AC 2010-2145: MEASUREMENT OF HYDROGEN IN HELIUM FLOW

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Abstract

The National Aeronautics and Space Administration (NASA) is one of the largest consumers of gaseous helium in the world. Because helium is a nonrenewable resource, it is desirable to conserve the gas whenever possible. This research is a first step toward enabling helium conservation through real-time measurement of H2 concentration in the purge gas. A commercial H2 sensor will be characterized for use as the real-time sensor and H2 concentration as an indicator of the effectiveness of the purging process, thus enabling the minimizing of helium waste. A test apparatus for water and liquid nitrogen flow research was retrofitted to provide for measurement of hydrogen in a helium flow stream. Results are currently being compiled but will be presented in the final paper, as well as the overall process and activities related to student learning.

Student Involvement

The project was the result of collaboration between the programs of Physics and Electronics Engineering Technology. Students participated in the design, specification, acquisition, and installation of appropriate hardware and software. Faculty and students conducted periodic meetings to develop strategies for accomplishing goals and reporting periodic progress. All students were able to assert their strengths in the project while strengthening their weaknesses in various engineering and scientific areas. Most of the work was completed by graduate students under direct supervision of a faculty.

Introduction

An existing pipe structure was available for retrofitting, which allowed for a quick turnaround in establishing a working test fixture. The available test fixture was designed to provide a flow of water at 80 gal/min continuously, via a recirculation system. Additionally, the fixture was fabricated with cryogenic rated materials and components and could also accommodate liquid cryogens with up to 8 supply dewars in parallel. Retrofitting included changing the input and output fittings, rewiring and rerouting of input and output devices, and installation of a hydrogen sensor.

Hydrogen Test Apparatus

The hydrogen test fixture was developed for measuring relevant process variables and enable helium concentrations measurements under fluid flow conditions. The dynamic flow test structure consists of a 7.62 m (25 ft) length of 5.08 cm (2 in) diameter stainless steel pipe with capabilities of accepting gas, water or cryogenic fluids. This test platform monitors pressure, temperature, and flow at various locations along the pipe stream. Output of the hydrogen flow channelled through an exhaust system and vented to the building exterior. Figure 1 shows the general layout of the test fixture hardware.

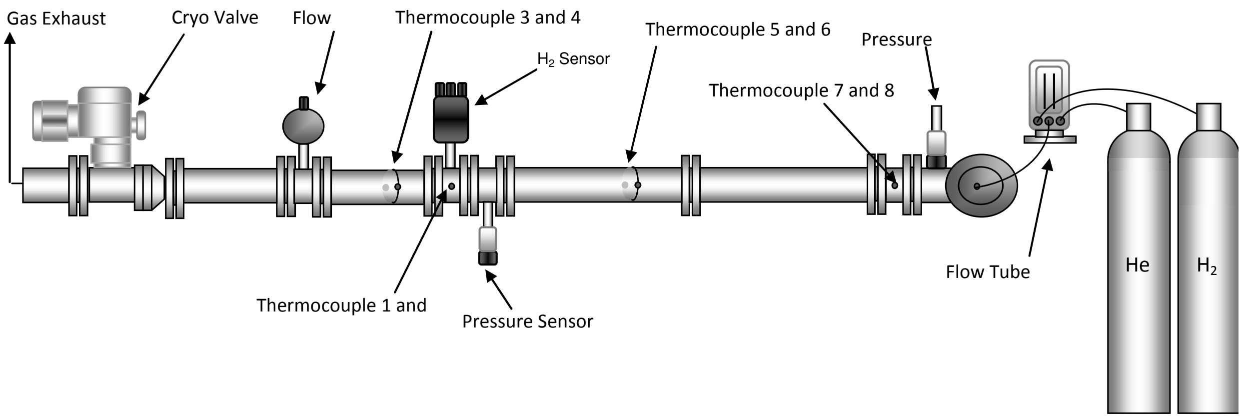


Figure 1. Simplified Hydrogen Test Fixture Diagram

Sensors and Instrumentation

Hydrogen flow is regulated by direct reading flow tubes designed for specialty gases. Pressure and temperature are monitored at the inlet of the supply and at the sensor itself. A turbine flow meter is situated downstream from the sensor for measuring flow rates during testing. An automated 1.5” ball valve at the outlet controls the system flow rate and provides variable back pressure to enable gas conservation. A computer data acquisition system with graphical user interface collects process data as well as controls the outlet valve position, for accurate and automatic data collection during testing. All data collected during testing is automatically saved to a file for future analysis. All sensors were calibrated per manufacturer’s specifications. Figure 2 shows the test fixture instrumented with the ball valve in the foreground and other process sensors mounted along the pipe fixture.

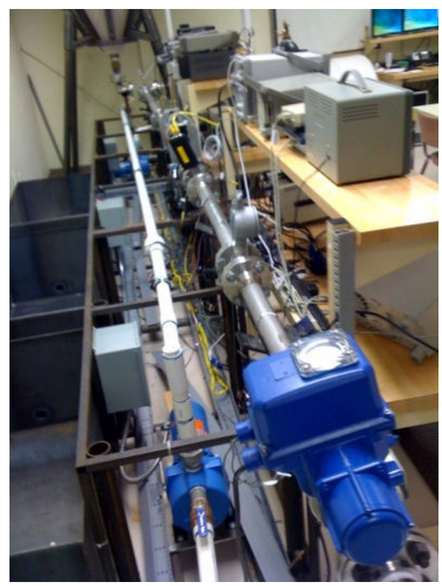


Figure 2. Hydrogen Test Fixture

The hydrogen sensor is designed to detect and/or measure hydrogen as a component of a gas mixture. The solid state sensor has a sensitivity of 0.5% to 100% at 1 atmosphere on a volume basis in a single component gas background. The sensor output is a 0-5V signal with internally activated outputs that are triggered at 2% and 0.8% H_2 concentration. Recommended operating temperature is rated for –20°C to +100°C, but future testing could develop methodologies for extending operation into the realm of cryogenic temperatures.

The sensor has an output of 0-5 V_{DC} and an RS232 digital output. The sensor output signal is connected directly to a Peripheral Component Interconnect (PCI) EXtensions for Instrumentation

(PXI) computer data acquisition system. The PXI also detects the position of the sensor relay contacts. This is accomplished by sourcing 10V dc from a Signal Conditioning for Instrumentation (SCXI) chassis. The SCXI is connected to the PXI via an SCXI extension chassis.

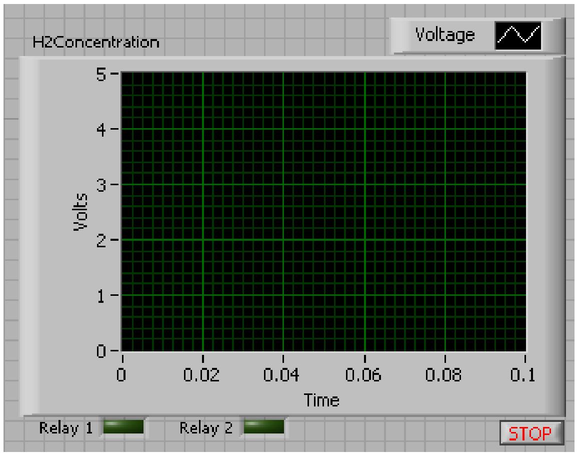


Figure 3. Hydrogen Graphical User Interface

Initially, multiple graphical user interfaces (GUI) were developed to accommodate manipulation and display of all input device data, as well as controlling system output devices. The Hydrogen GUI acquires the output from the hydrogen sensor as a 0-5V_{DC} input signal. The relay voltage is sourced from the SCXI 5 V dc output. The initial GUI shown in Figure 3 uses a graph indicator to represent the hydrogen sensor voltage output relevant to hydrogen concentration over time. Two virtual LEDs indicate the state of the hydrogen concentration relays.

Two pressure sensors were installed in the test fixture, with one at the inlet and the other near the hydrogen sensor. Each sensor measures from 0-300PSI and has an output of 4-20mA with zero and span adjustments. The sensor has a pre-linearized output and is connected directly to the PXI platform.

Redundant type K thermocouples are strategically placed along the test fixture at the inlet, near the hydrogen sensor, and near the outlet of the system. All thermocouples are connected to an FPGA controller. The PXI records data from each of the thermocouples via a TCP/IP connection with the FPGA controller.

The 1.5 inch ball valve (Fig. 4) is situated at the output end of the test stand. It has both manual and remote operation modes with a remote position indicator. An analog 4-20mA input signal is required to control the valve position, while a 4-20mA output signal indicates the position of the valve. The valve is connected to the PXI via the SCXI. The position can be read by the PXI and is integrated into the graphical user interface program. The valve is used to control the flow of gas through the system as well as provide control over back pressure.

Figure 4. Ball Valve

Test Procedure

The established test procedure involves mixing hydrogen in helium with pure helium. The gases will be mixed at various ratios to achieve a variety of H2 concentrations. The apparatus will be vented to air, so that H2 concentrations will remain below the lower explosive limit for hydrogen. The hydrogen sensor will be tested to identify its limits of detection for hydrogen in helium, thus verifying that operation in a helium background does not compromise the sensor calibration. Normally, calibration of the hydrogen sensor is conducted in a nitrogen environment. The test procedure will also incorporate various mounting and sampling methodologies in order to establish their respective measuring accuracy and response.

Data Collection and Analysis

An integrated virtual instrumentation GUI was developed that incorporated all input and output devices within the dynamic flow test fixture. With this program, all data is displayed on a single screen, and available control over the system is coordinated at the desktop.

Results

Initial tests included a pressurization of the system in a closed state, and a subsequent measuring of pressure over time to provide an indication of the leak rate of the system as shown in Figure 5. A single apparent leak was found, but the leak rate proved to be acceptable and the leak was not in an easily operable location. Therefore, testing proceeded with the system in its current state.

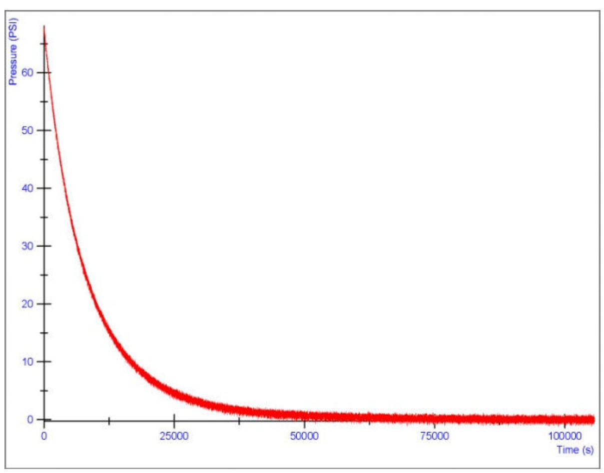
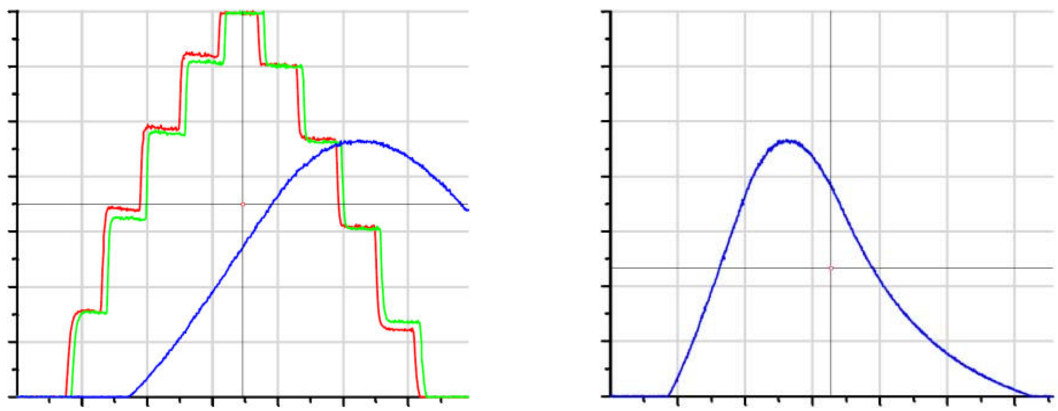


Figure 5. Test Fixture Leak Rate

The hydrogen sensor has a sensitivity range down to 0.5% for H_2 by volume at one atmosphere. If a threshold for explosive concentration of hydrogen is regarded as 4%, then testing could be performed at defined intervals from 0% to 3.5% without concern for explosion potential. Furthermore, the output of the system will be exhausted directly to air outside the building.

Characterization tests of the hydrogen sensor were conducted and results are provided in the following graphs (Fig. 6). The responses are presented without units due to proprietary and intellectual property agreements. However, the overall response can be observed with the understanding that the x-axis is time and the y-axis is sensor output voltage. The graphs show sensor output versus time during changes in composition of the hydrogen in helium concentration flow stream. All changes of input concentration were performed at one minute intervals and 0.5% increments from 0 to 2.5%. The red line indicates the original configuration, with the green line indicating response with the sensor placed at the gas input location. The blue line represents the sensor output when mounted in a 12-inch standoff.



Inline vs. Standoff　　　　Standoff

Figure 6. Measurement Response

Relative to specifications published by the manufacturer of the sensor, it was able to detect small changes in hydrogen content within a moving helium mixture stream. However, the output indication was in error when compared with the calibrated gas. The sensor provided an output that was about 1.5% higher than the actual value of concentration. Analysis showed that the sensor output provides an output peak of 4% when reading the calibrated 2.50% gas mixture. Measurements were taken while both incrementing and decrementing concentration, to determine if there were any hysteresis in the measurement process. Observed hysteresis was minimal.

The time delay for detecting a change in the stream was minimal. The standoff created an additional time delay, and may be more indicative of what response could be expected on the actual test stand.

Conclusions

Successful implementation of this project could lead to significant conservation of hydrogen. A key element of this project is that if successful, transferring the technology to a real world application should be fairly straight forward. Results of initial testing of system components were positive, with all components functioning as expected. The sensor was able to detect small changes in hydrogen content within a moving helium mixture stream. The measurement error compared to calibrated gas was consistent and repeatable, but inaccurate. The sensor provided an output that was about 1.5% higher than the actual value of concentration. Upon obtaining repeatability and minimal hysteresis, it is believed that the measurement accuracy can be resolved with additional efforts. Questions as to whether that time delay is acceptable or will be even further increased by implementation will need to be addressed in future investigations. Overall, the project was a good learning experience for all students involved. Students were heavily engaged in the test setup, calibration, and operation, as well as data analysis. The effects on students engaged in this process appear to be very encouraging, as there has been extensive positive interaction among the students and optomistic feedback regarding this project.