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Evaluation of current distribution in a PEMFC using a magnetic sensor probe

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Abstract

Many methods for measuring current distribution in proton exchange membrane fuel cells (PEMFCs) have been developed because it is important to determine the fuel cell's operating conditions. A method for measuring current distribution in the stack using a tri-axial magnetic sensor probe has been proposed. The advantage of this method is that it does not affect the PEMFC, because the measurement is non-destructive and makes no electrical contact. In this study, the current distribution was investigated and evaluated under the steady and dry-out conditions in PEMFC cells.

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Keywords: proton exchange membrane fuel cell; current distribution; magnetic sensor; in-situ

1. Introduction

A proton exchange membrane fuel cell (PEMFC) generates power by a reaction of hydrogen and oxygen. The characteristics of the PEMFC are low operating temperature, rapid startup, and low acoustic noise. Therefore, this type of fuel cell is used in co-generation systems and fuel-cell vehicles. Its widespread commercialization will depend on its reliability and on fault diagnostics for the PEMFC stack.

Many diagnostic methods for determining current distribution have been developed for PEMFCs because the current distribution is the most important indicator the fuel cell's operating conditions. One of the methods is the segmented cell method with a passive resistor network [1]. However, this method has the disadvantages of complexity, cost, and inaccurate measurement, because the resistor network must be embedded in the cells and electric contact must be established. The other method for measuring current distribution in the cell uses magnetic sensors [2, 3]. These methods have enabled the mapping of the current distribution on a single cell with simple equipment. However, these methods cannot be applied to the stack.

We have proposed a method for measuring current distribution in the stack using a tri-axial magnetic sensor probe. The advantage of this method is that it does not affect the PEMFC, because the

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measurement is non-destructive and makes no electrical contact. In the past, the Nexa Power module under the steady state, and a 20-cell stack under flooding conditions, have been evaluated [4, 5, 6]. In this study, the current distribution was investigated and evaluated under steady and dry-out conditions in PEMFC cells.

Nomenclature

α_x, α_y	the magnetic field response values for the current
B_x, B_y, B_z	*x, y, z*-axis of magnetic flux density
B'	ratio between the z component and the *x, y, z*-axis magnetic flux density
i	stack current density
i_{jn}	measured point of current density
i_{xn}, i_{yn}	*x, y*-axis of current
S	area of measurement
r_{d}	decrease rate of magnetic flux density
E	over circuit voltage
A	fitting factor of activation overpotential
R	fitting factor of ohmic overpotential
m, n	fitting factor of concentration overpotential

2. Methodology

2.1. Current density measurement

PEMFC generates by chemical reaction of hydrogen and oxygen. The electric current generated by the PEMFC produces a magnetic field by the Biot-Savart law. In this study, the sensor probe measured this magnetic flux density in the fuel cell's cooling holes. The magnetic sensor was a tri-axis electronic compass (Aichi Micro Intelligent: AMI306). This sensor has dimensions of 2.0 × 2.0 × 1.0 mm and was embedded with Magneto-Impedance sensors. Each sensor outputs the magnetic flux density of the corresponding axis. Output values were recorded on a PC. In this study, the x-axis of magnetic flux density B_{x} was the cell width, the y-axis B_{y} was the cell height, and the z-axis B_{z} was perpendicular to the cell surface.

When the stack current is *n* A, the *x*-and *y*-axis of current i_{xn} i_{yn} are calculated by the reference axis of magnetic flux density B_x B_y and response value α_x α_y:

$$\begin{aligned} i_{xn} &= \frac{1}{\alpha_x}(B_{xn} - B_{x0}) \\ i_{yn} &= \frac{1}{\alpha_y}(B_{yn} - B_{y0}) \end{aligned} \tag{1}$$

B_{x0} and B_{y0} denote the x and y components of the magnetic flux density at 0 A, which are used for removing the effects of geomagnetism and the ambient magnetic field. The measurement point of current density is given by

$$i_{jn} = \frac{\sqrt{{i_{xn}}^2 + {i_{yn}}^2}}{S} \tag{2}$$

2.2. PEMFC system and operating conditions

The PEMFC system is shown in Fig. 1. Hydrogen and air was supplied to the anode without humidification and measured using a digital flow meter. The stack comprised two cells connected in series and the voltages were measured using a digital multimeter. A 160-W DC electric load (Takasago: FK-160L2Z) was used for all experiments aimed at evaluating the fuel cell stack performance. The ambient temperature was 25 ± 1°C. The relative humidity was 50 ± 5%.

The characteristics of PEMFCs differ by their flow rates. This study assumed the two cases shown Table 1. The current density was gradually increased and recorded at 2-min intervals in these cases. At each interval, the current distribution in the PEMFC was measured. The overpotentials in the polarization curve were analyzed by the fitting method using the following equation [7]:

$$V = E - [A\ln(i)] - R \cdot i - m\exp(n \cdot i) \tag{2}$$

In the H2 case, the magnetic flux density and current density distributions were measured at a constant voltage of 1.2V using the magnetic sensor probe.

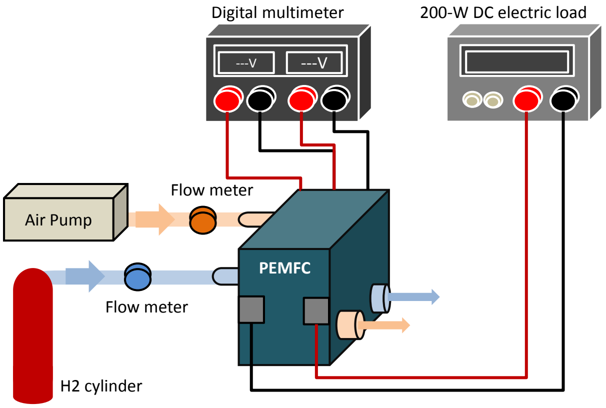

Fig. 1 Schematic diagram of the experimental system

Table 1. The case of the flow rate

Case	Anode		Cathode	
	Flow late (L/min)	Stoichiometric ratio at 15 A	Flow late (L/min)	Stoichiometric ratio at 15 A
H1	1	4.1	2	3.4
H2	2	8.1	4	6.8

3. Result and discussion

3.1. PEMFC characteristic each flow rate

Fig. 2 shows the polarization curves of the operating conditions. The maximum power was 32.0 W at 25 A in the H1 case. In the H2 case, the voltage decreased with higher current compared to the H1 case, because R was larger as shown in Table 2. Therefore, we determined that the membrane was being dried by the flow rate. The voltage was smaller in cell 1 than in cell 2. This was because the activation overpotential A was larger, as shown in Table 1.

Fig. 3 shows the current distribution in the H1 case. The maximum current density was 993.62 mA/cm^2 at (X, Y) = (81, 45). The minimum current density was 119.95 mA/cm^2 at (X, Y) = (45, 45). The current distribution tended to be concentrated at either end of the cell; this trend was similar to the H2 case and the previous study. The reason was the influence of the end terminals and was not the operating condition.

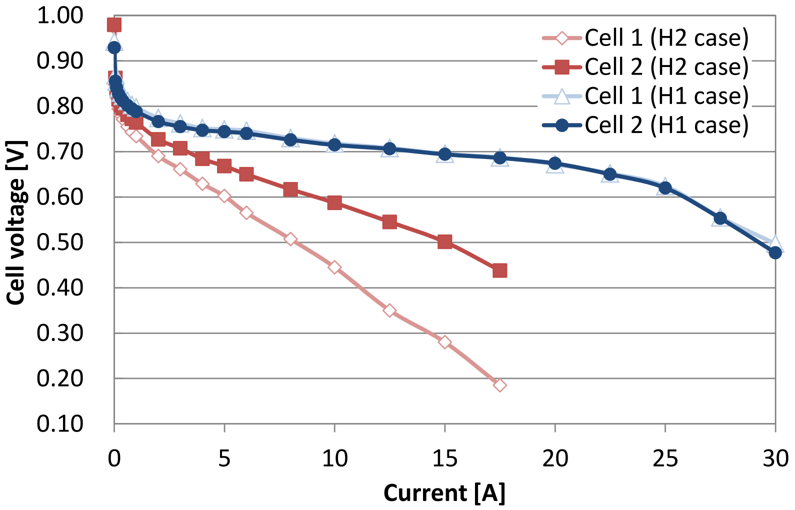

Fig. 2 Comparison of the polarization curves

Table 2 Fitted and calculated parameters

(a) H1 case

	R^2	*R*	*A*	*m*	*n*
Cell 1	0.995	0.126	0.021	0.068	1.814E-04
Cell 2	0.991	0.155	0.018	0.087	0.000E+00

(b) H2 case

	R^2	*R*	*A*	*m*	*n*
Cell 1	0.992	0.206	0.054	0.057	4.049E-03
Cell 2	0.999	0.245	0.028	0.106	1.735E-03

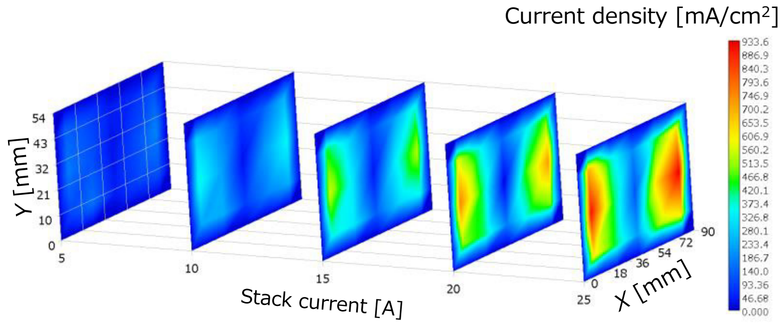

Fig. 3 Current distribution in the H1 case

3.2. Current distribution at constant voltage in dry condition

The H2 case featured dry conditions in the cell. The magnetic flux density and current density distributions were measured at a constant voltage using the magnetic sensor probe in this case. Figure 4 shows the current distribution at 5-min intervals. Each cell's current was 6.8, 6.1, 5.5, 5.2, and 4.9 A, respectively. In most cases, the measured current density decreased at each interval. In particular, at (X, Y) = (81, 9), the current density at 20 min was 40.4% smaller than at the initial state. We believe that this point was being dried by the air flow because of the nearby cathode outlet.

However, at (X, Y) = (27, 9) and (63, 45), the current density was rarely different from the initial state. In the previous study [5, 6], the Z component of magnetic flux density B_z' was used to evaluate faults such as flooding because B_z correlates to the current parallel to the cell surface. This ratio is defined as follows:

$$B_z' = \frac{B_z^2}{B_x^2 + B_y^2 + B_z^2} \tag{3}$$

The average B_z' at (X, Y) = (27, 9), (63, 45) in the experiment were 46.9 and 34.9%, respectively. Therefore, these points were determined to have a large current parallel to the cell surface because of such characteristics as the flow channel and the individual specificity of components, except where being dried by the large flow rate. At the other points, the maximum of B_z' at 20 min was 2.9% smaller than the initial state. This value was smaller than it was for the flooding condition.

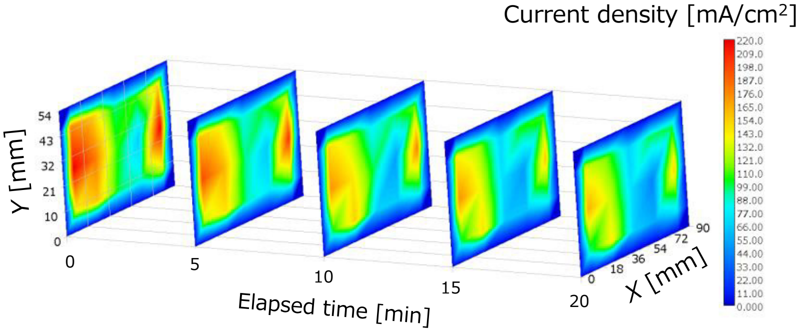

Fig. 4 Current distribution at a stack voltage of 1.2 V in the H2 case

4. Conclusion

We have proposed a measurement method for current distribution in the stack using a tri-axial magnetic sensor probe. In this study, the current distribution was investigated and evaluated under steady and dry-out conditions in PEMFC cells.

In the H2 case, the voltage decreased with higher current compared to the H1 case because the membrane was believed to be dried by the flow rate. The current distribution tended to be concentrated at either end of the cell because it was influenced by the end terminals.

In most cases, the measured current density at constant voltage decreased at each time interval. In particular, the current density near the cathode outlet was 40.4% smaller than the initial state because of the large air flow. At (X, Y) = (27, 9), (63, 45), the current density was rarely different from the initial state. The average B_z' at these points were 46.9 and 34.9%, respectively. Therefore, these points were determined to have a large current of parallel to the cell surface.

From these results, the measurement method is found to provide each point of the tri-axis magnetic flux density and the current density of the PEMFC for these conditions. The study shows that it is useful to evaluate the current density and faults on the PEMFC cell and stack using this method.

Acknowledgements

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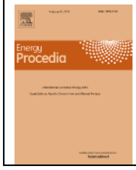

Biography

He received Master of Engineering from University of Tsukuba in 2014, and is presently a doctoral course student at University of Tsukuba. His research interests are fuel cell, FCHV, and Life Cycle Assessment.