V.K.5 Fuel Cell Balance of Plant Reliability Testbed*

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*Congressionally directed project

Objectives

There are two primary objectives of this project:

- To establish a testing program resulting in a reliability database for candidate proton exchange membrane (PEM) fuel cell balance-of-plant (BOP) components; and
- To enhance the education of the technical workforce trained in PEM fuel cell system technology.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section (3.6) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan: Technology Validation:

(A) Lack of Fuel Cell Vehicle Performance and Durability Data

(D) Maintenance and Training Facilities

This project also addresses the following technical barriers from the Education section (3.9) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan: Education:

(D) Lack of Educated Trainers and Training Opportunities

Technical Targets

Reliability of the fuel cell system BOP components is a critical factor that needs to be addressed prior to fuel cells becoming fully commercialized. The goal of this project will be to develop a series of test beds that will test system components such as pumps, valves, sensors, fittings, etc., under operating conditions anticipated in real PEM fuel cell systems. Results will be made generally available to begin removing reliability as a roadblock to the growth of the PEM fuel cell industry.

Stark State College students participating in the project, in conjunction with their coursework, will gain technical knowledge and training in the handling and maintenance of hydrogen, fuel cells and system components as well as component failure modes and mechanisms. This fuel cell workforce development program will result in students trained in PEM fuel cell system technology.

The Technology Validation sub-program element does not develop new component technologies or sub-system configurations and, therefore, does not have technology targets. However, the components must support the fuel cell stack which has the following technical target for longevity:

TABLE 1. Progress toward Meeting Technical Targets for BOP Components for Transportation Applications

Characteristic	Units	2010/2015 Stack Targets	2009 Project Status
Durability with cycling At operating T ≤80°C	Hours	5,000	To be determined

Accomplishments

- Students are being trained to the Hydrogen Safety Plan.
- Students have learned a greater depth of LabVIEW programming and are using a broader range of equipment and software programming techniques.
- Two of the test beds have been designed.
- Component assessments have been conducted.
- Test beds are in the process of being assembled.

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Introduction

One of the major challenges that needs to be addressed by the fuel cell industry prior to full commercialization is the reliability of the components that comprise the complete system, particularly the BOP. As a potential developer and integrator of fuel cell systems, Stark State College of Technology's team member, Lockheed Martin, has identified BOP component reliability as a critical factor that needs to be addressed before fuel cell systems will be incorporated into aerospace platforms.

Approach

Stark State College and Lockheed Martin will develop a series of test beds that will test fuel cell system components such as pumps, valves, sensors, fittings, etc., operating under conditions anticipated in real PEM fuel cell systems. The test beds will operate continuously for months, or years, until a component fails. Parts that continue operating will have demonstrated lifetime for potential fuel cell systems. Parts that fail will be removed (the rest of the test bed restarted) and examined to learn why they failed. Feedback will be provided to manufacturers for product improvement. Results will be made generally available to begin removing reliability as a roadblock to the growth of the PEM fuel cell industry. A total of three test beds will be developed in this project – two at Stark State College and one at Lockheed Martin. Those at the College will be built and monitored by engineering technology students as part of their education program. A database of parts, operating conditions and lifetime data will be generated and updated regularly.

Results

A fuel cell system consists of a fuel cell and its supporting BOP – the pumps, valves, sensors, fittings, piping, etc. needed to turn a fuel cell into a useful power plant. Components in this complex system can have long-term exposure to hydrogen, air (oxygen), high purity water, heat and other chemicals. The BOP reliability test beds will be a simplified design, simulating the conditions of an operating fuel cell. The first two test beds are designed to replicate humidified hydrogen exposure in the PEM fuel cell at ≤80°C. These test beds are a hydraulic loop simulation of the fuel cell system to test the piping, connectors, sensors, valves, pumps, etc., without the fuel cell. Testing will be done to simulate the flow rates, temperature and pressure of operation, initially under a humidified nitrogen system with eventual operation under reactant conditions. This exposure would simulate the anode flow areas just before the fuel cell entrance and conditions in the hydrogen re-circulation loop. The humidified hydrogen would be circulated using a hydrogen blower such as the Parker Hannifin Model 55™ Univane rotary compressor [1].

As required by DOE, a Hydrogen Safety Plan was prepared to address the issues of working with hydrogen. The greatest hazard is combustion from leaking hydrogen. A failure modes effects analysis of possible hazards leading to the accumulation of hydrogen and subsequent combustion was assessed for the test bed with the associated risk mitigation to limit or eliminate the components necessary to support a fire. All participants in the project are required to be trained in the safe use of hydrogen and compliance with the Hydrogen Safety Plan. Renovation of the project laboratory space at Stark State College has begun to comply with the safety standards.

Test bed component selection is also critical to safe operation with hydrogen. Electronic devices required one or more of the following: Factory Mutual compliance, intrinsically safe designation, compliance with Class I, Division 1, Group B operation or designated for hydrogen use. Stark State students have been selecting components and monitoring sensors for the operation of the test bed. All test bed equipment is commercial off-the-shelf, as components requiring non-recurring engineering costs or modification for fuel cell use were outside the scope of this project. Instruments were chosen for their compliance with materials and flow specifications. Students have been exposed to the various sensor instrumentation associated with fuel cells as well as the instrumentation and operation of fuel cells in the classroom.

Figure 1 shows the test bed process flow diagram. The test bed design can be viewed as two "separate" pieces. The upper flow diagram designated "Life Cycle Test" is the loop that will recirculate our humidified hydrogen. This loop will be pre-tested with nitrogen for leaks before hydrogen usage. Operating conditions will be 50 psi static, 80°C, 70-95% relative humidity and 6-7 SCFM flow rate in the closed-loop system. The lower loop is designated for dry nitrogen or air only. This consists of the blower platform and the dynamic response test system. This section is for the pre- and post-test validations in our reliability testing, pump performance mapping and pressure decay (leak) testing of the components.

Operation of the test bed requires participating students to have a greater depth of understanding in LabVIEW programming and exposure to a broader range of software programming techniques. The embedded controller requires LabVIEW programming and compiling to make a stand-alone program for data acquisition, control and analysis of the data. In addition, National Instruments DIADEM has been explored for its extra capability in data acquisition, data storage and analysis.

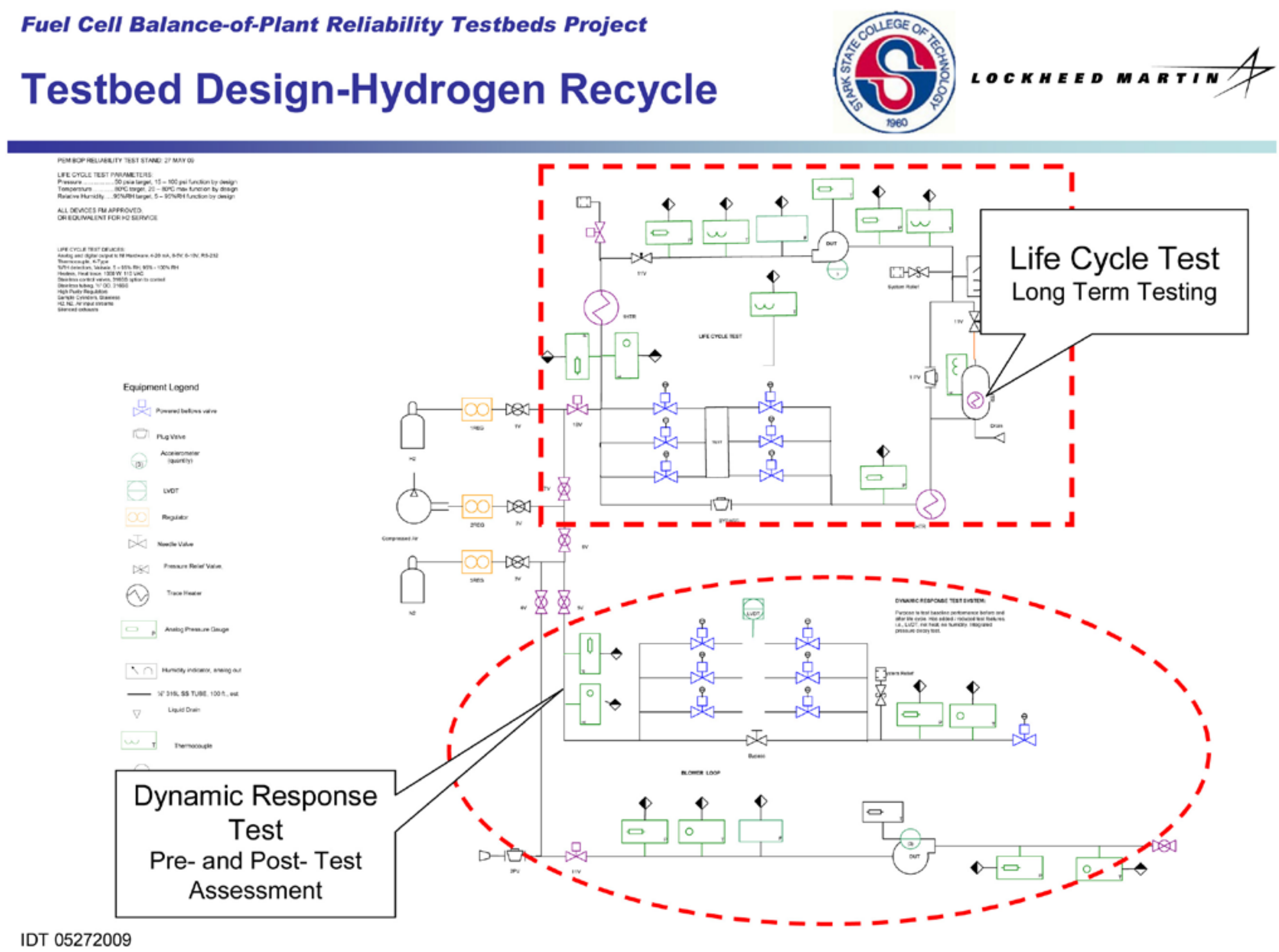

FIGURE 1. Fuel Cell BOP Reliability Test Bed Design

Test procedures are being developed to assess the reliability of the device under test.

For a complete reliability analysis, each candidate component in the fuel cell system has been identified. Design failure mode effects analysis for each component predetermines the likely failure modes. These failure modes establish the monitoring instrumentations necessary for the test bed, any additional test procedures required to establish and verify baseline performance, and aid in defining what constitutes a component failure to the system. For example, test valves will have separate static leak tests done before and after test bed operation to verify seal integrity. Another valve failure effect is actuation delay over time; this effect can be measured by monitoring linear variable differential transformers coupled to the actuator to determine any decrease in performance over time or operational failure.

Selection of the BOP components must be made on the basis that the materials chosen will affect the fuel cell lifetime. In the test bed assembly and testing procedures, care must be taken to minimize contaminants. Impurities such as iron, nickel or chromium must not be allowed to affect the fuel cell catalyst or membrane. The high purity water used in humidifying the system must be checked for changes in conductivity that would indicate signs of leaching, contamination arising from material contact with the humidified gas stream. Setting up a system with the appropriate level of purity requires choosing components with no incompatible materials.

Finally, the test plan will take advantage of existing vendor reliability data to minimize testing time or sample size. By employing Weibayes Analysis (i.e., the zero failure method) on the component's previous history, vendor data can be leveraged to obtain confidence and reliability estimates without the time and expense of testing to failure, resulting in fewer samples being tested to a greater confidence level.

Conclusions and Future Directions

Safety protocols are in place at both Stark State College and Lockheed Martin locations to ensure the safety of individuals working with and around the reliability test beds being created through this project. The first two BOP reliability test beds are in the process of being assembled and instrumented for reliability testing. This project continues as a cooperative program between industry and an educational institution for hands-on training of the PEM fuel cell workforce.

Future Work

- Student and subcontractor completion of test bed assembly and control logic.
- Operation of the test beds to obtain reliability data.
- Failure analysis of failed components.
- Construction and instrumentation of the third BOP reliability testbed in the coming academic year.

FY 2009 Publications/Presentations

1. *Fuel Cell Balance of Plant Reliability Testbed*, Vern Sproat, P.E., poster session at DOE Hydrogen Program Annual Merit Review, Washington, D.C., May 2009.

References

1. *Cost Analyses of Fuel Cell Stack/Systems*, J. Sinha, S. Lasher, and Y. Yang, DOE Hydrogen Program Annual Report, V.A.3.