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Experimental investigation of gas-tightness and electrical insulation of fuel cell stack under strengthened road vibrating conditions

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ABSTRACT

Gas-tightness and electrical insulation are two important evaluation indexes of fuel cell vehicle safety. In this paper, the variation of gas-tightness and electrical insulation of fuel cell stack under long-term vibrating conditions are experimentally investigated through a 150 h strengthened vibration test. 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. The test results show that the hydrogen leak rate of the stack increases 1.5 times during the test. Additionally, the insulation resistance of the stack experiences a rapid decline at first, and then a steady linear decrease to 17.55% of the original value. It is observed that the decrease rate at the first stage is 25 times higher than the one at the second stage.

1. Introduction

Fuel cell (FC) is a kind of device that can convert chemical energy from a fuel directly into electric energy. Among different kinds of fuel cells, proton exchange membrane fuel cell (PEMFC) is regarded as the most promising power source for future vehicles with its prominent characters such as low-operational temperatures (20–100 °C), high working efficiency and high power density [1]. With the breakthrough in FC research in the last decade and the success of fuel cell vehicle (FCV) demonstration running, manufacturers are working to develop fuel cells that can be mass produced for use in transportation, stationary and portable power applications, and hand-held electronic devices [2]. In this context, the U.S. Department of Energy plans to overcome remaining technical barriers and commercialize fuel cell vehicles by 2015 [3]. For the commercialization and popularization of FCVs, the safety of FCVs should be fully secured, especially in terms of electrical safety and hydrogen safety. The working voltage of FC stack is normally higher than 350 V, which can easily lead to electric shock. To ensure the safety of drivers and passengers of FCVs, electrical insulation of FC stacks must be guaranteed [4]. In addition, the flammability limits based on the volume percentage of hydrogen in air are 4–75%, the explosive limits of hydrogen in air are 18.3–59% by volume [5]. Therefore, it's easy for hydrogen to burn or explode. Moreover, hydrogen flame, while being extremely hot, is colorless and almost invisible. To prevent hydrogen from burning or exploding, the hydrogen leak rate must be controlled in a safe range.

In hydrogen dispersion, there are some reports focusing on the dispersion behavior under specific space conditions.

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Matsuura K et al [6,7] presented a numerical simulation of hydrogen dispersion in a partially open space. In these papers, they also discussed the transient behavior of hydrogen and the process of accumulation in the space. In the field of hydrogen leak investigation, research groups mainly focused on the leak of compressed hydrogen. Schefer RW et al. [8] aimed at the characterization of leaks from compressed hydrogen dispensing systems of FC stack. Watanabe S et al. [9] experimentally studied the leak of vehicular high pressure hydrogen tanks. However, few papers based on the experimental methods and associated with the hydrogen leaks of vehicular FC stacks are published.

Reaction occurs when hydrogen and air are both present in the anode side of FC, and the main sealing structure of the stack is gaskets connecting single cells. The FC stack is fixed with bolts. Tightening torque of the bolts varies with the change of environment temperature and is influenced by external mechanical vibrations or shock [10,11]. Under real road conditions, vibration and shock are inevitable due to the road roughness and the rotation of vehicle components. Thus, it can be concluded that the gas-tightness of FC stack varies with the tightening torque under long-term vibrating conditions. Rouss V et al. [12–15] conducted a vibration test of FC applied on airplanes, 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. During the test, no significant gas leakage was found. The gas leak rate in the anode side of the stack was about 25 mbar/h and the leakage was mainly detected at the fluidic stack connections/fittings of the anode side.

Rajalakshmi N et al. [16] analyzed 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. It was observed that the electrical insulation of the stack hardly varied during the test.

However, the investigations mentioned above have the following limitations. Firstly, the FC stacks employed in those papers are small and generally used in aircrafts and ships. Secondly, the load signals applied on the stack are sinusoidal signals, which cannot simulate the vibrating conditions of real roads. In addition, the load time of the test is relatively short. It's not suitable to take the test results as references for the investigation of gas-tightness and electrical insulation of FC stack under long-term vibrating conditions.

This paper aims to experimentally investigate the effects of long-term strengthened road vibration on the gas-tightness and electrical insulation of FC stacks. The 50 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. Test equipment

2.1. *Road simulation test bench*

A road simulation test bench (see Fig. 1) [17] 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 bench is 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 intended road and driving conditions, as well as reproduce the vibration environment.

2.2. *Six-channel Multi Axial Simulation Table*

Six-channel Multi Axial Simulation Table (MAST) [18,19] is a servo-hydraulic table. 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 simulations of the proving ground or service environment inside a laboratory.

3. 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. Afterward a stack was subjected to the obtained load spectra on the six-channel MAST, which was used to analyze the variation of gas-tightness and electrical insulation of FC stack under long-term vibrating conditions on strengthened roads.

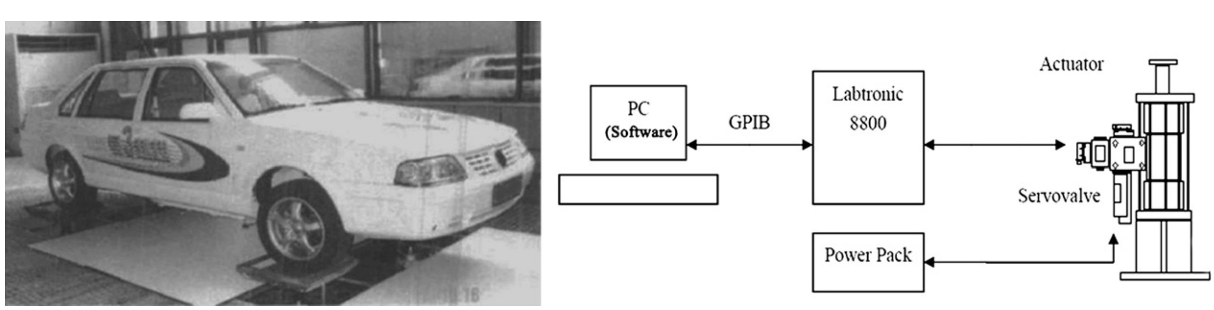

Fig. 1 – The road simulation test bench.