INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 37 (2012) 11887–11893

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

An investigation of characteristic parameter variations of the polarization curve of a proton exchange membrane fuel cell stack under strengthened road vibrating conditions

Yongping Hou[a,b,*], Binglong Zhou[a,b], Wei Zhou[a,b], Caoyuan Shen[a,b], Yuntang He[c]

[a] Clean Energy Automotive Engineering Center, Tongji University, Shanghai 201804, China
[b] School of Automotive Studies, Tongji University, Shanghai 201804, China
[c] China Automotive Technology & Research Center, Tianjin 300162, China

ARTICLE INFO

Article history:
Received 16 March 2012
Received in revised form
7 May 2012
Accepted 8 May 2012
Available online 2 June 2012

Keywords:
PEM fuel cell stack
Strengthened road
Vibration
Polarization curve
Characteristic variations

ABSTRACT

The characteristic of the polarization curve and the parameter variations of open circuit voltage V_0, Tafel slope b and ohmic resistance R in the curve are experimentally investigated through a 150 h strengthened vibration test in this paper, to analyse the steady-state performance of the fuel cell stack under long-term vibrating conditions on strengthened roads. The load spectra applied in the test are simulated by the acceleration signals of the fuel cell stack, which are previously measured in a vehicle vibration test. The load signals of the vehicle vibration test are iterated through a road simulator from vehicle acceleration signals which are originally sampled in the strengthened road of the ground prove. During the test, the current and voltage under steady-state operation of the stack were measured six times at regular intervals. The test results indicate a fluctuating variation of the polarization curves. In the meantime, the V_0 decreases by 3% of the original value, R increases by 55.8% and b declines by 28.0%. From the results it can be concluded that the strengthened road vibration exert a significant influence on the steady-state performance of the fuel cell stack, which cannot and should not be ignored during the research.

1. Introduction

Fuel cell (FC) is a kind of device that can directly convert chemical energy into electric energy [1]. Compared with other kinds of fuel cells, proton exchange membrane fuel cell (PEMFC) is widely regarded as the most promising power source for future vehicles with its prominent characters such as low-operational temperatures, high working efficiency and low aggression to the environment [2].

At the R&D stage, the performance degradation under long-term operating conditions is a major research theme in the field of the steady-state performance of PEMFC [3,4]. Current researches of such performance degradation are primarily focused on internal mechanisms, including the degradation of proton exchange membranes [5], the stability of the catalyst and the durability of the gas diffusion layer [6], and the performance degradation of core components in the long-term operation [7]. Additionally, the influence from external operating conditions of the FC system, such as dirty fuel, start-stop operation [8], gas impurities, temperature-humidity conditions etc [9,10], has also been fully studied.

The research works above are mainly focused on internal mechanisms. On the contrary, few papers about performance degradation under real road vibrating are published. Actually,

* *Corresponding author*. Clean Energy Automotive Engineering Center, Tongji University , Shanghai 201804, China. Tel.: +86 21 69589231.
E-mail address: yphou@tongji.edu.cn (Y. Hou).

doi:10.1016/j.ijhydene.2012.05.030

the FC stack in vehicle is highly impacted by the vibration under real road conditions due to the uneven pavement and the rotation of vehicle components [11], which is absolutely inevitable and could produce complicated effects on the stack. Rouss V et al. [12–15] conducted a vibration test of FC applied on aeroplanes, where the vibration frequency sweeping ranged from 6 to 2000 Hz, the amplitude of acceleration ranged from 1 to 20 g. The sine sweeping vibration was separately imposed on three axial directions. Rajalakshmi N. et al. [16] analysed a 500 W PEMFC stack through a sine vibration test with a sine sweep from 10 Hz to 200 Hz at 3 g and a random shock test, so as to obtain the vibration response characteristics and mechanical behaviours of the FC stack. However, the vibrating conditions in those experiments were totally not the real road conditions.

The author [17] has conducted a 150 h strengthened vibration test previously to investigate the gas-tightness and electrical insulation of FC stack under long-term strengthened road vibrating conditions. It is observed that hydrogen leak rate of the stack increases 1.5 times during the test. In the meantime, the insulation resistance of the stack decreases to 17.55% of the original value. The safety performances of the FC stack decline in evidence with vibration.

In order to study the effects of real road vibration on the performances of FC stacks, the variations of the polarization curve and related parameters (i.e. open circuit voltage (V_0), Tafel slope (b) and ohmic resistance (R)) will be analysed and discussed in this paper on the basis of the previous work.

The polarization curve is an important representation of the steady-state performance of the FC stack. The mathematical expression, which is a function corresponding to the current I, can be written as follow [18,19]:

$$U(I) = V_0 - b * \log(I) - R * I - m * \exp(n * I) \quad (1)$$

where V_0 is open circuit voltage, b is Tafel slope, R is ohmic resistance, m and n are two empirical constants. These three parameters are utilized to characterize the steady-state performance of the FC stack here and confirmed from Eq. (1) and the current–voltage (I–V) data, which are originally sampled from the steady-state polarization curve test.

This paper aims to experimentally investigate the variations of polarization curve and its 3 related parameters through a 150 h strengthened vibration test. The 45 kW FC power module used here are consists of a stack with 560 cells assembled in series. The effective membrane area per cell is 280 cm^2.

2. Experimental

2.1. Test equipment

2.1.1. Road simulation test bench

A Road simulation test bench [20] is a mechanical execution system, which is powered by hydraulic fluid together with an electronic control system and a servo function. With different functions, the test bench can be divided into five parts: signal generation system, electronic control system, servo-control system, mechanical execution system and hydraulic-powered system. The road simulation test bench can accurately simulate the driving conditions of the intended road as well as the vibration environment.

2.1.2. Six-channel multi-axial simulation table

The Six-channel Multi Axial Simulation Table (MAST) [21] is a servo-hydraulic system controlled by computer (see Fig. 1). The standard MAST configuration provides a six-degree-of-freedom motion for the table and test specimen. It includes three vertical actuators that provide vertical (heave), pitch, and roll motions, and three horizontal actuators that provide lateral, yaw, and longitudinal motions. The table is designed for applying the operational vibration loads to ground vehicle components and subsystems. It can be used to obtain real, accelerated simulation of the proving ground or service environment inside a laboratory.

2.1.3. FC system test bench

The FC system test bench (see Fig. 2) used in this paper is composed by a bench control system, an auxiliary power system, a hydrogen supply system, an electronic load system and the tested FC. The auxiliary power system consists of a 20 kW DC power and a 12 V battery, where the 20 kW DC power works as a power supply for the auxiliary system, and the 12 V battery serves as a power source for the control system. A Digatron™ electronic load system with a maximum power of 150 kW is applied as the load of the fuel cell system. All of the subsystems in the bench are controlled by the control system made up of a PLC control cabinet and a control terminal [22].

2.2. Test procedure

The 150 h strengthened vibration test was carried out by using a road simulation test bench and a six-channel MAST. The first stage of the experiment was intended to obtain the load spectra applied on the FC stack. Afterwards a stack was subjected to the obtained load spectra on the six-channel MAST, which was used to analyze the variations of the polarization curve and related parameters (i.e. open circuit voltage V_0, Tafel slope b and ohmic resistance R) of FC stack under long-term vibrating conditions on strengthened roads.

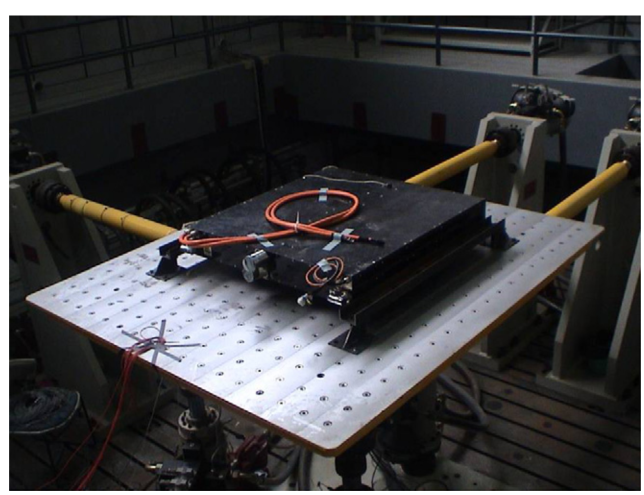

Fig. 1 – The six-channel multi axial simulation table used in the 150 h strengthened vibration test.