Energy Proceedings
Vol 31, 2023
ISSN 2004-2965

Prototype and Calibration of Polymer Electrolyte Membrane Fuel Cell Signal Amplification Sensor

Xiangfeng Wu[2,3] , Xuezhe Wei[2, 3*] , Haifeng Dai[2, 3] , Xueyuan Wang[1, 2]

[1]Department of Control Science and Engineering, Tongji University, 4800 Caoan Road, Shanghai, 201804, China
[2]Clean Energy Automotive Engineering Centre, Tongji University, 4800 Caoan Road, Shanghai, 201804, China
[3]School of Automotive Studies, Tongji University, 4800 Caoan Road, Shanghai, 201804, China

ABSTRACT

A distributed signal amplification sensor is designed and fabricated in this study for real-time detection of the distribution state of voltage signals in the fuel cell plane. The sensor employs a multilayer rigid laminated structure PCB technology to realize the functions of segment current collection, current conduction, and real-time signal amplification. The sensor has the features of realizing instant amplification of distributed signals in the fuel cell plane, shortening the signal transmission distance in the circuit, and avoiding transmission loss and interference. At the same time, the PCB design process avoids the buried resistance process, controls cost, and considers maintainability, increasing the feasibility of practical engineering applications. The total resistance of the measuring circuit of all zones remains unchanged in theory. In this study, a measurement system for calibrating PCB sensors was established, and all segment circuits in the plane were measured according to the theoretical value of the working current of the single-cell during normal operation. The segment current is loaded gradually from low to high. Therefore, the measurement accuracy of segment circuits can be determined respectively.

Keywords: Polymer electrolyte membrane, Printed circuit board, Distributed signal amplification sensor, Segment circuit calibration, Measurement accuracy

NONMENCLATURE

PEMFC	Polymer electrolyte membrane fuel cell
MEA	Membrane electrode assembly
PCB	Printed circuit board
DSAS	Distributed signal amplification sensor
SC	Segment calibration
N	Segment number
SN	In-plane segment
In	Segment current(A)
Vn	Segment ohmic voltage drop(V)
R0	Shunt resistor(Ω)
A	Segment measure accuracy
I_s	Segment load current
$I_{s\ data}$	Actual current
V_d	Drive voltage
$V_{s\ data}$	Segment amplified voltage

1. INTRODUCTION

Proton electrolyte membrane fuel cell (PEMFC) has become an important research object in energy because of its high efficiency, energy-saving, and zero pollution emission [1,2]. However, online measurement is not accessible due to the complex reaction mechanism and closed structure. In recent years, a significant number of model simulations and experimental verification have been conducted for internal parameters to optimize and improve the performance of fuel cells [3,4].

Based on the current detection level of the fuel cell, it is difficult to layout sensors to directly measure the internal cell information considering the closed structure of fuel cells. Invasive measurement methods will change the cell structure and increase the production difficulty, impacting the operating performance of fuel cells [5,6]. In addition, although non-invasive monitoring techniques can visualize changes in internal fuel cell parameters, they are not suitable for practical vehicle applications because of their more complex test systems and expensive testing [7-9].

Printed circuit board (PCB) technology is often used to study the current density distribution and internal polarization process of PEMFC. At present, according to the different principles of current sensor acquiring and converting current signal, the current measurement technology of PCB can be divided into several categories: Ohm's law [10,11], hall principle [12,13], and soft magnet magnetization [14].

Although the principle of Ohm's law is relatively simple in the above current measurement methods, it will lead to the loss of output voltage and the complexity of the PCB production process. The signal of the hall principle is easily disturbed. Magnetization methods also have problems such as the PCB embedding resistance process and thickness increase. Therefore, it is necessary to take some measurement means to amplify the weak voltage signal for acquisition to reduce the transmission loss and interference. In this paper, a printed circuit board (PCB) sensor is developed for real-time amplification and acquisition of planar potential signals of the fuel cell. PCB sensor includes three main functions: segmented current acquisition, segmented sampling, and signal amplification. The accurate measurement of the fuel cell plane is realized by expanding the PCB. At the same time, it can realize the real-time amplification of distributed signals in fuel cells, shorten the transmission distance of signals in the circuit, and avoid signal transmission loss and interference. In the design process of sampling resistance, the buried resistance process of PCB is avoided, the technical difficulty of PCB production is reduced, and the feasibility of practical engineering application is increased. In addition, the calibration experimental test system of the PCB sensor is designed to determine the measurement accuracy of each circuit in the segment, which is convenient for the practical application of the PCB sensor in fuel cell tests.

2. PROTOTYPE AND CALIBRATION

2.1 PCB Sensor Prototype

The PCB sensor for real-time amplification and acquisition of fuel cell in-plane distributed voltage signals adopts a four-layer rigid laminated structure. The PCB sensor prototype is shown in Fig 1. Its top layer corresponds to an effective active area of 25 cm2 for membrane electrodes. It is designed with nine segments (3*3 array) sink gold pads to realize the segment current collection function (shown in Fig 1). All segment pads are designed with the same dimensions to ensure the theoretical consistency of the total resistance of all measurement circuits.

The top layer pads are designed with metalized conductive through-holes, and the through-holes of the segments are connected to the circuits of other layers to realize the conduction of the segment currents. The layout characteristics of through-holes consider the current size, segment symmetry, consistency, and other factors. The components for current detection and signal amplification are arranged on the bottom layer of the PCB and correspond to the position of the segment pads, respectively. The surface mount process is used to improve the integration of the sensor and shorten the current path. The design of the middle layer circuit of each segment and the way of crossing holes are kept consistent. Meanwhile, using the four-wire connection method improves the measurement accuracy of the ohmic voltage drop. Each segment current through the middle layer of the through-holes after flowing through the PCB bottom corresponding shunt resistor after convergence to the bottom sink gold pad. The voltage signal line is led from the middle of the resistor pads and connected to the signal amplifier corresponding to the segment. The signal is connected to the PCB connector after amplification.

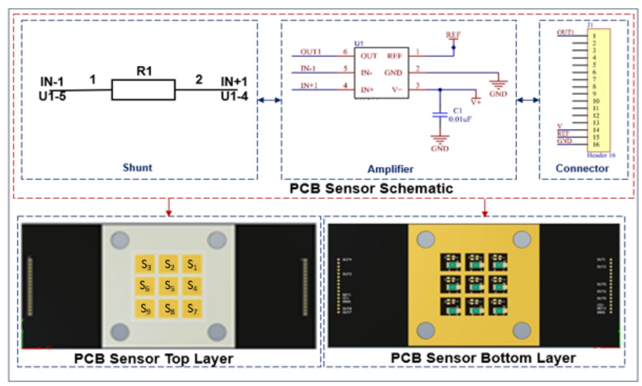

Fig 1 PCB seneor Prototype

The PCB sensor design method used above avoids the complex process of component buried resistance, reduces the technical difficulty of production, and achieves maintainability, increasing the feasibility of practical engineering applications. This PCB sensor can be used in fuel cell in-plane current density distribution measurements and multi-segment electrochemical impedance spectroscopy distribution experiments.

2.2 Segment Calibration Test

The PCB sensor segment calibration test system diagram is shown in Fig 2. The calibration test bench is mainly composed of a power supply, PCB sensor, precision multimeter, data acquisition equipment, and LabVIEW display. The power supply can provide the segment load currents Is, and drive voltage Vd for the amplifier chips. The high precision multimeter can show the actual current of the circuit Is data. The data acquisition equipment captures segment amplified ohmic voltage drop $V_{s\,data}$. In the calibration experiment, the PCB sensor segment unit is separately connected in series in the circuit. PCB sensor drive voltage Vd range is 2.7~26V, and is powered by the GPS-4303C DC power supply, which also supplies segment load current Is to the circuit. The type Keysight 34461A multimeter displays the actual current Is data in the circuit in real time. This current is the segment average theoretical value of the experimental current in the fuel cell bench test. The load is loaded on the independent segments from small to large. Continuously adjust the power supply near the theoretical current value so that the circuit current shows the set theoretical value on the multimeter. At this point, the voltage drop V_s through the segmented resistor is captured using a data acquisition equipment and through LabVIEW display. The segment current I_s on the shunt resistor can be calculated using Ohm's law equation and segment amplifier magnification factor. Therefore, the segment current value is compared with the measured value of high-precision digital multimeter to calculate the measurement accuracy of segmented circuit respectively.

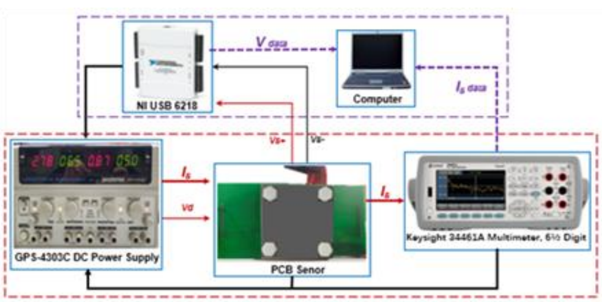

Fig 2 Segment calibration test system diagram

The PCB sensor segment measure accuracy A can be expressed by the following equation (1):

$$A = \frac{\left(\frac{V_{sdata}}{R_0} * \frac{1}{Gain}\right) - I_{sdata}}{I_{sdata}} * 100\% \tag{1}$$

Where *Gain* is the magnification factor, the PCB sensor segment calibration accuracy is shown in Fig 3. From the results of the calibration of the PCB sensor segments in Fig 3, it can be seen that the relative error between the measured value of the segment and the standard value is controlled to within 3%.

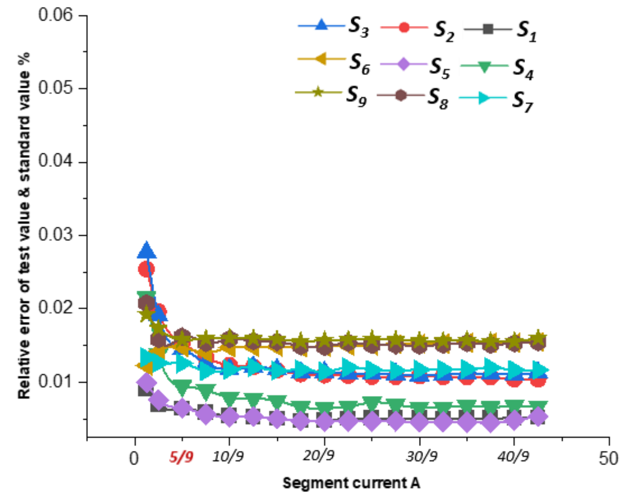

Fig 3 Segment calibration accuracy

In addition, it can also be found that under a small current load, the error range of this PCB sensor is a little larger than the high current, and when the current gradually increases, the accuracy of the sensor tends to stabilize, and the measurement error is basically controlled within 2%.

2.3 Conclusions

In this study, a distributed signal amplification sensor is developed for real-time detection of the distribution state of the voltage signal in the fuel cell plane. The sensor realizes the functions of segmented current acquisition, current conduction, and real-time signal amplification. It has the features of realizing instant amplification of distributed signals in the fuel cell plane, shortening the signal transmission distance in the circuit, and avoiding transmission loss and interference. It can be applied to measure the distribution of in-plane current density and the distribution of in-plane partitioned electrochemical impedance spectra of fuel cells. The PCB production technology selected for this sensor can avoid the buried resistance process, control the cost, and consider the maintainability, increasing the feasibility of practical engineering applications. This study established a measurement system for calibrating the PCB sensor. All segment circuits in the plane were measured and calibrated separately, and the measurement accuracy of the segmented circuits was determined.

ACKNOWLEDGEMENT

This work is financially supported by Tongji University's clean energy automotive engineering center.

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