Electrochimica Acta 215 (2016) 150–161

Contents lists available at ScienceDirect

Electrochimica Acta

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

Analysis of the clamping effects on the passive direct methanol fuel cell performance using electrochemical impedance spectroscopy

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ARTICLE INFO

Article history:
Received 8 June 2016
Received in revised form 16 August 2016
Accepted 17 August 2016
Available online 18 August 2016

Keywords:
Passive DMFC
clamping bolt torque
bolt configuration
electrochemical impedance spectroscopy

ABSTRACT

The clamping effects on a passive direct methanol fuel cell (DMFC) performance have been analysed using electrochemical impedance spectroscopy (EIS). The stainless steel bolts of size M 6 × 0.75 mm with a length of 50 mm have been used for clamping the cell. The passive DMFC performance was conducted for different combinations of clamping bolt torque and methanol concentrations. It is found that the cell performance decreases with under and over uniform clamping bolt torque, and it is maximum at a particular clamping bolt torque. It is concluded from the EIS study that both the ohmic and mass transfer resistance decides the optimum clamping bolt torque of the passive DMFC. The EIS study also reveals that the non-uniform clamping bolt torque deteriorates the DMFC performance due to increase of the ohmic resistance and mass transfer resistance as well. The effects of bolt configurations on the cell performance have also been discussed. In this study, eight bolt configurations passive DMFC under 8.0 N m uniform clamping bolt torque produces optimum cell performance at 4 molar methanol concentrations. It is therefore recommended to decide clamping bolt torque accurately during assembling of the passive DMFC.

1. Introduction

Direct methanol fuel cell (DMFC) is used to convert chemical energy of methanol fuel into electricity. However, it is needed that supply of adequate volume methanol and oxygen are maintained [1]. It is to be noted that the DMFC is superior to polymer electrolyte membrane fuel cells (PEMFC) as it allows easy handling and refueling, low emission, high energy density and are compact in structure [2–4]. DMFCs can be classified as active and passive DMFCs, depending on the feeding of methanol and oxygen. Fuel and oxidant are supplied in an active DMFC using pumps and blowers respectively. Nevertheless, the transport of reactants and products in passive DMFC occurs by diffusion and natural convection [5,6]. The passive DMFCs are compact in structure, show low parasitic power loss and offer high energy density over active DMFC. Therefore, the passive DMFC serves as one of the next-generation power sources for portable applications such as laptops, mobiles and personal digital assistants [7–12].

Fig. 1 shows the clamping sequence during assembling of passive DMFC. The components of passive DMFC are fuel reservoir, membrane electrode assembly (MEA), gaskets, anode and cathode end plate, anode and cathode current collector and several pairs of nuts & bolts. The clamping system plays a vital role during assembling of the passive DMFCs. The clamping system prevents leaking of reactants and products, provides uniform clamping pressure distribution at various interfaces and decreases contact resistance between the interfaces. Generally, the fuel cell can be assembled by various clamping design such as point, line and surface loaded design. In this study, the point loaded design assembly of several bolts and nuts are used. The clamping torque and bolt configurations are the two major parameters in case of the point load clamping design. Most of the literature available deals with the two parameters such as ohmic résistance and mass transfer resistance which affect the cell performance [13–21]. A few also discuss about designing of the clamping systems for the PEMFC.

Lee et al. [13] investigated the clamping torque effects on the PEMFC performance. The cell was assembled by four bolts and it was fastened using a clamping torque on each bolt. The torque was varied from 11Nm to 17Nm. They found an improvement of cell

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http://dx.doi.org/10.1016/j.electacta.2016.08.080
0013-4686/

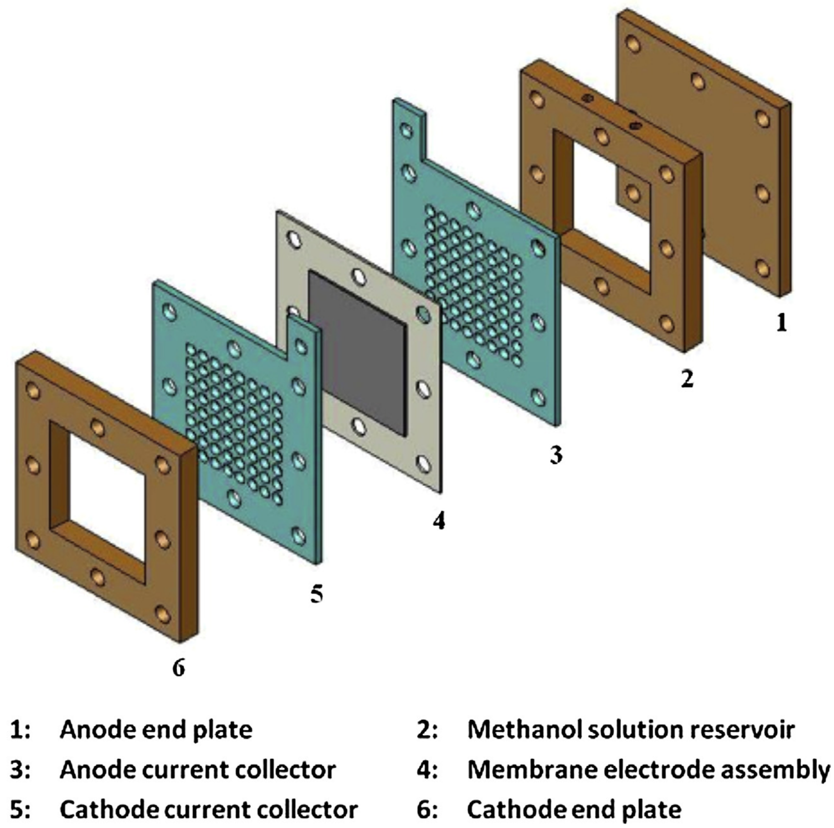

Fig. 1. Schematic of a passive DMFC.

performance by increasing the clamping torque upto an optimal clamping torque due to increase in electrical contact resistance. However, the cell performance deteriorated as a further increase of the clamping torque due to decrease of the porosity of GDL. Lee et al. [14] analysed the clamping pressure by point-load assembly design for a PEMFC using FEA procedure. They also compared the FEA results with the measured pressure distributions using a pressure-sensitive films and found similar pressure distributions. Liu et al. [15] studied the effects of assembly clamping pressure and positions the clamping bolts of the end plate on the MEA by response surface method (RSM). They found that the assembly clamping pressure should be 1.5 MPa and the bolts should keep at the middle of four margins of the end plate. It also showed that the assembly clamping pressure plays a dominant role on the pressure distribution of MEA than the position of the clamping bolts. Wang et al. [16] used a novel pressurized end plate using a hydraulic fluid pocket. They found more uniform contact pressure distribution for the novel hydraulic pressurized end plate than the conventional bolt-fastening end plate. Wein et al. [17] investigated the effects of different bolt locations and clamping torques on the PEMFC performance. They assembled the components of PEMFC using bolt configuration from 2, 4, to 6 with the torque moments of 8, 12 and16 N m. They showed that the cell performance increased as the clamping torque increased with keeping same bolt configuration and it also increased as the number of bolt is increased with the clamping torque remains unchanged.

Lin et al. [18] designed an equivalent stiffness model to optimize the tightening torque which balances the interfacial contact resistance and GDL permeability. Xing et al. [19] used a COMSOL model via MATLAB code for studying the assembly clamping pressure effect on the performance of PEMFC. They found that the fuel-cell performance improved under the clamping pressure of 1 or 1.5 MPa and high operating voltages, but it decreased under low voltage conditions. Gatto et al. [20] examined the bolt torque effect on the PEMFC performance with different gaskets. The cell was clamped using two copper end plates and tightened by four stainless steel bolts with the torque in a range between 7 and 13 N m. They found that both the nitrile rubber reinforced with cotton yarn and expanded PTFE achieved the best performance at the clamping torque of 11.0 N m while the PTFE reached same cell performance at 9.0 N m clamping torque. Chien et al. [21] analysed the effects of locking sequence of the bolts on the deformation and stress distributions at the flow-channel plates of a PEMFC using a three-dimensional FEM model. The cell was clamped using three pairs of bolts along the upper and lower portions of the end plates. They suggested that the locking of the middle upper or lower bolt produced more warpage, uniformities of deformation and Von-mises equivalent stresses than that of the locking either one of the four corner bolts.

EIS is a diagnostic testing tool for the passive DMFCs. It is a non-destructive technique and contributes a large amount of useful information for DMFC performance without perturbing system from equilibrium [22,23]. EIS is a best method for diagnosing the DMFC performance. This is mainly due to the capability of differentiating the individual contributions of each component and process such as the membrane and gas diffusion electrode interfacial charge transfer and mass transport in both the catalyst layer and backing diffusion layer respectively to fuel cell performance [24–26]. Various authors [22,27–29] have analysed the clamping pressure effect on the performance of the PEMFC using EIS.