III.2 Hydrogen Compression Application of the Linear Motor Reciprocating Compressor (LMRC)

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Project End Date: October 4, 2018

Overall Objectives

- Demonstrate the linear motor reciprocating compressor (LMRC) by integrating individually-developed Technology Readiness Level 4 or higher components.
- Demonstrate that the compressor portion of the LMRC has improved compression efficiency and a reduced capital and maintenance cost compared to conventional reciprocating compression technology.
  - Improve isentropic efficiency above 73% by minimizing aerodynamic losses and using low-friction bearings (goal is above 95%).
  - Reduce capital costs to half those of conventional reciprocating compressors by minimizing part count.
  - Reduce required maintenance by simplifying the compressor design to eliminate common wear items.
- Meet the design requirements for all three stages of compression: compress hydrogen from 290 psia (20 bara) to 12,690 psia (875 bara) with flow rates greater than 22 lbm/h (10 kg/h) and an isentropic efficiency of compression above 73%.
- Meet the test requirements for the first stage of compression: compress hydrogen from 290 psia (20 bara) to 1,030 psia (71 bara) with flow rates greater than 22 lbm/hr (10 kg/h) and an isentropic efficiency of compression above 73%.
- Meet the fiscal year (FY) 2018 test requirements for the first stage of compression: compress hydrogen from 290 psia (20 bara) to 1,030 psia (71 bara) with flow rates greater than 22 lbm/hr (10 kg/h) and an overall system specific energy of 1.6 kWh/kg or lower.

Fiscal Year (FY) 2017 Objectives

The overall objectives for FY 2017 are final fabrication, assembly of test loop, and testing of the LMRC.

- Fabricate and assemble low pressure (LP) stage compressor parts.
- Construct the test stand and integrate the compressor.
- Commission and start up the demonstration model.
- Test the bench-scale system.
- Analyze the single stage test results.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration (MYRDD) Plan.

(B) Reliability and Costs of Gaseous Hydrogen Compression

Technical Targets

During the proposal phase and kick-off of the project, the DOE technical targets were based on the 2012 MYRDD Plan. A 2015 MYRDD Plan was updated in August of 2015. Table 1 compares the predicted characteristics of the LMRC design with 2020 targets from both MYRDD reports.

FY 2017 Accomplishments

- Finalized plans for commissioning, safety, and operation of the test stand.
- Fabricated and assembled all of the LP stage compressor parts.
- Constructed the test stand.

TABLE 1. Progress towards Meeting Technical Targets for Hydrogen Delivery with Small Compressors: Fueling Sites (~100 kg H_2/h peak flow)

Characteristic	Units	2012 MYRDD Target for 2020	2015 MYRDD Target for 2020	LMRC 2020 Status (Predictions)
Reliability		High	NA	High
Availability	%	NA	≥85	TBD
Compressor Efficiency	Isentropic %	80%	NA	80% - all 3 stages
Compressor Specific Energy	kWh/kg	100 bar inlet: NA 500 bar inlet: NA	100 bar inlet: 1.6 500 bar inlet: 1.4	20 bar to 875 bar: 1.8 (Compressor Only) 9.2 (LMRC) 100-bar Inlet Pressure: 1.45 (Optimized LMRC)
Losses of H_2 Throughput	% of flow	<0.5%	0.5%	<0.4%
Uninstalled Capital Cost (Based on 1,000 kg/d Station, [~100 kg H_2/h Peak Compressor Flow])	$	$240,000 (1 Compressor, No Backup)	NA (1 Compressor, No Backup)	20-bar to 875-bar: $284,000 (1 Compressor, No Backup)
Uninstalled Capital Cost (Based on 750 kg/d Station, [~100 kg H_2/h Peak Compressor flow])	$	100-bar inlet: NA 500-bar inlet: NA (1 Compressor, No Backup)	100-bar inlet: 275,000 500-bar inlet: 90,000 (1 Compressor, No Backup)	100-bar to 875-bar: $195,000 500-bar inlet: $105,000 (1 Compressor, No Backup)
Annual Maintenance Cost	% of Installed Capital Cost	2.0%	4%	1.2% of Uninstalled Capital Cost
Outlet Pressure Capability	bar	860	950	875
Compression Power	kW	240 (20 bar at Inlet)	NA	170 (20 bar at Inlet) (Compressor Required Power)

NA – Not Applicable
TBD – To Be Determined
100-bar inlet – pipeline delivery of gas to the compressor
500-bar inlet – Tube Trailer Delivery of gas to the compressor

INTRODUCTION

SwRI® and ACI Services, Inc., are developing an LMRC to meet the DOE goal of increasing the efficiency and reducing the cost of forecourt hydrogen compression. The proposed advanced compression system utilizes a novel and patented concept of driving a permanent magnet piston inside a hermetically-sealed compressor cylinder through electromagnetic windings. The LMRC is an improvement over conventional reciprocating compressors as it minimizes the mechanical part count, reduces leakage paths, and is easily modularized for simple field installation (U.S. Patent 8,534,058) [1].

APPROACH

The LMRC is a novel concept compared to conventional reciprocating compression technology. The compression system replaces the functions of an electric motor drive and reciprocating compressor with an integrated, linear, electrically-actuated piston. It will have a magnetic piston within a cylinder and a gas compression chamber at each end of the piston. The compressor cylinder is comprised of an electromagnetic coil that is operable with the piston to convert an input of electrical power to a reciprocating movement of the piston. This uses the same technology seen in magnetic bearings in turbomachinery and does not require oil for lubrication. Since the driver and compressor are integrated into the same hermetically-sealed component, there is a significant reduction in the number of parts and materials needed to construct this device. In addition, the simplicity of the design reduces required maintenance, minimizes seal leakages and wear, and allows for oil-free operation.

The LMRC system minimizes parasitic losses by using reduced piston speeds, low-pressure-drop contoured valves, and inter-stage cooling manifolds. Working at low reciprocating speeds of approximately 300 cycles per minute (5 Hz), the LMRC prototype is expected to meet an isentropic efficiency goal of greater than 95% per stage [2]. That efficiency can be compared with current state-of-the-art technology that typically has an efficiency of closer to 73%. The improved isentropic efficiency and reduced mechanical losses result in an increase in overall efficiency for the LMRC system.

RESULTS

The LMRC test loop plans were finalized for testing and safety. A schematic showing the location of the LMRC test loop in relation to the existing building can be seen in Figure 1. The two chillers, electrical panel and filter, water tank, and gas cylinders rack are in place and piped together as designed. The data acquisition cabinet wiring is shown in Figure 2.

Assembly of all the machined and fabricated LMRC parts is complete. The completely assembled LMRC mounted on the test stand can be seen in Figure 3.

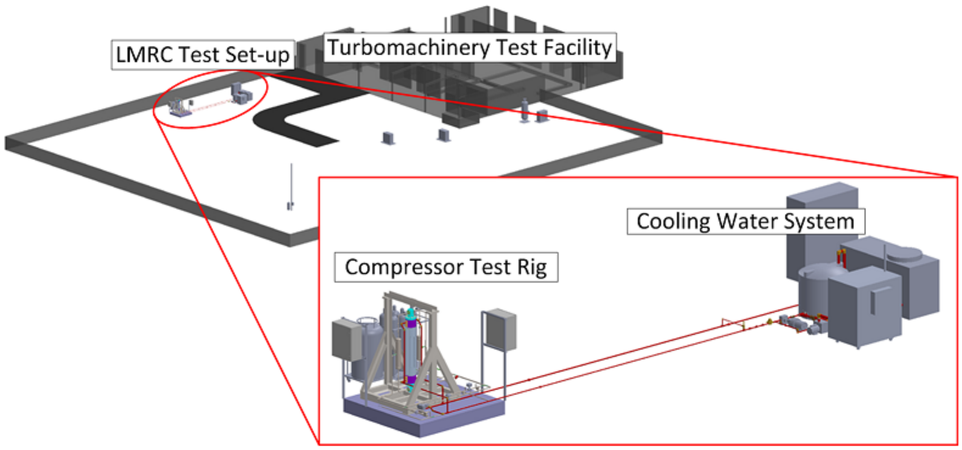

FIGURE 1. Schematic of test loop equipment and existing building

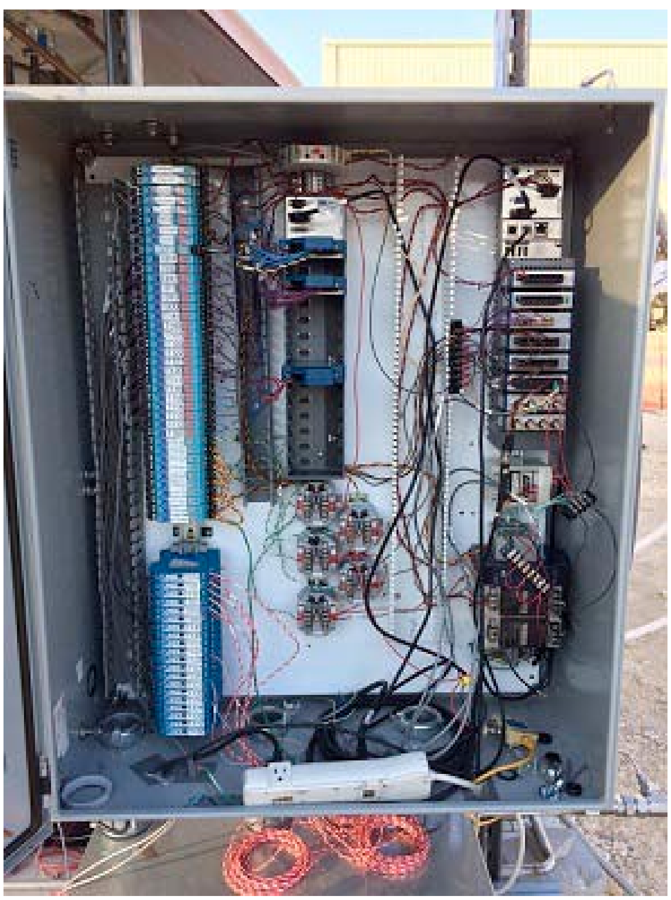

FIGURE 2. Photo of the data acquisition cabinet wiring

FIGURE 3. Photo of LMRC fully assembled and mounted on the test stand supporting structure

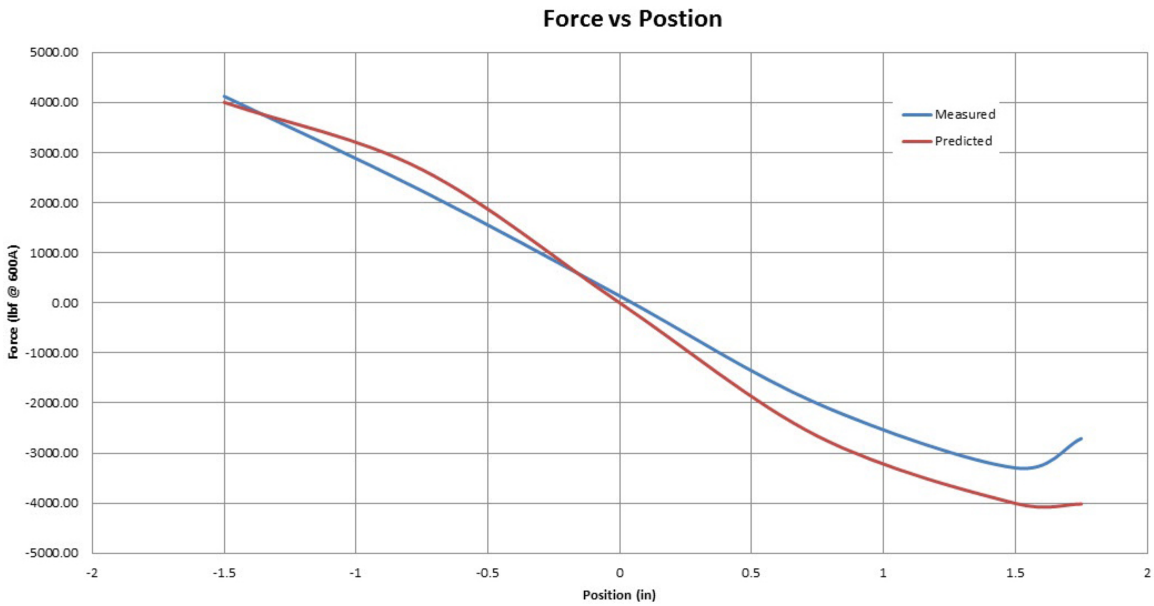

FIGURE 4. Measured and predicted motor forces plotted as a function of position

Calibration testing was performed in an effort to validate motor force predictions. It was found that there is close correlation between the predicted forces of the motor and the measured forces. Measured and predicted forces are plotted as a function of position in Figure 4.

Issues with the capabilities of the vendor-supplied electrical power controller significantly delayed testing of the LMRC. A new electrical power controller was recently received. The first stage LMRC test loop is now fully assembled. Commissioning efforts are being finalized, and testing will commence in the near future.

CONCLUSIONS AND UPCOMING ACTIVITIES

Conclusions derived from the work conducted in FY 2017 are:

- Updated predictions still indicate that highly efficient hydrogen compression is possible with an LMRC used for the compression process.
- It is concluded that the measured forces diverge from the predicted forces at the top of the LMRC (see Figure 4) as a result of the magnetic field disruption associated with the calibration fixture that was necessary for performing the measurements.

Future work in Project Year 4 (FY 2018; Budget Period 3) will include:

- Redesign the motor portion of the LP LMRC such that the overall system will have a specific energy of 1.6 kWh/kg or lower.
- Fabricate and assemble the more efficient LP LMRC.
- Commission the test bench using an inert gas and following the plan previously defined.
- Complete testing of the LMRC system according to the defined test matrix with hydrogen.
- Analyze the results from the improved LP system testing (20 bar to 71 bar pressure range, specific energy of 1.6 kWh/kg or lower).

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Broerman, E.L., J. Bennett, N. Shade, “Designing, Building, and Testing a Linear Motor Reciprocating Compressor (LMRC),” presented at the 2016 GMRC Gas Machinery Conference, October 4, 2016, Denver, CO.

REFERENCES

1. U.S. Patent 8,534,058. Issued Sept. 17, 2013. “Energy Storage and Production Systems, Apparatus and Methods of Use Thereof,” Patented in United States of America.

2. Deffenbaugh, D., et al., “Advanced Reciprocating Compression Technology,” DOE Award No. DE-FC26-04NT42269, SwRI® Contract No. 18.11052, December 2005.