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Rapid cold start of proton exchange membrane fuel cells by the printed circuit board technology

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ABSTRACT

Cold start from subzero temperature is one of the key barriers, which prevents proton exchange membrane fuel cell (PEMFC) from further commercialization. In this paper, we have applied the printed circuit board (PCB) technology to study the current density distributions of PEMFC and optimized the technology under rapid cold start. The results show that increasing the initial load, and the setup temperature can help to lower the cold start time and achieve rapid warm-up of PEMFC. The cell can be rapidly cold started for 10 s at −5 °C and 55 s at −10 °C under 0.2 V operation condition, but it failed at −15 °C and −20 °C. The inlet region and middle region produce half of the total current before the overall peak current density is reached, which is important for the successful cold start. Based on these characteristics, we optimized the rapid cold start strategy by co-operation of hot reactant gas and waste heat generation of PEMFC. It becomes possible to start up the PEMFC at temperatures down to −20 °C with about 20 min.

Introduction

PEMFC has the advantages of high efficiency, high-power density, quick response, zero emission and low operating temperature, which is considered as a potential power source for the transportation and portable generators [1–3]. However, cold start from subzero temperature is one of the key barriers, which prevents PEMFC from further commercialization. The water produced by the electrochemical reaction could freeze and lead to an ice-formation under sub-freezing temperature. The formed ice would stop the gas supply and induce a shutdown during the cold start process. It has been reported that this freezing caused various kinds of degradation of PEMFC performance [4–6]. As shown in Fig. 1, there is a production of water and water vapor just after stopping. The remaining water vapor could frost when the temperature drops below 0 °C. If the generated water is within the water storage capacity after start-up operation exceeding 0 °C, it is a successful cold start. Otherwise, it is a failed cold start. There are three ways to increase the cold start capacity, including drainage by purge, increasing water capacity and rapid warm of PEMFC temperature [7–9].

In order to solve the problem of PEMFC's cold start, rapid start-up strategy is used to speed up warm-up and minimize the cold start time [10–14]. Recently, Toyota had resolved this cold start problem with a “rapid start-up” methodology. The normal operation point generated little waste heat. The fuel

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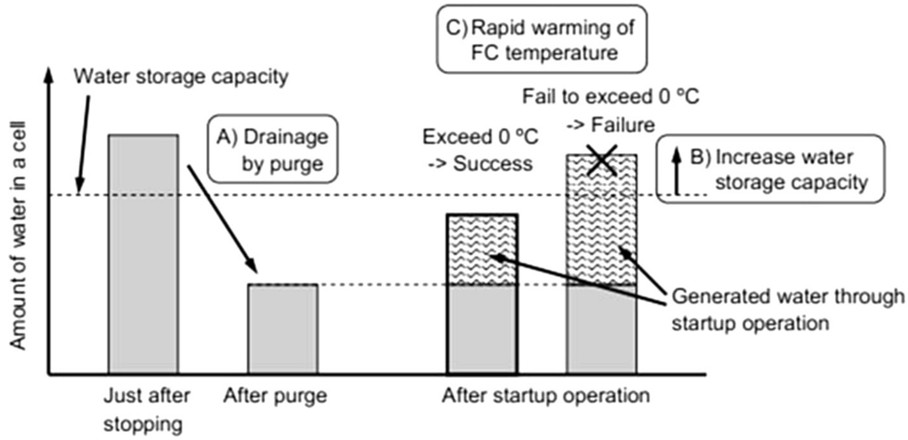

Fig. 1 — Water balance for the cold start operation.

cell could be short-circuited to convert the hydrogen energy solely into waste heat. But in this case, no electricity is available for the vehicle and also this operation is very dangerous and may cause the damage of the materials of fuel cells. The large operation point showed a way to produce sufficient waste heat while simultaneously providing the required power to the vehicle during start-up in cold-weather [10]. Henao studied a global strategy which aimed at providing an efficient method to minimize the energy consumption during the startup of a PEMFC. A time optimal self-heating approach based on the Pontryagin minimum principle was proposed and tested. The experimental results had shown that the proposed approach was efficient and could be implemented in real-time on fuel cell hybrid vehicles [11]. Jiao investigated the effects of the start-up temperature, load condition and flow arrangement on the cold start characteristics and performance of PEMFC through in-situ experiments with the simultaneous measurements of the current and temperature distributions. The experiment achieved successful cold start from $-10\,^{\circ}C$ while failed from $-20\,^{\circ}C$ at 0.3 V. During the failed cold start process, the highest current density was initially appeared near the inlet region of the flow channels, and then it moved downstream, reaching to the outlet region eventually. Almost half of the cell current density was produced in the inlet region before the cell current peaks, and the region around the middle of the cell had the best survivability [12,13]. Tabe studied the cold start characteristics of a polymer electrolyte membrane fuel cell, and microscopic observations

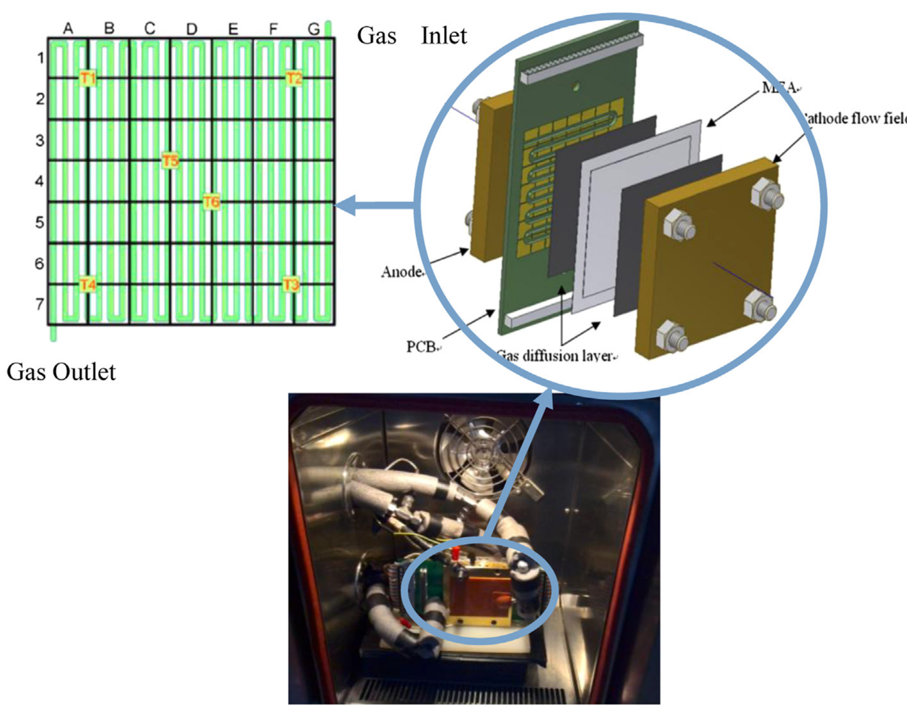

Fig. 2 — The schematic of the fuel cell assembly and the segmented flow field of current density distribution measurement board.