VI.4 Modular, High-Volume Fuel Cell Leak-Test Suite and Process

Ian Kaye (Primary Contact), Ru Chen, Matt Mendez
UltraCell Corporation
399 Lindbergh Avenue
Livermore, CA 94551
Phone: (925) 455-9400; Fax: (925) 455-7750
E-mail: ikaye@ultracellpower.com

DOE Technology Development Manager: Pete Devlin
Phone: (202) 586-4905; Fax: (202) 586-9811
E-mail: Peter.Devlin@ee.doe.gov

DOE Project Officer: Lea Yancey
Phone: (303) 275-4944; Fax: (303) 275-4753
E-mail: Lea.Yancey@go.doe.gov

Contract Number: DE-FG36-08GO18054

Subcontractors:
- Pacific Northwest National Laboratory (PNNL), Richland, WA
- Cincinnati Test Systems (CTS), Cleves, OH

Project Start Date: September 1, 2008
Project End Date: August 31, 2011

Objectives

- Design a modular, high-volume fuel cell leak-test suite capable of testing in excess of 100,000 fuel cell stacks per year (i.e., 50 fuel cell stacks per hour).
- Perform leak tests in-line during assembly and break-in steps.
- Demonstrate fuel cell stack yield rate greater than 95%.
- Reduce labor content to 6 minutes.
- Reduce fuel cell stack manufacturing cost by 80%.

Technical Barriers

This project addresses the following technical barriers from the Manufacturing section (3.5.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(F) Low Levels of Quality Control and Inflexible Processes

Contribution to Achievement of DOE Manufacturing Milestones

This project will contribute to achievement of the following DOE milestones from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 9:** Select stack assembly processes to be developed. (4Q, 2010)
- **Milestone 10:** Develop automated pilot scale stack assembly processes. (4Q, 2012)
- **Milestone 12:** Demonstrate pilot scale processes for assembling stacks. (4Q, 2013)

Accomplishments

- Completed analysis of fuel cell stack manufacturing processes. The analysis includes all manufacturing procedures, throughput time, labor time, yield, and failure modes.
- Completed the survey of mechanical properties of fuel cell stack components.
- Investigated and selected leak-test methods for the leak-test suite.
- Created specification for fuel cell leak-test suite lab prototype.
- Working on the design of leak-test suite lab prototype.

✧ ✧ ✧ ✧ ✧

Introduction

There are three fluid circuits in a fuel cell stack. Any fluid leakage between these circuits or to the external atmosphere leads to reduced individual cell or stack performance and results in a failure during stack testing. Fuel cell stacks are typically hand assembled and tested, and it is very time-consuming. Furthermore, the leak-test equipment is often composed of expensive analytical devices, with extensive and excessive capabilities, that are not well suited to rapid testing of stack assemblies in medium- or high-volume manufacturing environments. High labor content and expensive test equipment limit the amount of online leak checks during the assembly process, leading to high scrap rates and low yields.

The development of a Modular, High-Volume Fuel Cell Leak-Test Suite and Process is proposed to address these challenges by reducing labor content; providing more robust, high confidence automated testing; and increasing the speed and throughput at which manufacturing is performed. Each leak test component will be highly specialized to its specific task and optimized for high throughput, thereby allowing for dramatic cost savings. A variety of methods will be employed to test for leaks between the fuel cell fluidic paths and the environment during the entire process from build to break-in to final test. The test suite will enable manufacturers to select modular test components as needed.

Approach

Six leak-test methods were proposed in the project. These tests include crossover current, current interrupt, voltage decay, pressure decay, flexo-tiltometer test, and fuel cell sensor for coolant leak. These methods will be investigated, and some will be selected to implement in the leak-test suite. These tests will automatically perform in-line during fuel cell stack manufacturing. The leak-test methods not only check the overall leakage, but also identify the location of leak and accelerate the diagnostics and remediation of fuel cell stacks.

The phase I of the project focuses on the analysis of current manufacturing processes, stack failure modes, and leak-test processes. A variety of leak-test methods will be surveyed, and recommendations for the leak-test suite will be made. The leak-test suite prototype will be designed, fabricated, and evaluated. A leak-test suite with 50 stacks per hour capability will be designed. Phase II will focus on pilot production line modification, leak-test suite fabrication, integration, and verification. A limited production test run will be carried out to validate the 50 stacks per hour operation.

Results

We completed the analysis of stack manufacturing and assembly processes. Usually, stack manufacturing includes parts preparation, stack assembly, compression, leak test, break-in, performance test, and leak test after performance test. Qualified stacks are then integrated into fuel cell systems. All the steps are carried out manually, and the process is labor intensive and time-consuming. The throughput time (the elapsed time between parts entering and stack exiting the manufacturing process) is about several hours. The dominant factor is the break-in process, and reduction of break-in time has a huge impact on the final design of leak test suite, especially flexo-tiltometer. Typical break-in time for a phosphoric acid/polybenzimidazole membrane electrode assembly (MEA) is 16–24 hours. By MEA pretreatment and conditions optimization, UltraCell is able to reduce the break-in time to several hours. The cell voltage reaches more than 95% of the maximum performance in a short period of time after the beginning of the break-in process. The yield of the stack build is not stable, and it highly depends on the quality of incoming parts, especially the MEA, and the skills and experience of the stack builders. There is a great opportunity to improve the stack yield. Several stack failure modes during manufacturing have been identified. Initial work was focused on developing linkages between common stack failure modes and the underlying root causes. Methods for screening these root causes out earlier in the manufacturing process, through incoming material control and in-line measurement, will then be developed. To this end, PNNL and UltraCell have begun review and analysis of the stack build history in an effort to better understand the various failure modes, their root causes, and the component and process parameters which contribute. The inspection data of bipolar plate (thickness, socket depth, flow channel depth, and flatness) were collected. The dimensional variation of stack components was analyzed to determine whether it is a major source of stack failure.

A variety of fuel cell components, provided to PNNL by UltraCell, were surveyed using dynamic mechanical analysis. The first objective was to ensure that quality data could be obtained on the instrument available and to understand this particular instrument's limits. Secondly we wished to examine various dynamic mechanical tests and begin to understand which would be most useful in a plant assembly line. Third, we wished to qualitatively understand the basic mechanical properties of each component. All tests so far were conducted in a compression mode. The following tests were used for this round of experiments: static stress scan, creep and recovery, frequency scan, and dynamic temperature scan. Compressive Young's modulus of individual fuel cell stack component can be obtained from the static stress scan test. The creep of stack components under constant load can be obtained from the creep and recovery test. The frequency scan and dynamic temperature scan are not very informative for some gaskets due to the small thickness. The static stress and creep and recovery tests are very important for the selection of materials with better sealing properties. The test results also help us better understand the stack behavior during manufacturing and operation, identify the root causes of fuel cell stack leakage, and reduce the stack failures.

Several leak-test methods were investigated. They are the crossover current test, current interrupt test, voltage decay test, and pressure decay test. In summary, the crossover current test, current interrupt test, and voltage decay test can be used to detect crossover leak in fuel cell stacks. All three methods are capable of pinpointing the location of crossover leaks. However, the current interrupt test is not very sensitive, and it does not meet the detection limit required for fuel cell stacks. Both the crossover current test and voltage decay test have good sensitivity and are easy to implement. These two methods and the pressure decay test will be included in the fuel cell stack leak-test suite and laboratory prototype. Some results of these tests are shown in Figures 1, 2, and 3.

UltraCell, PNNL, and CTS worked together to develop a specification for the leak-test suite laboratory prototype. The flowchart of the test suite is shown in Figure 4. The specification includes required functions, detail procedures to perform these functions, hardware, software, graphical user interface, gas interface, electrical interface, heating system, and compression stand. CTS is currently working on the mechanical design of the fuel cell test fixture. This fixture is comprised of components which will:

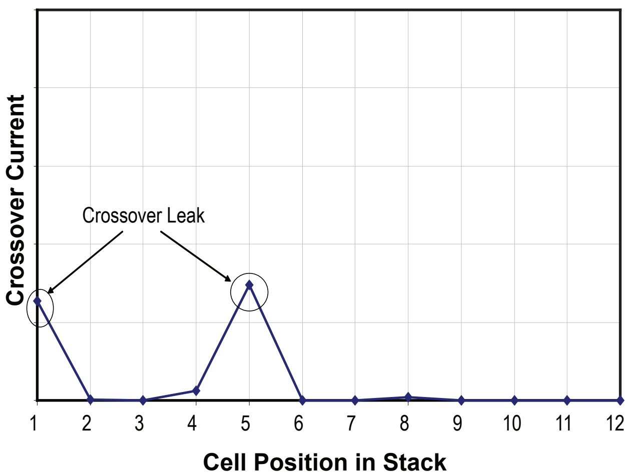

FIGURE 1. Crossover Current Test (fuel cell with crossover leak shows high crossover current)

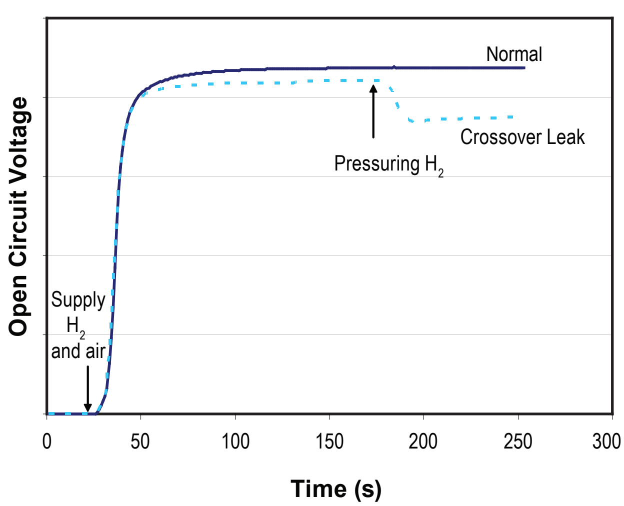

FIGURE 2. Open Circuit Voltage (OCV) Decay Test (fuel cell with crossover leak shows low OCV and high decay when hydrogen is pressurized)

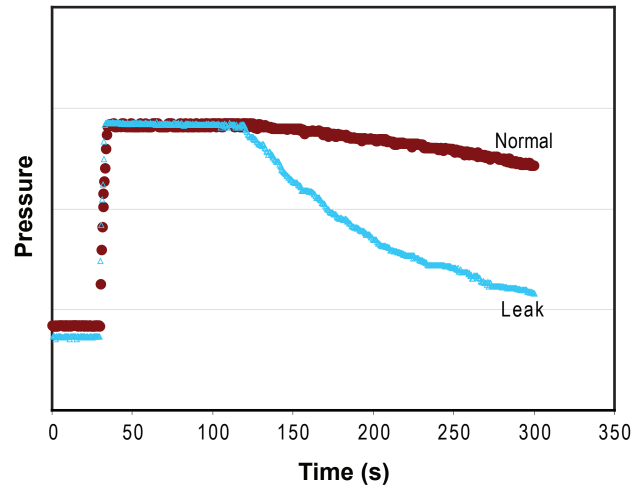

FIGURE 3. Pressure Decay Test (fuel cell with leak show high pressure decay)

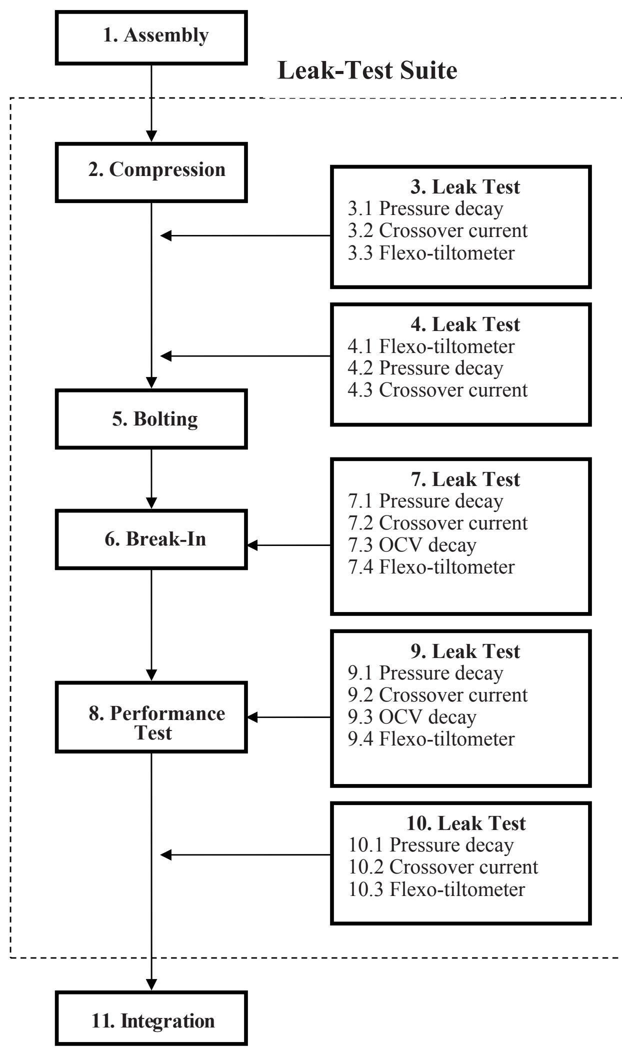

FIGURE 4. Leak-Test Suite and Processes

- Accurately locate and maintain the fuel cell in the fixture.
- Provide sealing mechanisms to provide leak-free connections between the fuel cell and the leak test equipment.
- Provide a means of accurately applying static and dynamic compression force to the fuel cell stack.
- Provide mounting locations for height sensors to measure fuel cell compression.
- Provide for location and application of an electrical interface to monitor the fuel cell performance.
- Provide for heating/cooling and temperature monitor of the fuel cell assembly.
- Provide a means to torque tie bolts while the stack is compressed in the fixture.
- Provide change tooling as necessary to support testing of fuel cell stacks with different number of cells.

Conceptual design of the sealing mechanism for the gas ports has been completed. Work is continuing in the design of the electrical connectors, as well as the part fixture and heating components. CTS is currently working on the specification of the control, electrical, pneumatic, and hydraulic hardware for testing of the fuel cell stack assembly. As the specification for the flexo-tiltometer forces and frequency are refined and confirmed, a hydraulic package will be selected and quoted.

Conclusions and Future Directions

The conclusions include the following:

- Completed the analysis of fuel cell stack manufacturing processes. The stack break-in process is a dominant factor determining the throughput time, and has a significant impact on the leak-test suite design. Several failure modes have been identified. There is room to improve the stack yield.
- Investigated and selected leak-test methods for leak-test suite. Crossover current, open circuit voltage decay, and pressure decay will be included in the leak-test suite.
- Investigated fuel cell stack components. Dynamic mechanical analysis is an excellent method to study mechanical properties and behavior of a fuel cell stack and its components.
- Created specification for leak-test suite lab prototype. Detail procedures have been written.
- Started design leak-test suite lab prototype.

Future directions include the following:

- Design and fabricate leak-test suite lab prototype with 5 parts per hour capacity.
- Test leak-test suite lab prototype and generate stack quality metrics.
- Design leak-test suite with 50 parts per hour capacity.

FY 2009 Publications/Presentations

1. Kaye, I. et al., "Modular, High-Volume Fuel Cell Leak-Test Suite and Process", presentation at the 2009 Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting, Arlington, Virginia, May 18–22, 2009.