A review of current, temperature and water distribution diagnosis technique for PEMFC

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Abstract. Diagnosis technology is a key means for understanding the electrochemical reaction process of fuel cell. With the increasing demand for high-power stacks in the market, Membrane Electrode Assemblies (MEA) with large active area have been a hot topic. Obtaining the current, temperature, and water distribution information over the entire active area is critical to structural design and performance control of fuel cell. This paper reviews the diagnosis technique that can be used for in-suit measurement of current, temperature, and water distribution. The applicability of various techniques and specific applications in fuel cell diagnosis are summarized, and future developing trend is prospected.

1. Introduction

Fuel cell is a device that directly converts chemical energy into electrical energy, which involves material science, electrochemistry, interface science, catalytic science and so on. Due to the complexity of the reaction, it’s a great challenge to fully understand the internal mechanism. Diagnostic technology is helpful for understanding the electrochemical process, but single electrochemical testing technology cannot meet the needs of fuel cell diagnosis.

With the continuous applications of fuel cells, the market has put forward new demands for high-power stacks, and the active area of MEA continues to increase. As for large-area fuel cells, local performance and uniformity are critical to the overall performance and durability. Obtaining local characteristics within the entire active area is beneficial to optimize the performance. In this paper, the relevant techniques for fuel cell current, temperature, and water distribution diagnosis are reviewed.

2. Current Distribution Diagnosis Technology

Due to inhomogeneous reactant concentration, hydrothermal management and contact pressure, an uneven current distribution may generate in fuel cell. However, stack monitoring usually measures total current, and the current distribution is not clear. It is necessary to measure the local current density and draw a current distribution map covering the entire MEA in real time.

J. Stumper et al. [1] firstly proposed three kinds of methods for detecting the current distribution (partial MEA, subcells and current mapping method). Partial MEA method needs to set several local MEAs, and each piece corresponds to a different part of active area. This method is simple to operate,
but the spatial resolution is not high enough. In the subcells method, multiple subcells are set at different locations in MEA. Each one is isolated from the main cell and other subcells. This method is helpful for understanding the current distribution along the flow field, but the manufacturing process of MEA and flow field plate is complicated. In the current mapping method, a passive resistance network made of resin-insulated graphite blocks is placed between the bipolar plate and diffusion layer. This method improves the spatial resolution. Since then, other detection technology, printed circuit board (PCB) method, passive resistance network method, and sensor method were developed for measuring current distribution.

2.1. Printed Circuit Board Method
Based on PCB technology, S.J.C. Cleghorn et al. [2] developed a new method to measure the current distribution. A PEMFC with an active area of 100 cm² was tested, in which the current collector and flow field were segmented. The effects of reaction gas stoichiometric ratio, flow rate, and humidity on the current distribution were studied. Although the cell was segmented into only 18 segments (as shown in Fig. 1), PCB method allows fabrication of larger number of segments for high-accuracy testing. D.J.L. Brett et al. [3] improved the PCB method. There is no need to segment the MEA and separate loads were used to control each part and monitor the current. The effects of cell polarisations and reactant flow rates on current distribution and dynamic response were studied [2].

2.2. Passive Resistance Network Method
P.C. Ghosh [4] developed a simple and cost-effective method for current distribution testing. A segmented plate made of expanded graphite was used as a passive resistor network (as shown in Fig. 2), which was easily integrated into a single cell or stack and there was no need to modify the bipolar plate or MEA. The experimental set-up had been used to investigate the current distribution of a 240 cm² single cell [4].
2.3. Sensor Method

Based on the dependence of the permeability of soft magnetic materials on magnetization and temperature, J. Lobato et al. [5] developed a new method for current distribution measuring. Fig. 3 presented the image of the sensor plate and its location inside a fuel cell. The 49 cm² sensor plate was formed by an array of 100 sensors for detecting local current density [5].

![Figure 3. Diagram of the sensor plate, and its location in a single fuel cell](image)

3. Temperature Distribution Diagnosis Technology

Temperature plays an important role in ensuring high-performance of fuel cells. High temperature may cause membrane dehydration and decrease the proton conductivity, leading to poor stack performance. The catalyst can’t perform best activity at low temperature and uneven current will generate in the cell. Therefore, it is very critical to obtain the temperature distribution under operation, which can be used to optimize the cell design. Lots of work has been carried out on temperature distribution diagnosis, which can be roughly divided into three categories: 1) thermocouple method; 2) infrared thermal imaging method; 3) sensor method.

3.1. Thermocouple Method

As for thermocouple method, micro-thermocouples are inserted into different positions of the fuel cell, and the temperature distribution mapping can be obtained by collecting the relevant data at each position. Since thermocouples are easy to get and have little effect on the overall performance of the fuel cell, they can be widely used for fuel cell temperature detection. H.C. Pei et al. [6] studied the in-suit temperature distribution of a stack by inserting 40 thermocouples between the gas diffusion layer surface and the coolant water inlet and outlet (as presented in Fig. 4). Moreover, effects of current density, air flow rate, air inlet temperature and coolant water flow rate on the temperature distribution were discussed [6].

![Figure 4. Schematic positions of the thermocouples in the stack](image)

3.2. Infrared Thermal Imaging Method

Infrared thermography [7] could capture the thermal radiation of an object to form a temperature image in real time, which is suitable for measuring the temperature distribution of fuel cell. However, the cell configurations must be modified in order to allow infrared light to be transmitted into the cell. M.H. Wang et al. [8] measured the temperature distribution of MEA through infrared thermal imaging technology. The structure of the fuel cell was shown in Fig. 5. Variations of temperature distribution...
with current and time were explored. Through this, hot spots on the surface of MEA are easy to locate, which is helpful for thermal management and cell design [8].

![Figure 5. Structure of the experimental PEMFC](image)

3.3. Sensor Method
H. Shao et al. [9] developed an in-situ measurement method by using micro-sensors to observe the temperature and relative humidity distribution of a fuel cell with an active area of 250 cm$^2$. As shown in Fig. 6, the sensor array was integrated into the cathode flow field. The performance and electrochemical impedance spectoscopy of the fuel cell under anode gas humidification were studied [9].

![Figure 6. Schematic diagram of flow field plate (a) and sensor installation (b, c)](image)

4. Water Distribution Diagnosis Technology
While a fuel cell is in operation, a certain degree of hydration is required to ensure the ion conductivity of membrane, but excessive liquid water will cause flooding problem. Exploring the water transfer mechanism and balancing approach have been the focus of many researchers. At present, diagnosis technology for water distribution mainly includes nuclear magnetic resonance (NMR), neutron imaging, X-ray and transparent cell.

4.1. Nuclear Magnetic Resonance Method
S. Tsushima et al. [10] studied the behavior of water in PEMFC through NMR technology. In order to discuss the mobility of water in the membrane with different water contents, the self-diffusion coefficient of proton was measured. By detecting the time-series images of water in the membrane (as shown in Fig. 7), the relationship between water content in the membrane and the output current was discussed. This study confirmed the feasibility of NMR technology for water behavior analysis, but the resolution was relatively low [10].
4.2. Nuclear Magnetic Resonance Method
M.A. Hickner et al. [11] used neutron imaging technology to observe the in-situ water distribution of fuel cells. The liquid water distribution was quantified as a function of cell temperature, current density and gas feed flow rate. The detailed information of the water content in the cross section of MEA and gas flow channel was obtained, as shown in Fig. 8 [11].

![Figure 7. NMR images of water in membrane after the fuel cell starts to work: (a) 0s, (b) 33s, (c) 67s, (d) 119s, (e) 204s](image)

4.3. X-ray Method
Based on ultra-high-energy X-ray diffraction method, V.R. Albertini et al. [12] successfully obtained high-resolution measurement of hydration distribution in a running fuel cell. This method can ideally "slice" the membrane, and thus the correlation between the degree of hydration and time in each layer could be measured with high accuracy under different conditions, as shown in Fig. 9 [12].

![Figure 8. Water distribution image. Red and green show high water content; blue and black show low water content.](image)

4.4. Transparent Cell Method
D. Lee et al. [13] studied the water distribution in a small stack formed by three transparent cells connected in series. Fig. 10 showed the experimental setup. Fuel was supplied to each cell through a manifold to observe the water flow behavior in the stack. Water slugs and droplets were observed at
both anode and cathode. Water condensed near the corners of cathode channel, but water slugs and droplets formed in the entire area of anode [13].

Figure 10. Photo of the experimental setup for water visualizing

5. Conclusion
Great progress has been made in real-time diagnosis of current, temperature and water distribution for fuel cell, but there are still certain limitations. Future research will focus on the following aspects:

1) Intrusive detecting technology requires material or structural modification, which makes the working conditions of test cell and standard fuel cell inconsistent, affecting the reliability of the results. Developing non-destructive and non-invasive diagnostic technology will be an important topic.

2) Fuel cell electrochemical reaction involves the coupling of electricity, heat and water. Simultaneously monitoring the behavior of electricity, heat and water will help to understand the correlation between them. Technology for comprehensive measuring of current, temperature and water will be another important direction.

3) Current diagnostic technology is mainly based on single cell, of which the operating state is different from high-power stack, and some technology has limitations in detecting stacks. Developing technology suitable for in-suit detection of fuel cell stack is also a key problem in future study.

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