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Dynamic response of proton exchange membrane fuel cell under mechanical vibration

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ABSTRACT

The dynamic response of proton exchange membrane fuel cells (PEMFCs) under mechanical vibration is an important criterion in the application to automotive systems. The effect of mechanical vibration on dynamic response was investigated on an automobile vibrating platform. The PEMFC voltage was acquired according to the current density change under a variety of amplitude, frequency and air stoichiometry. Furthermore, liquid water formation and transport were investigated under the mechanical vibration by employing a transparent PEMFC. The results show that a new steady-state of the voltage under vibration and no vibration take about 50s and 20s respectively after the current density step. The PEMFC dynamic performance was slightly improved under amplitude at 4 mm, compared to operation at no vibration. Also, the voltage fluctuation was detected under the vibration, the small droplets merged into larger droplets is due to the sudden vibration. These larger droplets interfere with the mass-transfer process in the gas channels.

Introduction

Proton exchange membrane fuel cells (PEMFCs) are widely regarded as a potential new power source for future vehicles with its prominent characters such as low-operational temperatures, high working efficiency and low aggression to the environment [1]. The transient response and dynamic characteristics of PEMFCs under load change conditions are very important in transportation applications. Under load change conditions, an abrupt load change tends to cause large water generation. A variation of water transport inside the PEMFCs causes adverse dynamic behaviors such as massive flooding and voltage fluctuation [2]. In addition, the PEMFCs in vehicles is highly impacted by the vibration under real road conditions due to the uneven pavement and the rotation of vehicle components. However, PEMFC vehicles on the road are often accompanied by vibration. Therefore, it is necessary to characterize the dynamic behaviors of PEMFCs under vibration to achieve high performance and reliability in the vehicular application.

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As the vehicular PEMFC works under irregular load condition, a better dynamic behavior is expected to quickly respond to the changes in load. In order to reveal the internal mechanism of heat and mass transfer and the electrochemical reaction of PEMFCs under the changes in load, many experimental and modeling studies have been conducted in the last decade.

There have been some efforts in experimental studies on dynamic behavior under the different operating condition including stoichiometry, temperature and humidity conditions. The dynamic response under different stoichiometry conditions and the different of channel type were studied [3,4]. The characteristics of the transient response of a PEMFC under a variety of stoichiometry, temperature and humidity conditions were analyzed [5]. It is shown that undershoot behavior consists of two stages with different time delays: one is of the order of 1 s and the other is of the order of 10 s. The effects of operating and controlling parameters on the transient response of a PEMFC for achieving more stable performance under load change conditions was investigated [6]. The results shown that the optimal air stoichiometry was determined to be between 2.0 and 2.5. The transient response of a fully humidified PEMFC in terms of dynamic water transport under lower operating temperature conditions. The results shown that the dynamic behavior for the tested operating temperature (30–50 °C) conditions was mainly governed by water transport characteristics related to cathode flooding [7]. The transient response of a PEMFC under various temperature and humidity conditions were studied [8,9]. Several dynamic PEMFC models have been proposed in the papers, these dynamic modeling usually combine a time-dependent mass balances with steady-state electrochemical model [10–16]. Meanwhile more detailed processes in different parts of PEMFCs have been analyzed by several researchers. Kang et al. [17] developed a quasi-three dimensional dynamic modeling of a PEMFC with consideration of two-phase water transport through a GDL. Ferreira et al. [18] numerically investigated the two-phase flow in a gas channel by using CFD. Yang et al. [19] developed a three-dimensional numerical PEMFC model to illustrate of current density distribution with varying land ratios, found that a narrower rib gives the best performance. However, a wider rib produces poor performance given a specific inlet relative humidity level. Diloyan et al. [20] analyzed the effect of mechanical vibration on platinum particle agglomeration. It was observed that the average diameter of Pt particles under vibration was 10% smaller than the ones under no vibration. Hou et al. [21–23] experimentally investigated the performance of stack under strengthened road vibrating condition. EI-Emam et al. [24] investigated the effects of orientation and vibration on the performances of PEMFC. It was found that an improvement in the performance was achieved when the stack was vibrated with low values of amplitude and frequency.

In this paper, we investigated the dynamic response of the PEMFC at the different vibration amplitude and frequency. In order to explain the effect of vibration on the dynamic response of the PEMFC, the liquid droplets exudation and growth progress were studied in a transparent PEMFC with its anode flow field on the vibration test bench.

Experimental

Transparent and non-transparent PEMFC

A transparent PEMFC was designed for this dynamic study, as schematically shown in Fig. 1. It consists of two end plates, two gas distributor plates, and a MEA. The MEA active surface area was 25 cm^2, and the proton exchange membrane (PEM) used was Nafion 211, which has a thickness of 25 μm, and the platinum catalyst loading on each electrode side was 0.5 mg/ cm^2. The two end plates of transparent PEMFC were made of transparent Lucite material. Through the transparent end plate, the liquid water inside the PEMFC could be distinctly visualized and recorded by the image recording system. The gas distributor plates was composed of 316 stainless steel to avoid corrosion. As can be seen in Fig. 1, bipolar plate consisted of two portions, the channel area and the extension area. The channel area acted as the distributor for supplying fuel to the MEA, in which the channels have been cut to a depth of 1 mm, width of 2 mm, with a rib width of 2 mm, and the total length of 5 cm.

The non-transparent PEMFC has effective area of 25 cm^2 with a parallel serpentine channel (1 mm $\times$ 1 mm). The MEA is the same with the transparent fuel cell.

Experimental setup

Fig. 2 shows a schematic diagram of the experiment setup. The PEMFC test bench was composed of seven main parts, including electronic load unit, a water management system, temperature control system, gas supply system, flow rate control unit, vibration test bench and an imaging systems including a digital camera (Lumenera). Ultra-high purity hydrogen and air were used as reactant gas on the anode and cathode sides. In the air and hydrogen gas pipeline was equipped with inlet valve, the mass flow controller and bubbling humidifier.

Test conditions and procedure

The test conditions for transient operation of the non-transparent PEMFC under mechanical vibration are

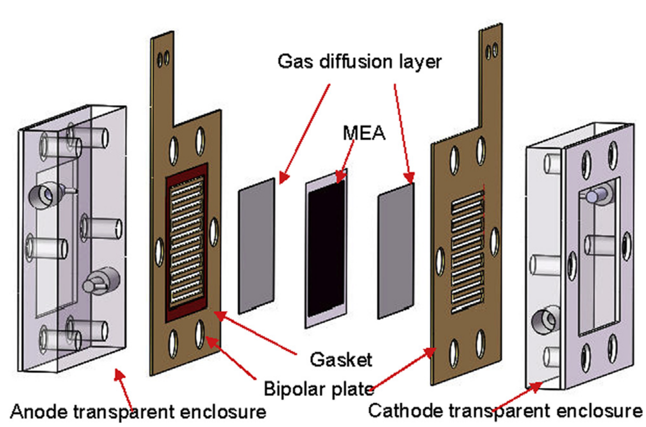

Fig. 1 – Scheme of transparent PEMFC.