III.19 Advanced Sealing Technology for Hydrogen Compression

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Objectives

Develop and demonstrate feasibility of using a close clearance, non-contacting, and dynamic compliant foil seal in hydrogen and/or natural gas pipeline compressors.

- Reduce leakage rate of hydrogen.
- Reduce system cost and increase reliability.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(B) Reliability and Costs of Hydrogen Compression
(I) Hydrogen Leakage and Sensors

Technical Targets

This project is directed towards the development of oil-free gas seal technology for hydrogen transportation and delivery compressors. The developed foil seals will be tested to assess the leakage flow as a function of differential pressure. The project addresses the DOE technical targets from the Hydrogen Delivery section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan (see Table 1).

TABLE 1. Technical Targets for Hydrogen Compression

Category	2005 Status	FY 2012	FY 2017
Reliability	Low	Improved	High
Energy Efficiency	98%	98%	>98%
Capital Investment ($M) (based on 200,000 kg of H2/day)	$15	$12	$9
Maintenance (% of Total Capital Investment)	10%	7%	3%
Contamination	Varies by Design		None

Accomplishments

- Several seal designs were evaluated in static and dynamic tests. The variations included the radial clearance, presence or absence of face bumps, preload level, and the axial length.
- Tests were conducted both with air and helium as the substitute gas for hydrogen. The effect of inlet pressure and speed were evaluated. The gas temperature was varied from the ambient to 500°F. The results confirmed that the flow factor, or seal leakage, decreased as the inlet pressure was reduced or the speed was increased.
- Presence of the face bumps decreased leakage, while preload had only a minor effect. Longer seals did not necessarily improve the seal performance. Seal leakage was significantly reduced at higher temperatures. A smaller leakage was obtained with helium as compared with air. The seal performance and durability improved when all surfaces that would come into contact were also coated with the Korolon® 7 coating.
- A continuous 3.5-hour test confirmed excellent durability for the seals as no wear or erosion were observed on the seal components after the test and the flow factors remained constant throughout the testing period.

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Introduction

The objective of this project is to develop and demonstrate feasibility of using a close clearance, non-contacting, and dynamic compliant foil seal in hydrogen and/or natural gas pipeline compressors. The goal of this seal is to enhance the economic viability of hydrogen as an energy carrier and to substantially improve the efficiency of centrifugal compressors so that they become feasible for use in transportation and delivery of hydrogen. Under Phase I, MiTi® completed the design of a compliant foil seal suitable for the previously sized hydrogen transportation and delivery compressors and fabricated the designed seal and tested it statically to assess the leakage flow as a function of differential pressure. Results showed considerably reduced leakage with the foil seal over other technologies and previous versions of the compliant foil seal. Under Phase II, the foil seal design is to be refined based upon lessons learned from Phase I: additional static testing is to be conducted to validate the design; and finally, dynamic testing of the final full-scale design will be completed to demonstrate that performance capabilities meet the specified needs of a hydrogen transportation and delivery compressor.

Approach

Additional testing will be performed using the seal design and hardware developed under Phase I to further characterize the secondary/tertiary losses and to assess approaches to reduce the secondary losses. The design will be revised to mitigate secondary leakage losses. Full-scale compliant foil seals will be tested under dynamic rotating shaft conditions. The critical foil seal dimensions and operating clearances will be selected to minimize leakage between stages of a hydrogen transportation centrifugal compressor capable of delivering up to 1,000,000 kg/day. Ambient hydrogen gas pressures, pressure rise per stage, shaft surface speed and expected rotor motions will be included in the analysis and seal design. A new test rig (or modifications to an existing test rig) will be developed to evaluate and characterize the seals under realistic operating conditions of speed, rotor radial displacements and differential pressures. The full-scale seals will be evaluated with the dynamic test rig to determine leakage and differential pressures representative of that expected in an operating hydrogen centrifugal compressor. During testing key parameters, such as upstream and downstream pressure, leakage flow, shaft speed, rotor radial motions and seal foil, temperatures will be measured. Based upon test data, the compliant foil seal design will be revised to address identified areas for improvement. A final report documenting the key seal design parameters and component sizing, the test results and an assessment of the benefits of the seal to the performance of hydrogen compressor will be prepared.

Results

The initial dynamic testing was carried out with four seal configurations in progressive settings in order to safely run to full operating speed and high inlet pressures. The static and dynamic performance of each seal configuration was first evaluated with a loose radial clearance and no face bumps. The flow factor was reduced as the speed was increased from 0 to 60,000 rpm due to centrifugal growth of the rotor and the developed hydrodynamic pressure. The results also confirmed that the leakage was higher for the static seal as compared to the dynamic conditions. The seal leakage increased as the inlet pressure was increased from 20 to 100 psi (see Figure 1).

Since the first set of tests were successfully performed with loose radial clearance seals and no face bumps, the face bumps were then installed without preload, using the same radial clearance as before. Both the static and dynamic performance of this seal configuration was then evaluated. The seal leakage was reduced as the speed was increased and as the inlet pressure was reduced. In the next series of test, the face bumps were preloaded while the radial clearance remained the same as before. The results were similar to those for the other two seal configurations described above.

As the last configuration for this series of parametric study, the seal radial clearance was reduced while the face bumps were kept loose without preload. The

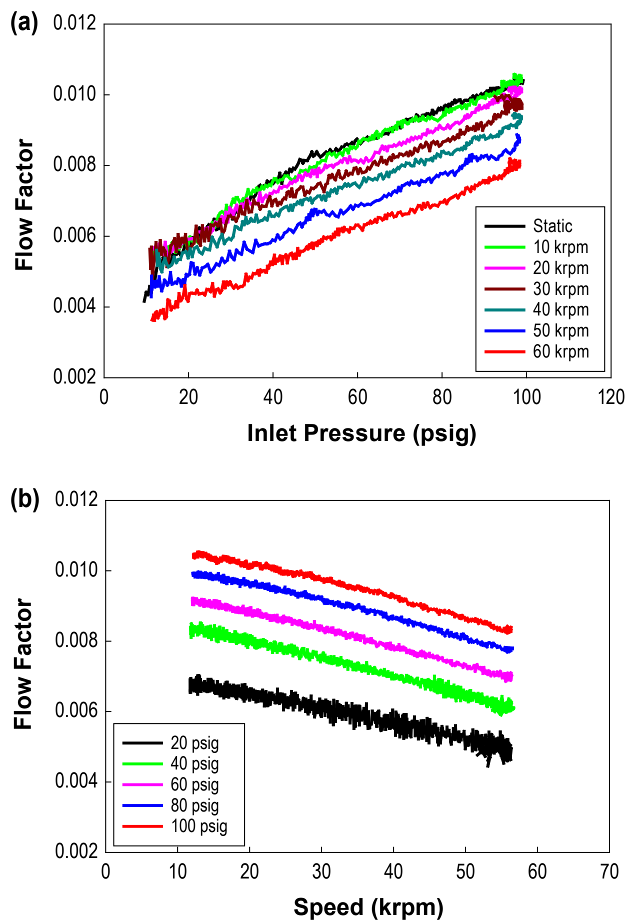

FIGURE 1. Flow factor versus (a) inlet pressure and (b) speed for seal configuration with loose radial clearance and no face bumps.

dynamic performance of the four seal configurations under the same testing conditions was further compared as a function of inlet pressure at a fixed operating speed of 60,000 rpm, and as a function of operating speed at a fixed inlet pressure of 100 psi. The seal leakage was reduced when the face bumps were installed in the seal assemblies, while preloading the face bumps had no effect on the seal performance. The most significant contribution to the seal performance was from the radial clearance between the sealing surface and the test journal - the smaller the radial clearance the less seal leakage. The seal configuration with loose radial clearance and loose face bumps was selected for further testing to evaluate the seal performance under various conditions.

Elevated Temperature: To characterize the seal performance at elevated gas temperatures, four heat torches were installed at the air inlet of the high-speed test rig. The static and dynamic performance was evaluated first when the heaters were off. The heaters were then turned on and the temperature was set at 500°F. After the temperature reached the steady-state value, the seal performance was evaluated under static conditions and then under dynamic conditions at various speeds. The seal leakage was significantly reduced at the higher temperature.

To protect the seals from being damaged, the testing procedure was revised and the inlet pressure was kept above 70 psi during dynamic testing. Figure 2 compares the dynamic performance of the seals under ambient, 250°F, and 500°F temperatures. The leakage was reduced as the speed and temperature were increased and as the inlet pressure was reduced.

Testing with Helium: The seal performance was evaluated under ambient and elevated temperatures with helium as a substitute gas for hydrogen. While it was desired to test with helium subjected to higher inlet pressures up to 250 psi, the pressure was limited to about 120 psi due to heating by the heat torches used. The leakage was reduced as the temperature increased. The flow factor with helium was smaller than that with air under the same conditions at 500°F.

Dynamic tests with helium were conducted next at various temperatures; however, significant buzzing came from the inside of the test rig at ambient temperature. The seals were removed and examined after the test was completed. Significant erosion had occurred at the overlapped trailing and leading edges of both inner and outer smooth foils of the outboard mounted seal. However, the inboard mounted seal showed no visible damage. Therefore, it was decided to coat not only the sealing surface of the smooth top foils, but also the two touching surfaces of the inner and outer smooth foils with thinner Korolon® coating. The new seals were also tested at 250°F and 500°F. The additional coating reduced buzzing during testing and prolonged

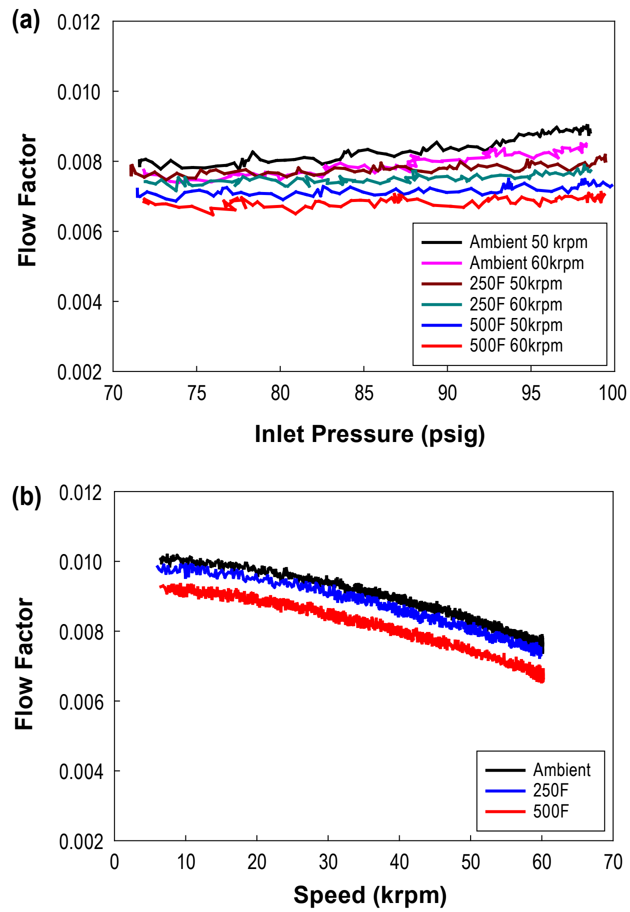

FIGURE 2. Flow factor versus (a) inlet pressure at 50,000 and 60,000 rpm under various temperatures and (b) speed at 70 psi under various temperatures.

the seal life. Figure 3 shows the dynamic test results with and without the additional coating and compares the dynamic performance of the seals with helium at different temperatures. Similar to air, both temperature and speed help reduce the seal leakage.

Different Coatings: The smooth foils in the tests described above were coated with Korolon® 900. To compare the seal performances with different coatings, new seals were made and coated with Emralon® and Teflon®. The dynamic performance of the three coatings at operating speeds of 50,000 and 60,000 rpm at 70 psi were compared. For each coating, the leakage increased as the inlet pressure increased, and decreased as the operating speed increased. The leakage of the Korolon® coated seals was slightly larger than that from the other two coatings. However, these tests were conducted at ambient temperature only; the Korolon® coating has been designed for and has demonstrated excellent performance at elevated temperatures.

Longer Axial Length Seals: In order to further improve the seal performance, the seal design was modified. The axial length of the smooth foils was

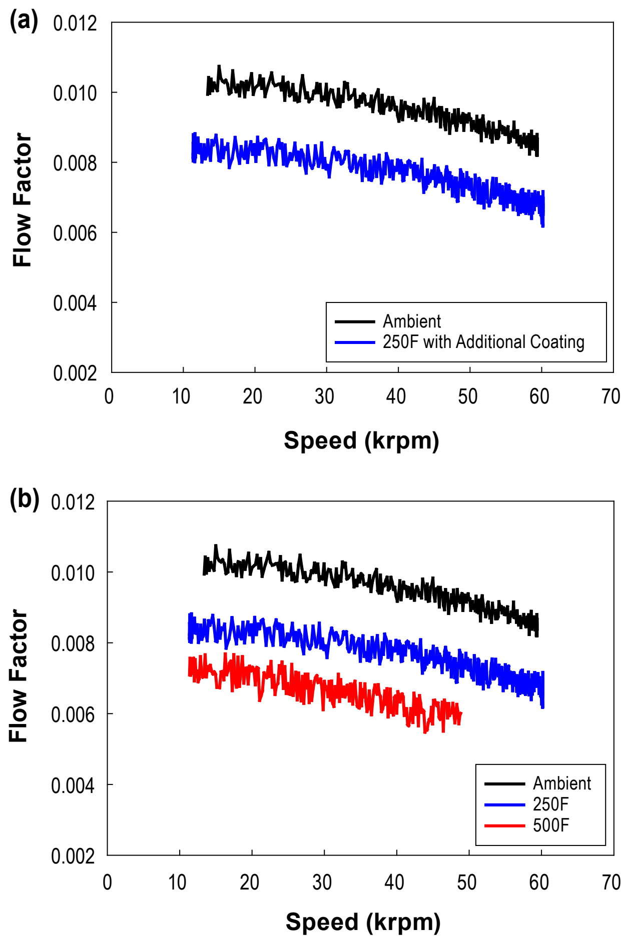

FIGURE 3. Flow factor versus speed with helium at 70 psi (a) with and without additional coating and (b) at different temperatures.

increased by 75% given the limitation of the test rig, and two rows of bump foils were used and offset from each other. The smooth foils were coated with Korolon® 900. The longer seals did not reduce the leakage as much as expected, even when the radial clearance was decreased.

Durability Testing: Long-term durability testing was conducted to verify seal life. Two standard axial length seals with Korolon® 900 coating were tested with air under ambient temperature at an operating speed of around 40,000 rpm and an inlet pressure of about 50 psi. The flow factor as a function of time during the 3.5-hour test was constant. The seal foil temperatures remained low and the flow factor stayed steadily below 0.007. The seals were checked after the test and showed no wear marks; therefore, the seals were capable of running continuously for an extended period of time.

Conclusions and Future Directions

Several seal designs were evaluated in static and dynamic tests. The variations included the radial clearance, presence or absence of face bumps, preload level, and the axial length. Tests were conducted both with air and helium as the substitute gas for hydrogen. The effect of inlet pressure and speed were evaluated. The gas temperature was varied from the ambient to 500°F. The results confirmed that the flow factor, or seal leakage, decreased as the inlet pressure was reduced or the speed was increased. Smaller clearance values decreased the leakage through the seals. Presence of the face bumps decreased leakage, while preload had only a minor effect. Longer seals did not necessarily improve the seal performance. Seal leakage was significantly reduced at higher temperatures. A smaller leakage was obtained with helium as compared with air. The seal performance and durability improved when all surfaces that would come into contact were also coated with the Korolon® 7 coating. A continuous 3.5-hour test confirmed excellent durability for the seals as no wear or erosion were observed on the seal components after the test and the flow factors remained constant throughout the testing period. The following tasks are planned for next year:

- Prepare the final report

FY 2010 Publications/Presentations

1. "Oil-Free Seals for Hydrogen Compression," DOE Hydrogen Program Annual Review and Peer Evaluation Meeting, June 2010, Washington, D.C.