VII.4 Hydrogen Component Validation

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Subcontractors
Spectrum Automation Controls Inc., Arvada, CO

Project Start Date: April 1, 2013
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Improve hydrogen compressor reliability
- Operate a compressor in a highly accelerated lifecycle testing environment to reproduce failures on a short time scale
- Correlate findings with real-world data
- Work with manufacturer to improve design and reduce downtime

Fiscal Year (FY) 2014 Objectives

- Integrate PDC 4-Series compressor into the existing Wind-to-Hydrogen system at the National Wind Technology Center
- Demonstrate unattended operation with appropriate safety systems and controls
- Operate system for 350 hours (assuming no major failures)

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 3.4: Validate station compression technology provided by delivery team. (4Q, 2018)

FY 2014 Accomplishments

- Integrated compressor system with the existing hydrogen, electrical, and cooling systems at the Wind-to-Hydrogen site at the National Wind Technology Center
- Commissioned system with manufacturer and conducted Readiness Verification with NREL staff
- Operated system with attendant for 80 hours (including one seal failure and replacement)
- Completed initial performance analysis of power versus pressure profile and study of hydraulic oil pressure for troubleshooting

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INTRODUCTION

Data from the National Fuel Cell Technology Evaluation Center shows that hydrogen compressors are responsible for the most scheduled and unscheduled maintenance in both material handling and fuel cell electric vehicle infrastructure. With the expected increase in hydrogen demand from the 2015-2017 vehicle roll-out in California, increased reliability is critical to ensure the success of hydrogen refueling stations.

Based on real-world operation, it is understood that compressor reliability is an issue. However, there is a lack of detailed compressor reliability data and analysis available for root cause investigation and reliability improvements. This research aims to operate the compressor in an accelerated manner, though similar to what is experienced in the field to capture performance data, reproduce failures and investigate the causes.

APPROACH

Integration of the compressor with the Wind-to-Hydrogen system enables the accelerated reliability testing in a full system that includes hydrogen production to vehicle dispensing. A specific test plan was developed for the compressor operation in a system configuration. This enables a detailed analysis on compressor reliability without ignoring potential influences that the overall system may also have on compressor reliability. This research will identify failure modes of a compressor in a shorter time frame than would be experienced in the field by operating at higher duty cycles. NREL is targeting 4,500 hours of system operation and 17,000 kg of compressed hydrogen over a 12 month period. Specifications for the PDC4-Series compressor are provided in Table 1.

TABLE 1. PDC4-Series Compressor Specifications

Parameter	Specification (Normal Operation)	Unit
Inlet Pressure	100	psig
Inlet Temperature	100	°F
Outlet Pressure	6000	psig
Capacity	20	SCFM
Stages	2	
Maximum Crankshaft Speed	425	rpm

psig – pounds per square inch gage; SCFM – standard cubic feet per minute; rpm – revolutions per minute

Two systems, a recirculation loop and remote control, were implemented to support the highly accelerated testing. The recirculation loop is pressure regulated piping that was installed between the compressor supply and discharge system. With this loop in place it is not necessary to continuously produce hydrogen when operating the compressor. The control system is capable of switching the compressor suction from the low-pressure storage tanks to the recirculation loop. The remote control system allows a user to start and stop the compressor from anywhere with internet access. This allows for operation cycles much longer than the standard work day.

A critical part of this research is the collaborative deep-dive analysis of failures with the compressor manufacturer. It will be performed as failures occur and the results will be communicated to the manufacturer in an effort to improve overall compressor reliability. The compressor has additional instrumentation to capture various operational parameters such as power consumption, pressure and temperature that will aid in the failure analysis, but also be used to characterize compressor performance and improve Pacific Northwest National Laboratory compressor modeling. Data collected will inform DOE on performance data of compressors.

RESULTS

Data collected on the compressor is listed in Table 2.

The flow rate versus discharge pressure is one example of the type of analysis on data collected. Station designers must consider the discharge rate of a compressor when sizing the various components at a station. Figure 1 shows data for discharge pressures from 3,600 psig to 6,000 psig, a typical operating range at hydrogen stations.

TABLE 2. Compressor Data Collection

Parameter	Frequency
Motor Current	1 Minute
Motor Voltage	1 Minute
Motor Apparent Power	1 Minute
1st Stage Inlet Pressure	10 seconds
1st Stage Outlet Pressure	10 seconds
1st Stage Inlet Temperature	10 seconds
1st Stage Outlet Temperature	10 seconds
2nd Stage Inlet Pressure	10 seconds
2nd Stage Outlet Pressure	10 seconds
2nd Stage Inlet Temperature	10 seconds
2nd Stage Outlet Temperature	10 seconds
Coolant Water Inlet Temperature	10 seconds
Coolant Water Outlet Temperature	10 seconds
Operational Hours	10 seconds
Ambient Temperature	10 seconds
Crankcase Oil Temperature	10 seconds
Crankcase Oil Injection Pump Pressure	10 seconds
Leak Detection Pressure	10 seconds
Process Filter Pressure	10 seconds
1st Stage Oil Pressure	0.00004 seconds
2nd Stage Oil Pressure	0.00004 seconds

Power consumption data is also collected when the compressor is operating. A power meter captures both voltage and current waveforms using transducers. The unit calculates real and reactive power, as well as the power factor. This data is captured simultaneously with pressure data to analyze the relationship between power consumption and discharge pressure.

When initially analyzed, the power data was extremely variable and thus unusable. Several diagnostic techniques were utilized to determine the cause of such a large variation. An example of this variation was captured with a high-speed oscilloscope and is shown in Figure 2. It was discovered that at a constant discharge pressure of 4,500 psig, the current draw fluctuated between 17 and 33 A_{max}, but the voltage was very stable. A periodic cycle of fluctuation was found every 150 ms. The frequency of compression cycles was obtained from the manufacturer and corresponded directly with current variations. Thus, it was reasoned that the variable motor current was a result of the motion of the

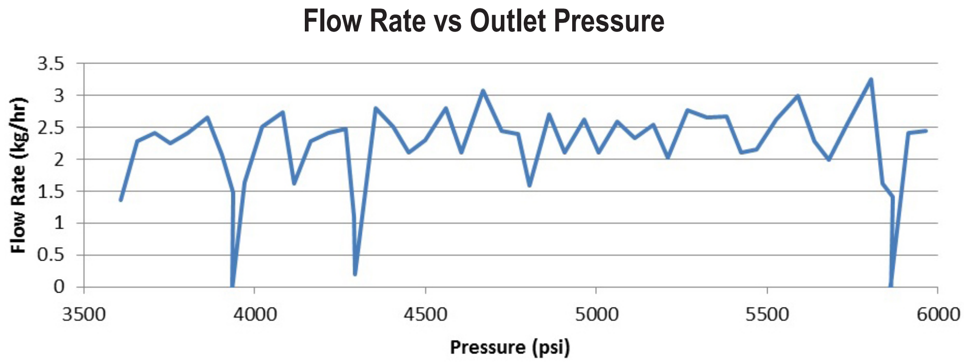

FIGURE 1. Flow rate in kg/hr is plotted against discharge pressure in psig. It can be seen that an average flow rate is experienced across various discharge pressures.

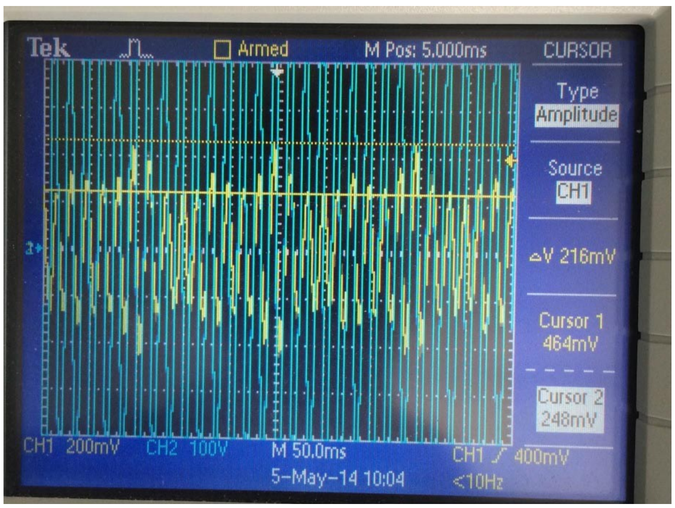

FIGURE 2. An oscilloscope was placed on the motor supply circuit to show voltage (cyan) to be uniform and current (yellow) to be variable over multiple periods.

piston driven by the motor. This was later confirmed with the manufacturer.

To make the power data usable, an averaging scheme was applied to the current and the resultant is now used to calculate power consumption. An example of the power versus pressure data is provided in Figure 3. The amount of power required by the compressor motor increased monotonically with the discharge pressure. A nearly 3.5 kVA range was recorded over the 3,000-6,000 psig range. The compressor motor is rated to 30 HP, or 26 kVA. In the upper range of discharge pressures, the compressor was observed to be consuming a maximum of 18.9 kVA which is 72% of rated power.

At the 60-hour operation mark, the compressor system experienced a failure. The second stage discharge check valve o-ring was partially destroyed and caused a hydrogen leak. The failure was discovered when a loud noise of gas escaping was heard with each compression cycle. The system had to be shut down manually while the problem

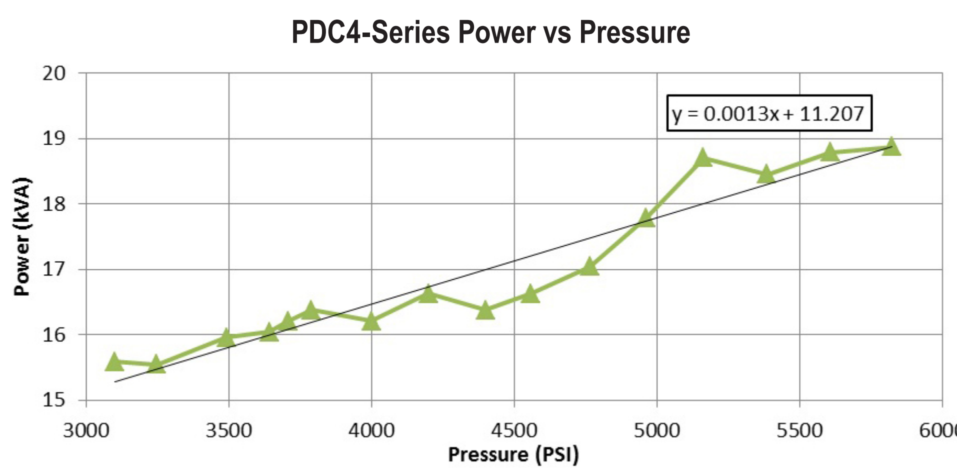

FIGURE 3. One critical piece of performance data is the power consumed by the compressor over a range of discharge pressures. This graph shows the average measured power for various discharge pressures with a line of best fit.

was diagnosed and repaired. The failed part was removed, documented and explained to the manufacturer. The other check valve o-rings were inspected and contained no damage. The compressor was then run to verify proper operation. The system is operational and at the time of this report, no other failures have occurred. Figure 4 shows the o-ring after it was removed from the compressor.

FIGURE 4. The seal on the second stage discharge check valve failed and required replacement at 60 hours.

The check valves are recessed about 8” into the head making access difficult. The repair procedure required very long skinny tools to reach the check valves. NREL has a set of dental tools that were used to grasp the valve and pull it out. Total downtime was one week, most of which elapsed while waiting for guidance and spare parts from the manufacturer. Actual repair time was about three hours.

The tedious nature of the procedure and difficulty for field operators was communicated to the manufacturer. A product of the conversations with the manufacturer was the acknowledgement that this is a common problem and typically observed with large ambient temperature cycling. The failure took place in April, during which Colorado experienced days with temperatures up to 70 degrees and days of snow. One lesson learned from this failure is the importance of having spare o-rings for all components on hand.

CONCLUSIONS AND FUTURE DIRECTIONS

- Significant knowledge and expertise of mechanical and electrical systems in classified environments is required to incorporate this component into a hydrogen system.
- Compressor performance study is valuable as multiple parties have contacted NREL team for data.
- Future research will focus on long duty cycle testing and failure analysis.
- A robust performance characterization will be formed as more data is collected.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. “Hydrogen Component Validation,” Harrison, Kevin; Terlip, Danny; Peters, Michael; Penev Michael. 2014 DOE Annual Merit Review. 16 June 2014. Washington, D.C.