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Numerical and Experimental Modal Analysis of a 400 W Polymer Electrolyte Membrane Fuel Cell

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ABSTRACT: With the increasing utilization of polymer electrolyte membrane fuel cells in cars, ships, and airplanes, the study of vibrational behavior of fuel cells has gained particular importance. In this paper, a modal analysis of 400-Watt 4-cells fuel cell with an active surface area of 225 cm^2 has been performed numerically and experimentally. The time domain method has been used to extract global fuel cell frequencies. By interpreting the output data of the sensors and using the phase response angle, two natural frequencies of the model were extracted. The results of the test showed that the first transverse and longitudinal frequency of the model is 500 Hz and about 2500 Hz, respectively. Then, the simulation of the finite element model was studied in detail. A comparison of the frequencies obtained from the test and numerical analysis showed that the maximum difference is about 8%. Therefore, numerical analysis of the model with sufficient detail can adequately cover the vibrational properties of the real model. Also, the results showed that by changing the geometrical and mechanical properties of the membrane by 45%, the natural frequency of fuel cell changes through 4%. Furthermore, removing the membrane plates, in addition to reducing the number of model elements, reduces the contact constraints.

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1. INTRODUCTION

In recent years, the use of fuel cells as a new and clean energy source in land, air and sea transport, which is associated with shock and vibration, has been considered. Under dynamic loading, the plates may slip over each other, or due to localized failure, leakage of hydrogen and oxygen gases can lead to a combination of reactive gases and explosion in a fuel cell [1]. Therefore, the study of fuel cell behavior under these types of loading is essential. Accordingly, in recent years, the study of the vibrating behavior of the fuel cell has been considered by many researchers. Rouss et al. [2, 3] conducted a vibration test on a fuel cell for aircraft applications. Shakeri and Imen [4] examined the effects of mechanical loads or mechanical vibrations on an open cathode polymer fuel cell. The overall results showed that mechanical vibrations with considered conditions had no significant effect on fuel cell performance during the test period, and only hydrogen leakage was increased slightly. Wang et al. [5] simplified polymer membrane fuel cells as a multi-layered composite structure and analyzed the vibrational response of a single cell. Liu et al. [6] used a modal analysis method to study the fuel cell vibrational response by the finite element method. Using this method, they were competent to isolate the local modes from the main modes of the structure. An experimental study of the modal properties of a real-sized fuel cell, numerical simulation of the fuel cell with full details and numerical model validation, and providing solutions to simplify numerical modeling of fuel cell are among the innovations of this research.

2. METHODOLOGY

2.1. Experimental modal analysis of fuel cell

To perform a modal test, a fuel cell is suspended with rubber belts on a framework to provide free boundary conditions (Fig. 1).

The shaker connects to a point of the fuel cell and applies a force with amplitude in the specified range. The fuel cell structure is stimulated in two transverse and longitudinal directions, and the response is simultaneously read by three

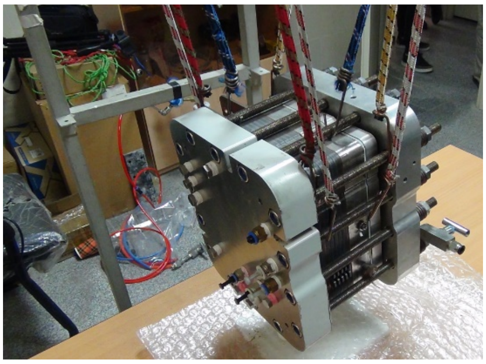


Fig. 1. Suspended fuel cell with free boundary conditions.

*Corresponding author's email: barzegari@mut.ac.ir accelerometer sensors mounted on the endplates and fuel cell current collector plates.

2.2. Fuel cell finite element modeling

For numerical modeling of 4cell fuel cells, commercial software has been used. The sealing gaskets are considered as hyperelastic material. Then the model is meshed. At this stage, due to the presence of gas channels, the size of the mesh seeds should be very fine. The meshing of the finite element created on the model is shown in Fig. 2.

It is important to note that the dimensions of the finite element mesh at the contact surfaces are smaller than other points.

3. RESULTS AND DISCUSSION

3.1. Modal test results

Subsequently, the frequency response function and the Mode Identification Function for sensors connected to current collector plates are shown in Fig. 3.

As seen in Fig. 3, the first frequency is about 340 Hz. Due to the available experimental equipment, as well as the very high rigidity and complexity of the fuel cell structure, the phase angle method was used to determine the fundamental natural frequencies. As shown in Fig. 4, at the frequency of 500 Hz the phase angle

Difference between the excitation and the response signal is approximately 90 degrees. Therefore, the first natural transverse frequency of the structure was approximately 500 Hz. To determine the longitudinal frequency of the fuel cell, the shaker is mounted on the inlet endplate and the excitation is applied in a longitudinal direction. For this test, an excitation of 3075 Hz was applied to the fuel cell. By decreasing the frequency to 2500 Hz, the phase difference is approximately 90 degrees.

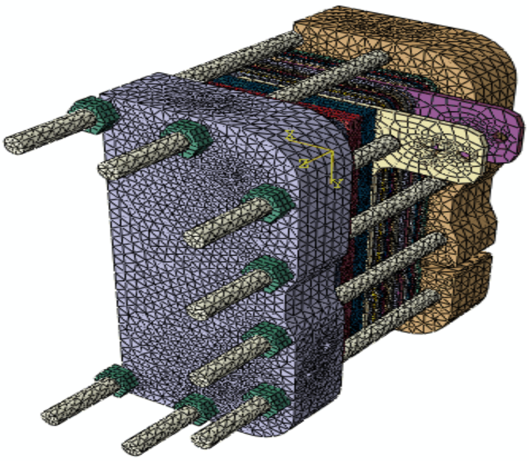


Fig. 2. Fuel cell model mesh.

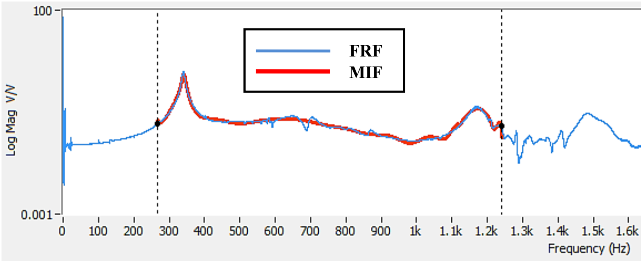
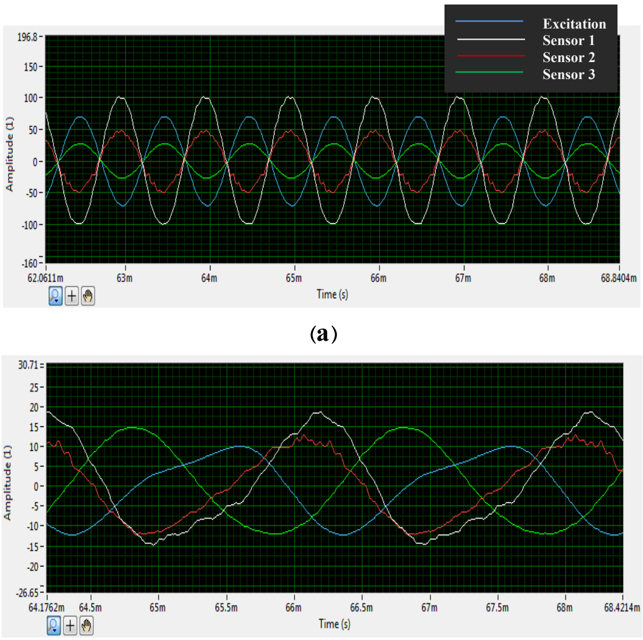


Fig. 3. Local frequency response diagrams of the current collector tab.



(a)

(b)

Fig. 4. Excitation and response diagrams at the excitation frequency (A) 1000 Hz, (B) 500 Hz.

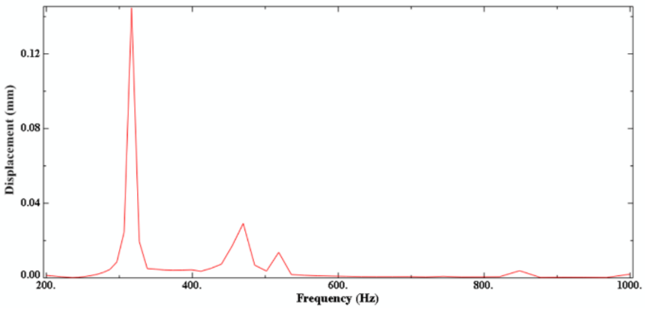


Fig. 5. Numerical frequency response analysis of fuel cells under transverse excitation.

3.2. Finite element method modeling results

In this section, the results of numerical analysis of the fuel cell response to external excitation in the frequency domain are evaluated. Fig. 5 shows the frequency response analysis of one node on to the current collector plates. As can be seen, the first frequency is 320 Hz and the second frequency is 470 Hz. Also, the numerical simulation results show that the longitudinal natural frequency of the fuel cell to be 2300 Hz, which is closed to the experimental results (2500 Hz).In addition, the results showed that by 45% changing the geometric and mechanical properties of the membrane, the natural fuel frequency of the fuel cell decreased by 4%. It is important to note that the removal of membrane plates will reduce the contact constraints. In the present study, the removal of membrane plates, while maintaining the accuracy of the model, reduces the numerical computation cost by 17%.

4. CONCLUSION

In this paper, a modal test of a 400-Watt fuel cell consisting of 4 cells was performed and the obtained experimental data were compared with numerical simulation results. The results show that due to the high rigidity of the fuel cell and the complexity of its structure, the natural fuel frequencies of the fuel cell are obtained by comparing the phase difference between the input excitation and response signals. A comparison of the frequencies obtained from the test and numerical analysis showed that the maximum difference is about 8%. Therefore, numerical analysis of the model with sufficient detail can adequately cover the vibrational properties of the real model.

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