IV.H.8 Sensor Development for PEM Fuel Cell Systems

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Objectives

- Define the requirements for flow, pressure, temperature, and humidity sensors for use in hydrogen PEM fuel cell applications. Verify the requirements through a broad market survey.
- Develop physical sensors and demonstrate their ability to meet the necessary requirements in a laboratory environment.
- Optimize sensing technologies and package into prototype samples for third party fuel cell system testing and evaluation.
- Demonstrate the sensors on operating fuel cells and reformers at third party facilities.

Technical Barriers

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

- B. Sensors

Approach

- Establish requirements for each physical sensor.
- Research and deploy existing technologies and develop packaging strategies to minimize sensor cost.
- Design prototype sensors that will be fabricated at Honeywell and tested in third party fuel cell systems.
- Analyze laboratory and third party test results.

Accomplishments

<u>Humidity Sensor</u>

- Specifications have been defined.
- Package concept evaluations are completed.
- Package material selection has been made.
- Micro-filter research and performance testing in a condensing environment has been completed.
- Initial condensation recovery tests are complete.
- Global research effort of alternative and emerging technologies indicates that deployed Honeywell technology is best in class.

- Modeling and empirical testing have shown that temperature control at the sense die will allow a uniform dew point shift.
- Benchtop-tested the heater and packaging concept.
- Material research and selection for all surfaces exposed to the fuel cell media have been completed.

Flow Sensor(s)

- Specifications have been defined.
- Package concept evaluations are completed.
- Package material selection has been made.
- Micro bridge technology has been applied to a solid glass substrate that utilizes backside interconnects (TTW – Through the Wafer).
- Feasibility study of TTW technology on Quartz substrate has been completed.
- Research effort was initiated for a back-etched silicon substrate. This will provide a production process to minimize sensor cost.
- Application-Specific Integrated Circuit (ASIC) selection was made allowing package size reduction, cost reduction, inclusion of diagnostics, and gain/linearization of the output function.
- Initial concept validation of rugged glass sense die development with backside interconnects has been completed.
- Performance-tested mechanical bypass sampling technology.
- Material research and selection for all surfaces exposed to the fuel cell media have been completed.

Pressure Sensor

- Specifications have been defined.
- Package concept evaluations are completed.
- Package material selection has been made.
- ASIC selection was made allowing package size reduction, cost reduction, inclusion of diagnostics, and gain/linearization of the output function.
- Concept validation has been completed. Design is proven inert from hydrogen gas.
- Competitive analysis is complete.
- Package analysis (finite element analysis)/vibration analysis indicates a robust housing design with minimal stresses in the package.
- Material research and selection for all surfaces exposed to the fuel cell media have been completed.

Temperature Sensor

- Specifications have been defined.
- Package concept evaluations are completed.
- Package material selection has been made.
- Technology determination of resistance thermal device (RTD) has been made.
- ASIC selection was made allowing package size reduction, cost reduction, inclusion of diagnostics, and gain/linearization of the output function.
- Alpha I circuit board design is complete.
- Alpha II circuit board design is complete.
- Initial time response testing is complete.
- Material research and selection for all surfaces exposed to the fuel cell media have been completed.

Future Directions

Humidity

- Determine and evaluate Alpha II sensor design.
- Finalize packaging methodology.
- Optimize packaging for time response.
- Design and debug circuit.
- Test endurance of selected Ultra-H die.
- Conduct polymer research effort relative to accuracy and drift.
- Release soft tools for Beta housing.
- Test and evaluate Beta.
- Provide prototype samples for field test.

Flow

- Complete Alpha II testing.
- Finalize circuit design and debug.
- Release soft tools for Beta housing.
- Test and evaluate Beta.
- Provide prototype samples for field test.
- Complete TTW research on silicon substrate.

Pressure

- Release soft tools for Beta housings.
- Debug final circuit.
- Test and evaluate Beta.
- Provide prototype samples for field test.

Temperature

- Evaluate Alpha II circuit and probe design.
- Finalize packaging methodology.
- Procure Beta packaging.
- Debug final circuit.
- Complete Beta testing and evaluation.
- Provide prototype samples for field test.

Introduction

Honeywell is conducting a 38-month research and development project that will lead to the creation of physical sensors suitable for monitoring and controlling a polymer electrolyte membrane (PEM) fuel cell-based power plant, including the fuel reformer, fuel cell stack, and thermal management system.

Fuel cell compliance requires the ability to monitor parameters throughout the system. Ensuring compliance will not only assist optimization of performance but also improve reliability and robustness. Economical sensing solutions are needed for humidity, flow, pressure, and temperature that will meet the stringent performance requirements of fuel cell applications and eliminate the need to use expensive instrument grade sensors that are not conducive for this application.

Instrument grade sensors are not only very expensive but also hard to package because of size and weight.

Approach

The approach is to look at the fuel cell system and establish requirements for each physical sensor, then deploy existing technologies and develop packaging strategies to minimize sensor cost. Prototype sensors will be designed and fabricated at Honeywell prior to testing in third party fuel cell systems. The final phase will analyze test results.

Results

Effort completed in the past year includes finalization of specifications for each sensor through an extensive "Voice of the Customer" market survey effort, work with technology concepts, packaging, and preliminary testing.

Humidity Sensor

The technical solution being deployed for humidity sensing includes use of the best known capacitive polymer sense die with an application-specific integrated circuit (ASIC). A heated die chamber will shift the dew point, allowing relative humidity (RH) sensing in environments that are above 100%, and a micro-filter that will manage the amount of media presented to the sensing die. Concept testing of the micro-filter has been completed in addition to sense die recovery from saturation, and the ability to shift RH using a heated die chamber concept has been demonstrated (Figure 1). This packaged concept will offer the best opportunity for success in meeting DOE robustness and cost targets.

Flow Sensor(s)

Mass flow anemometer sensing will provide the base technology for both the 400-SLPM and 4,000-SLPM fuel cell sensors. Initial modeling and testing of rugged sensor die technology has been completed in addition to bench top testing of circuit boards, and performance flow testing for both 400 and 4,000 SLPM housings which indicate stability and minimal pressure drop at the point of bypass and restrictor area respectively (Figure 2). Minimal hysteresis was also noted during performance flow testing for both the 400 housing (Figure 3) and the 4,000 housing.

Pressure Sensor

Concept validation testing and competitive analysis have been completed. Sensor design and package analysis (Figure 4) are complete, and soft tooling is ready for release. Combination

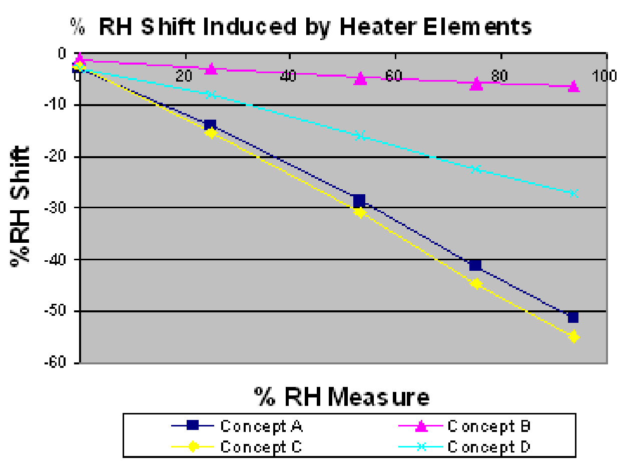

Figure 1. Ability to Shift the Dew Point Using a Heated Die Chamber

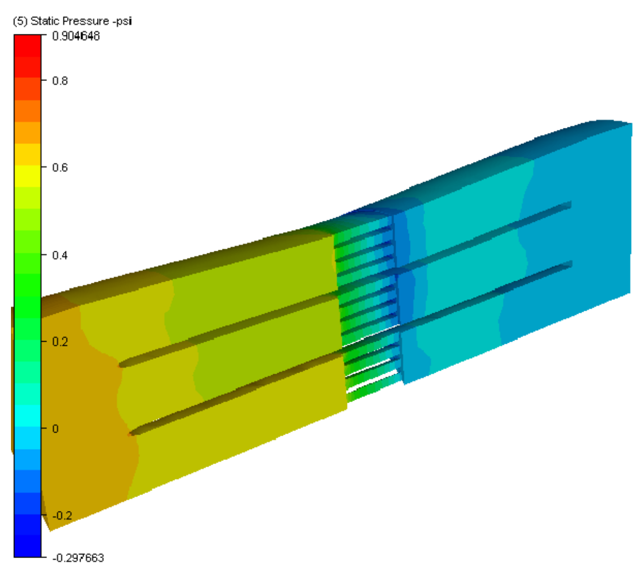

Figure 2. Stability at By-pass and Pressure Drop

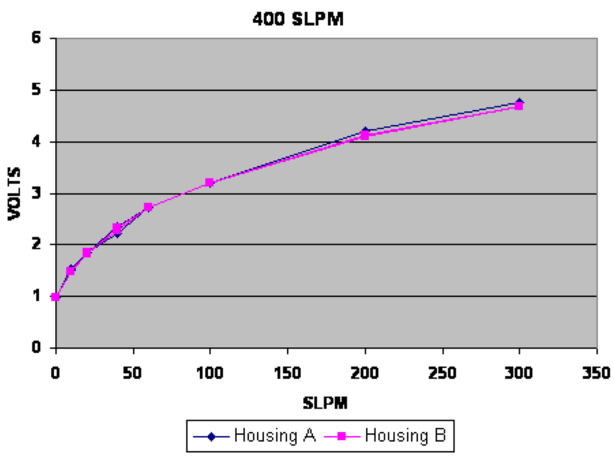

Figure 3. 400-SLPM Performance Curve

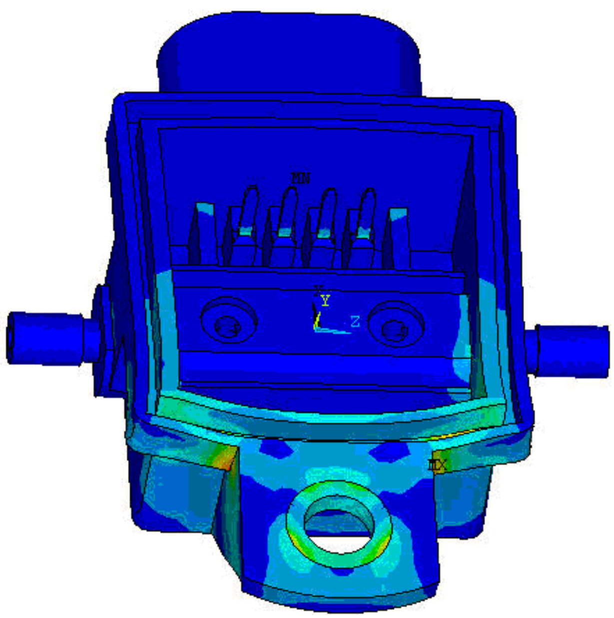

Figure 4. Pressure Package Stress Analysis

temperature sensing, which was identified as a secondary Critical to Quality (CTQ) specification during development, will not be realized because of the less than acceptable response time test performance.

Temperature Sensor

Extensive time response testing has been completed utilizing thermistors and resistance thermal devices (RTDs) in addition to a variety of packaging schemes to optimize performance. Performance concerns regarding thermistor technology resulted in design selection of an RTD as the base sensing technology. Early testing indicated

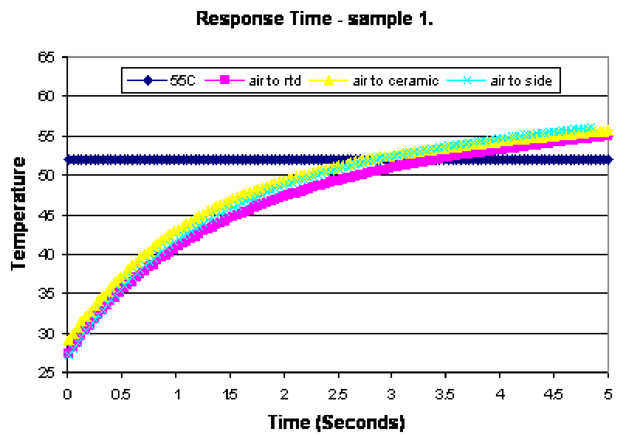

Figure 5. Temperature-Time Response Testing

a 20-second response time when packaged in a stainless steel probe. Research has resulted in marked improvements, with the latest design response time being reduced to approximately 3 seconds (Figure 5), primarily due to RTD selection and package concept evaluations. Additional work remains underway to investigate the 2-second time response requirement.

Conclusions

Specifications for humidity, flow, pressure, and temperature sensors have been defined by fuel cell users, and development efforts are underway to deliver functioning prototypes that will be built by Honeywell and tested in real-world applications. The challenges posed in fuel cell applications are extreme but do not appear to be insurmountable. Additional research to improve robustness of chosen technologies has been defined. Economical sensors for fuel cell systems are crucial to ensure performance and reliability.

FY 2004 Publications/Presentations

1. “Sensor Development for PEM Fuel Cell Systems,” presentation to the FreedomCAR Fuel Cell Tech Team Meeting by Richard Alderman and Bruce Figi, August 2003.

2. “Sensor Development for PEM Fuel Cell Systems Annual Program Review,” presentation to the 2004 DOE Hydrogen, Fuel Cells and Infrastructure Technologies Program Review by Steve Magee, May 2004.