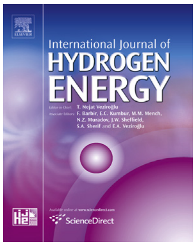
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 7370–7381

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he



Evolution of thermal drifting during and after cold start of proton exchange membrane fuel cell by segmented cell technology

Rui Lin [a,b,*], *Xuwei Lin* [a,b], *Yuanming Weng* [a,b], *Yingshi Ren* [a,b]

[a] *Clean Energy Automotive Engineering Center, Tongji University, Shanghai 201804, China*
[b] *School of Automotive Studies, Tongji University, Shanghai 201804, China*

ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form
3 April 2015
Accepted 12 April 2015
Available online 4 May 2015

Keywords:
Cold start
Segmented cell technology
Current density distribution
Thermal drifting
Uniformity

ABSTRACT

This paper focuses on the cold start performance of proton exchange membrane fuel cell (PEMFC) in order to improve its capability and survivability. With the printed circuit board (PCB) technology, the change of internal current density and temperature under different operations would be obviously shown. The result shows that the initial voltage load and setup temperature is significant for the cold start ability. Polarization curves show almost no performance degradation after the successful cold start, but it degrades quickly after the failed cold start. The highest current density appears in the inlet region and then it reaches to the middle region of the cell, which accompanies with the thermal drifting. When the cell continues to work at normal condition, a decreasing tendency appears in the inlet and middle regions, but the performance of the outlet region is increasing. Based on these characteristics of performance, the method of delivering humidified H_2 and air to the PEMFC was adopted to optimize the uniformity of the current density distributions of the cell.

Introduction

The cold start capability and survivability of PEMFC is one of the key barriers for future commercialization. The key problem of PEMFC cold start is that the water produced by the electrochemical reaction would freeze below zero degrees. It would lead to failed cold start because the ice-formation under sub-freezing temperature blocks the cathode catalyst layer. Furthermore, the formed ice would switch the gas supply and induce a shut down during the cold start process, causing the unrecoverable degradation of the PEMFC performance [1–5].

At temperatures below freezing, the freezing water becomes ice inside the electrode and the gas diffusion layer. During the cold start processes, the formation of water would affect the ongoing chemical reaction [6,7]. Study on the cold-start problem is important for both the customers' demand of a quick start-up process and great influence on the PEMFC cold start cycles [8]. In order to solve the cold start problem of PEMFC, many experimental and numerical studies have been carried out to investigate the cold start processes, especially

---

[*] *Corresponding author*. Clean Energy Automotive Engineering Center, Tongji University, Shanghai 201804, China. Tel.: +86 13916799765; fax: +86 21 69589225.

E-mail address: ruilin@mail.tongji.edu.cn (R. Lin).

http://dx.doi.org/10.1016/j.ijhydene.2015.04.045

on the balance of heat generation and ice formation in cathode catalyst layer. It is useful to improve the cold start capacity and survivability by purging the drainage, increasing water capacity and rapid warm of PEMFC temperature [9–11]. Constant voltage mode is efficient to warm up the cell and shorten the cold start time [9,12–15]. Recently, Toyota had used "rapid start-up" methodology to resolve the cold start problem. Compared with the normal operation point, it generated sufficient waste heat so that the fuel cell could be quickly warmed up while simultaneously providing the required power to the vehicle during the start-up in cold-weather. The operation was very safe and it caused minimum damage for the materials of fuel cell [9]. Jiao et al. had studied the characteristics of a PEMFC cold start through the simultaneous measurement. For both the successful and the failed cold start processes, the highest current density and the temperature were initially near the flow channel inlet region and also went downstream in the middle region after the overall peak current density was reached, which showed that the middle region of the cell had the best survivability [14]. Tajiri et al. had developed a method by using partially humidified gases to effectively control the water distribution of the cell before cold start. The membrane was a key component to enhance the intrinsic capability of isothermal cold start from −30 °C. What's more, they had evaluated the effect of the ice formation on the cathode catalyst [16]. But all efforts were limited to numerical studies because there was only one section. Tabe had studied the cold start characteristics of a PEMFC, conducting microscopic observations to clarify the freezing mechanism. It was found that there were two types of freezing mechanism: freezing in the cathode catalyst layer at the temperature of −20 °C and freezing resulting in super cooled water near 0 °C at the interface between the catalyst layer and the gas diffusion layer [15].

In our study, we paid attention to the local current density and temperature distribution of a PEMFC under constant voltage load mode by the PCB technology and compared with the capabilities of cold start [14]. The cold start time was the time when the PEMFC average temperature reached zero from start-up temperature. In addition, the behavior of the degradation of fuel cell operated before and after cold start was characterized by polarization curves and the current density distribution of fuel cell, which would be helpful to understand the mechanism of cold start processes and find the optimum strategy for the successful cold start of PEMFC when it continued to work at normal condition.

Experiment

Printed circuit broad (PCB) technology

With PCB technology, the current density and the temperature distributions from the flow field plate with unmodified MEA can be measured through experimental methods. The PCB board that was first fabricated by non-conducting material and covered with conducting layers replaced the bipolar plate of the anode side. The top layer was gold plated to eliminate resistance and prevent corrosion. The layer contacting with MEA was divided into 49 segments on an active area of 25 cm^2 to avoid connection [16–18]. Each current collector covered about 0.5 cm^2 while the 49 segments were divided as 7 × 7 square. Both width and depth of the channels were 0.5 mm. Every segment was numbered by the alphabet (A to G) and number (1 to 7). G1 is the inlet part, and A7 is the outlet part. The PCB board was combined with circuits to measure the current density distributions and the temperature distributions by measuring the voltage drop of the resistor buried in each segment. The back side of the PCB was plated with entail gold to collect segment currents to the load. The PCB was placed between the MEA and anodic collector in order to reduce the influence on the fuel cell performance and the flow field on the PCB board for the transport of hydrogen was a single channel serpentine (as is shown in the Fig. 1) [18–20].

Measurement system and control strategy

Fig. 2 shows the current density and temperature distribution measurement system of PEMFC [1]. The operating parameters were set up and measured by the current density and temperature distribution measurement system of PEMFC, such as backpressure, start-up temperature, load, gas flow rate and humidity. The environmental chamber (Parter PTC14003-MV) was used to set the start-up temperature of PEMFC to simulate the cold start in a cold environment, and it ranged from −40 to 150 °C with the accuracy of ±1 °C. The PCB of the PEMFC was connected with a data acquisition unit (Aglient 34970A) and test bench, to collect the local current density and temperature distribution, transferring the data to the computer software to realize the online vision. Furthermore, the uniformity of the current density distribution was obtained by the computer software with the span of 20%. The reactant gas went through a cooling pipe in the environmental chamber before going into the PEMFC. Because the temperature of the supplied air and hydrogen was at room temperature, the reactant gases were cooled to the start-up temperature to simulate the cold start at the real environment condition. The cooling pipe was 3 m long and the inner diameter of it was 4 mm. The temperature sensors were used to measure the air and hydrogen temperatures out of cooling pipes. MEA was at the thickness of 23 μm, which was purchased from Wuhan Xinyuan Corporation. Pt/C catalysts of MEA were both 0.4 mg/cm^2 for the anode and cathode side. The cell temperature was obtained by the PCB inside the cell, and it was proved that 4 h were enough for the cell cooled to setup temperature with the difference of ±1 °C. In addition, the cell was covered with the thermal insulation material to prohibit heat convection in the environmental chamber during the cold start process. Before the cold start of PEMFC, the cell was activated under optimized condition for 6 times. With the measurement system, we could easily test the local current density distribution, which would be more precise in reflecting the local electrochemical reaction. The reactant flow was at serpentine flow field. Hydrogen and air stoichiometry was respectively kept at 1.4 and 2.5. The cell temperature was 60 °C and the humidity of anode and cathode were 100% at the ambient pressure. Dry nitrogen gas was supplied to anode and cathode flow channels at 40–60 °C for purging to remove the residual water from the cell, which could reduce the initial water distribution for subzero startup. The flow rate of nitrogen for purging was