogen consumption H, that is, the amount of hydrogen consumed from starting to idling [4].

2 Experimental design of hot and cold starting characteristics of fuel cell system

Samples of fuel cell engine with different power were selected, and the fuel cell engine sample with power value of 30kW was numbered ①, the fuel cell engine sample with power value of 60kW was numbered ②, and the fuel cell engine sample with power value of 90kW was numbered ③. The above experiments were carried out on the three samples of ①②③ at six temperatures of -30°C, -20°C, -10°C, 0°C, 10°C, and 20°C in the container laboratory ambient temperature comprehensive test system. The cold and hot starting experiment process will follow the test preparation → pre-inspection → performance test → finishing work.

2.1 Preparation for cold and hot starting experiment

Received first experimental samples and sample test, and the test samples appearance inspection, check if there is any breakage, leakage, and so on and so forth, to measure the size of the sample at the same time, so that the follow-up can choose the appropriate test equipment, the final inspection on the identity of the test sample, finish the inspection of the test before, and confirm whether there is any missing problem again.

Formulate a plan, according to the sample test requirements, equip corresponding test equipment and develop a test plan at the same time, so that the experimental needs can be completed completely in the case of diversity of samples. Figure 1 shows the equipment required for the test.

Fig. 1 Experimental test equipmentContinue

Fig. 2 Fuel cell pressure retaining system

According to the developed implementation plan, install the experimental samples to meet the test requirements. Connect the sample with signal line and power line through data line to ensure the normal connection between power and communication line. After the completion of the connection, debug the CAN communication protocol to match the protocol requirements required by the test equipment and ensure the connectivity of the subsequent tests.

Precheck the sample, including air tightness test, insulation test, and performance test.

The gas tightness test of fuel cell system includes fuel chamber gas tightness test, fuel chamber and oxidation chamber gas tightness test, hydrogen leakage test. During the fuel chamber air tightness test, one outlet of the fuel chamber is blocked, while the other outlet is connected with a pressure retaining device, and the nitrogen pressure is adjusted to 0.5bar, the pressure drop value in the fuel chamber is recorded within 20min, and the leakage amount of the fuel chamber is obtained through the analysis of the pressure drop value data. The equipment required for the fuel chamber air tightness test is shown in Figure 2.

Cavity in fuel and oxygen chamber air tightness test at the same time, oxidation and fuel cavity each block an export, remain an exit together, and then turn on the fuel cell system, adjust the nitrogen pressure to 0.5 bar, record within 20 min in oxygen and fuel chamber cavity pressure drop of common values, through data analysis, it is concluded that the pressure drop values oxidation and fuel cavity in a leakage, Fuel cell pressure retaining system is required.In the hydrogen leakage test, hydrogen with a certain working pressure is passed into the fuel chamber and oxidation chamber of the fuel cell to detect whether there is an obvious leakage point, and the maximum leakage value is recorded. The point with the maximum leakage value is used to find out the obvious leakage point and record it.

During the insulation pre-inspection, the insulation performance of the fuel cell is further detected by detecting the positive and negative output of the fuel cell system and the insulation value of the shell.

Make the insulation values of the positive and negative output ends of the fuel cell and the housing meet the general electric technical conditions (meet the requirements of more than or equal to 100 ohms/v. The electrical safety of fuel cell system test can be judged by this test method.

Pre-check the performance of fuel cell system samples, and the working steps are divided into four steps:

The first step is to supply hydrogen to the fuel cell system and adjust to the appropriate working pressure. Hydrogen supply is one of the conditions for the normal operation of the fuel cell system.

The second step is to supply power to the high pressure auxiliary system on the fuel cell system, so that the fuel cell system can meet the power supply demand required during operation.

The third step is to manually debug the fuel cell system to confirm the normal operation of each loop and ensure the safe operation of the fuel cell system. During this period, you will need to use the Digatron power test system, the linear DC voltage and current stabilized power supply, the fuel cell engine test control platform, the thyristor rectifier, the hydrogen mass flow meter, the digital temperature and humidity meter, and the portable gas detector. This is shown in Figure 3.

Fig. 3 Fuel cell engine test platform

Fig. 4 Pressure gauge and gas flow calibrator

The fourth step is the automatic test of the fuel cell system, the automatic operation test, to confirm that the communication protocol is correct, the automatic operation procedure of the fuel cell system sample is normal, to ensure the normal operation of the communication and automatic control procedure. During this period, you will also need to use the Digatron power test system, the linear DC voltage stabilized power supply, the fuel cell engine test control platform, the thyristor rectifier, the hydrogen mass flow meter, the digital temperature and humidity meter, and the portable gas detector.

2.2 Cold and hot starting orthogonal experiment process

First of all, routine test is carried out. The routine test process is divided into four steps: air tightness test, starting test, power generation performance test and shutdown test.

The first step is air tightness test, the outlet of hydrogen chamber, oxidation chamber and coolant chamber is blocked, and only one inlet of hydrogen chamber is left. The pressure gauge and flow meter are connected, the pressure is adjusted to the maximum working pressure, and 60s is maintained to detect the hydrogen leakage. The experimental equipment is shown in Figure 4.

The second step, starting test, in the condition of fuel cell system cold machine, the fuel cell system cold start and idle running 10 min, continue to run to the rated power for 10 min, continue to overload the power run 3 min, record the response time of the idle, idle time to rated power, rated power to overload power of time, through the records of these numerical parameters identified.

The third step is power generation performance test. In the cold machine state, the fuel cell system starts from cold to idle for 10min, continues to run at rated power for 10min, and continues to run at overload power for 3min. The system operating parameters in the idle power, rated power and overload power running periods of the fuel cell engine are recorded. Confirmation of the test parameters is carried out through the recorded experimental data of the power generation performance test.

The fourth step, shutdown test, the fuel cell system from the rated power output state to the idle state to the shutdown of the end of the time required, record the system operating parameters, through the test recorded data to confirm the parameters.

Secondly, low temperature storage test and room temperature storage test were carried out in five steps respectively. According to the manufacturer's shutdown procedure, shutdown, low temperature storage for 12h, restore 23℃±2℃ insulation for 12h, repeat the second and third step twice each, and test the air tightness, starting performance, power generation performance and shutdown performance at 23℃±2℃.

The first step is to shut down the fuel cell engine in accordance with the manufacturer's shutdown procedures. The running state of the fuel cell engine is crucial to the time required for the engine to complete, energy consumption and the amount of matter consumed.

The second step, low temperature storage for 12h, insulation: 0℃ ~ -40℃ low temperature environment, low temperature storage test, the specific ambient temperature in accordance with the test requirements; Storage 12h at room temperature, insulation: 0℃ ~ 30℃ at room temperature, room temperature storage test, the specific ambient temperature according to the test requirements. The equipment required to complete this test is the container laboratory normal temperature comprehensive test system, as shown in Fig. 5.

Fig. 5 Temperature and humidity display panel of the normal temperature comprehensive test system in container laboratory

The third step, restore 23℃±2℃ heat preservation for 12h, stored in the room for heat preservation for 12h.

The fourth step. repeat Step 2 and Step 3 twice each.

The fifth step, air tightness, starting performance, power generation performance, shutdown performance test at 23℃±2℃, in order to verify the low temperature storage performance.

3 Data analysis of the fuel cell system's cold and hot starting characteristics

3.1 Hot and cold start data sheet

See Table 1 for the cold and hot start test data table.

Table 1 Cold and hot start test data

Sample	T/°C	Starting time t/min	Energy consumption E/kWh	Hydrogen consumption H/g
① (30KW)	-30	8-16	2.47	28.5
	-20	5-7	1.97	21.5
	-10	3-4	1.47	13.1
	0	2	0.02	7.8
	10	0.7-1	0.015	6.4
	20	0.5	0.01	5.6
② (60KW)	-30	8-16	5.45	29.5
	-20	5-7	4.37	25.5
	-10	3-4	3.87	22.1
	0	2	0.035	12.8
	10	0.7-1	0.03	11.4
	20	0.5	0.02	10.6
③ (90KW)	-30	8-16	10	31
	-20	5-7	8	27
	-10	3-4	7	25
	0	2	2.1	22.5
	10	0.7-1	2	18
	20	0.5	2	17.5

The selection of fuel cell launching and its auxiliary systems is different. The start-up time, energy consumption and hydrogen consumption are all determined by their performance, and the general trend of change is similar.

3.2 Analysis of cold and hot start data

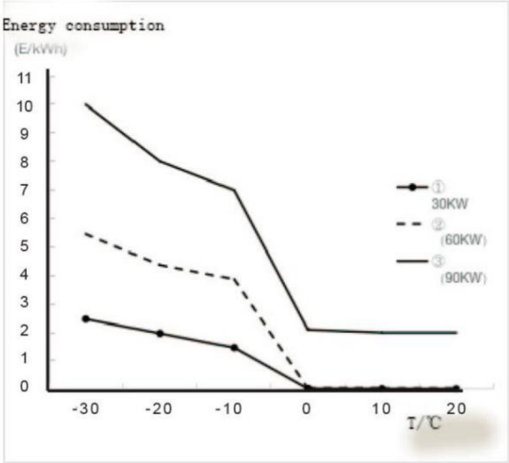

Figure 6 Temperature-energy consumption relationship diagram

According to the comparative analysis of the test data, as shown in Figure 16, overall, with the increase of the starting temperature, the energy consumption of the fuel cell engine becomes lower; relative to the power of the fuel cell engine, the higher the power of the engine is at the lower temperature The engine consumes less energy when starting than the power and consumes more energy when starting at a low temperature.

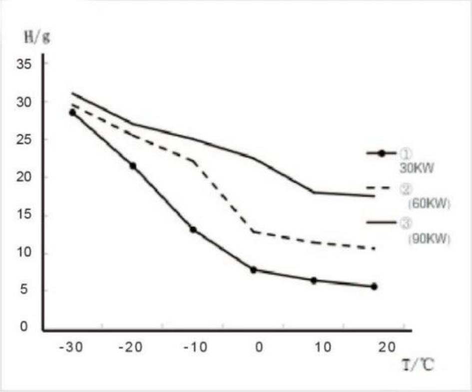

Figure7 Temperature-hydrogen consumption relationship diagram

According to the comparative analysis of test data, as shown in Figure 7, in general, as the temperature of the fuel cell system starts to increase, the consumption of hydrogen gradually decreases. Compared with the power of the fuel cell engine, the fuel cell engine with high power is The hydrogen consumption is lower than the power when starting at low temperature. The fuel cell engine consumes more hydrogen when starting at low temperature.

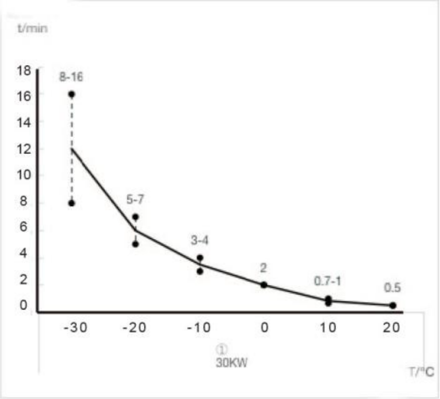

Figure 8 30KW start time line chart

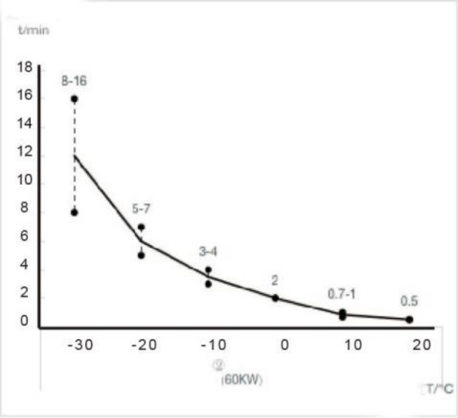

Figure 9 Line chart of 60KW starting time

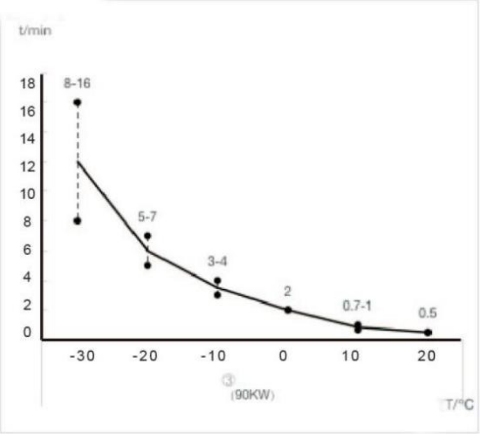

Figure10 90KW start time line chart

According to the graphs shown in Figures 8, 9, and 10 above, fuel cell engines of different power sizes are within a fixed range when the temperature increases, and this range is gradually approaching a fixed range. value.

3.3 Conclusion of cold and hot start analysis

According to the analysis of the test results, the start-up time of the fuel cell system decreases with the increase in temperature, showing an inverse relationship. It can be seen intuitively from the line graph that temperature is a crucial factor affecting the start-up time of the fuel cell system. When the temperature of the same sample increases, its energy consumption and hydrogen consumption are gradually decreasing. When the temperature of different samples increases, its energy consumption and hydrogen consumption are gradually decreasing.

4 Conclusion

Based on the test results obtained from the test design, it can be concluded that the start-up time of the fuel cell system decreases with the increase in temperature, showing an inverse relationship. From the data analysis in the article, it can be seen intuitively that temperature is a crucial factor that affects the start-up time of the fuel cell system. Since only the influence of the starting temperature on the starting time of the fuel cell engine is considered during the experiment, the influence of factors such as intake air temperature and intake air volume on the starting time of the fuel cell engine will also be considered in the subsequent research process.

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