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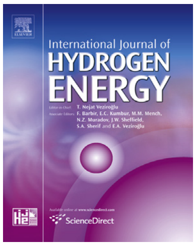

Investigation of contact pressure distribution over the active area of PEM fuel cell stack

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ABSTRACT

Contact pressure distribution over the active area of proton exchange membrane fuel cell (PEMFC) has significant effects on the performance of PEMFCs. Even clamping pressure over the membrane electrode assembly (MEA) affects contact resistance, characteristics of porous media and sealing task. This paper develops a PEM fuel cell model to study the contact pressure distribution over the membrane electrode assembly using finite element model. At first, the three-dimensional model of a single cell was reduced to a two-dimensional model to decrease the calculation time. After validation of the obtained results via the pressure sensitive films, the effect of some parameters such as thickness and material of the end plates, sealant hardness, number of the stack's cells and position of the cell on the contact pressure distribution over the MEA were investigated. The results reveal that optimizing mentioned parameters leads to design PEM fuel cells with proper contact pressure distribution over the MEA.

Introduction

Recently, proton exchange membrane fuel cell has attracted much attention due to its high efficiency, low temperature, quick startup and being clean energy converter which converts the energy stored in hydrogen and oxygen into electricity. The premise for a wide diffusion of this technology mainly depends on two crucial factors: cost reduction and energy efficiency improvement.

Clamping system is one of the most important parameters of PEMFCs. The purposes of the clamping systems can be mentioned as providing sealing pressure and proper pressure distribution at various interfaces and decreasing contact resistance between interfaces. Uneven contact pressure distribution over the MEA results in non-uniform current density and heat generation distribution which may cause hot spot formation in the MEA [1,2]. High clamping pressure leads to an increase in the contact area between bipolar plate (BPP) and gas diffusion layer (GDL) which decreases the contact resistance. However, a large pressure may cause GDL to become over-compressed which results in decrease of GDL's porosity [3–5].

There are few literatures about designing clamping systems. Most of them studied the effect of clamping system on different parameters such as interfacial contact resistance [6–9] and ohmic resistance [10,11]. Researchers demonstrated that around 59% of the total power loss in a polymer electrolyte membrane fuel cell can be due to contact resistance between BPPs and GDLs [5]. Contact pressure distribution varies

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throughout each individual cell and the stack itself. Moreover, contact pressure distribution may affect thermal conductivity and seal performance [7]. Lai et al. [6] implemented the model on a 2D bipolar plate/gas diffusion layer assembly based on the experimental interfacial contact resistivity. They showed that the contact resistant decreases as rapid as the clamping pressure. In addition, Zhou et al. [7] developed a 2D simulation and optimized the structure of the bipolar plate ribs to have better contact resistance. Wu et al. [8] proved that the contact resistance can be reduced by controlling the surface roughness of the bipolar plate and the fiber configuration of the gas diffusion layer. Zhou et al. [10] investigated the effect of non-uniformity of the contact pressure distribution on the electrical contact resistance. They proved that when there is no separation between two neighboring components, the electrical contact resistance cannot be reduced by improving the contact pressure distribution. Zhang et al. [11] proposed two semi-empirical methods for estimating the contact resistance between BPPs and GDLs based on an experimental contact resistance–pressure constitutive relation. Wen et al. [12] investigated the effects of different combinations of bolts configuration and clamping torque on the performance of a single PEMFC and a 10-cell stack using pressure sensitive films. They showed that the uniformity of the contact pressure distribution, the ohmic resistance and the mass transport limit current has linear correlations with the mean contact pressure. They also proved that increasing the mean contact pressure improves the uniformity of the contact pressure distribution and reduces the contact ohmic resistance. Montanini et al. [9] measured the clamping pressure distribution using piezo-resistive sensor arrays and digital image correlation techniques. They showed that increasing end plates stiffness leads to obtain more efficient load transmission mechanism. Wang et al. [13] used pressure sensitive films to compare their new clamping system with conventional clamping system and they concluded that their new clamping system has better contact pressure distribution than conventional one.

The purpose of this paper was to improve a two-dimensional model that can accurately prognosticate compression pressure distributions over the active area of the PEMFC stack. The active area of tested MEA was 400 cm^2 (20 cm × 20 cm). Simulation results were validated through experiments with pressure sensitive films to optimize the compression pressure distribution. For decreasing computation time, two-dimensional simulation was applied after verifying with three-dimensional simulation. The effects of end plates material and thickness, number of cells, position of the cell in the stack and sealant hardness on the contact pressure distribution of MEA were studied.

Description of the model

Geometry

The PEM fuel cell model geometry is illustrated in Fig. 1(a). The present model consists of end plates, current collectors, cooling plates, bipolar plates, MEA, sealants and fastening elements (bolts and nuts). The contact behavior between these components is nonlinear. It is assumed that gas diffusion layers are integrated into the membrane. Fig. 1(b) demonstrated the two-dimensional single cell model which includes all components of PEMFCs.

Dimensions of the fuel cell components which are used for modeling are as follows. The active area of MEA is 400 cm^2 (20 cm × 20 cm). Bipolar plates and cooling plates with dimensions of 295 mm × 295 mm × 3 mm are used. Current collectors are copper alloy with thicknesses of 4 mm and the same length and width as bipolar plates. In addition, the model comprises two end plates with dimensions of 350 mm × 350 mm and variable thickness. GDL and membrane dimensions are 202 mm × 202 mm and 295 mm × 295 mm, respectively. The thickness of carbon paper GDL is 0.235 mm and the thickness of membrane is 0.09 mm. All of the sealants have width and thickness of 3 mm and 1.15 mm, respectively. Designed sealant groove width is 6 mm for both bipolar and cooling plates. Moreover, designed sealant groove depths are assumed to be 0.76 mm and 0.95 mm for bipolar plates and cooling plates, respectively.

Mechanical properties

The mechanical properties of the fuel cell components are listed in Table 1.

Numerical simulation

Commercial finite elements numerical code ABAQUS has been used for simulation of the fuel cell behavior. Four-node bilinear plane-strain quadrilateral reduced integration elements (CPE4R) are used to mesh the components of the two-dimensional model. In order to reduce the size of the problem and simulation time, symmetry conditions were applied onto all internal section boundaries. The schematic diagram of a quarter-cell is shown in Fig. 2. In addition, the bolt load is applied as concentrated force on the end plate.

Fig. 3 shows three-dimensional model of the single cell. As shown in Fig. 3(a), only one eighth of three-dimensional sample was modeled due to its symmetric condition. Eight node linear brick reduced integration elements (C3D8R) are used to mesh the components of the model. Moreover, the bolts loads are applied on the washer exerted to the end plate which is shown in Fig. 3(b).

The membranes are very thin in comparison with GDLs. Therefore, their influence on the mechanical characteristics is negligible. In this work, the membrane layers are integrated into the GDLs similar to those given in Refs. [15,16]. In finite element model, magnitudes of bolts loads are adjusted to become equal to the real one. The applied pressure over the MEA varies from 0.5 MPa to 1.5 MPa for the PEM fuel cells reported in different studies [15,16]. In this article, the considered mean pressure is set as 1 MPa. The contact properties are assumed to be penalty with the friction of 0.3 for contact surfaces which one is sealant and other are 0.1.

In this paper, 60 Shore A EPDM[1] which is a kind of elastomer is used as fuel cell sealant. Generally, elastomer is assumed to be incompressible. Elastomer is often modeled as

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[1] Ethylene Propylene Diene Monomer.