III.11 Investigation of H_2 Diaphragm Compressors to Enable Low-Cost Long-Life Operation

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Overall Objective

Reduce compressor operation and maintenance cost by reducing instances of diaphragm failure and the resulting need for repair of hydrogen gas compressors

Fiscal Year (FY) 2013 Objectives

- Identify the causes for the reduced lifetime of the diaphragm compressors operated under start-stop mode
- Develop material and compressor design solutions to enhance the lifetime of diaphragm compressors

Technical Barriers

This project addresses barriers "B" and "O" from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(B) Reliability and Costs of Gaseous Hydrogen Compression

(O) Lack of Reliable Hydrogen Compressors

Technical Targets

This project is conducting research to decrease compressor operation and maintenance costs by improving the reliability of hydrogen compressors. Understandings gained from this work will be applied to future compressors to enable them to meet DOE 2015 compressor targets:

- 2.5% of installed capital cost for maintenance
- Improved reliability and life

INTRODUCTION

The goal of this project is to reduce the instances of diaphragm failures and the resulting need for repair of hydrogen gas compressors. Achieving this goal will help enable economical operation of hydrogen vending stations in support of DOE's goal of developing a hydrogen distribution network. For this project, PNNL has partnered with PDC Machines, Inc., a leader in hydrogen compressor technology, to develop materials and engineering solutions to the problem of repeated breakdown of hydrogen compressors. The team will investigate the diaphragm failures through materials characterization and modeling and identify diaphragm materials, compressor design, and operational procedures that will increase the life of diaphragms, especially under intermittent operation.

Short life of the diaphragms subjected to intermittent operation of the compressors is a key hurdle in developing an economical hydrogen distribution network. This hurdle exists because the repair costs and the downtime associated with repeated compressor breakdown may substantially increase the costs for fueling stations to serve as hydrogen vendors for hydrogen fuel cell vehicles. Consequently, there is a need to enhance the life of hydrogen compressors and enable a successful establishment of a wide-spread hydrogen distribution network via the existing gas stations and establishment of new stations.

APPROACH

PDC Machines, Inc. will share with PNNL its data and operation experience on compressor performance. Based on the data provided by PDC Machines, Inc., PNNL will perform an engineering analysis to systematically understand the diaphragm performance under different operating regimes. This analysis will include finite element models to understand the evolution of stresses and strains in the diaphragm leading to its final failure. Fatigue analysis will also be performed for the different operating cycles and the combined mechanical plus residual stress levels using the available fatigue curves for the alloys of interest. The microstructure of the diaphragm materials will be analyzed with special attention to the role of texture (anisotropy) and presence of residual stresses. Fractographic analysis of the failed diaphragms will be performed to help identify the failure mode, failure origin and eventually, the possible causes of the failure. Thus, the approach outlined in the preceeding will help us understand how the interplay

of the compressor design, operational procedures, and microstructure-dependent deformation behavior of the diaphragm may be controlled to enhance the diaphragm life.

ACCOMPLISHMENTS

This project was developed in conjunction with PDC Machines, Inc., a commercial supplier of diaphragm hydrogen compressors and has benefitted greatly from their assistance, both technical and material. The company provided detailed drawings of compressor designs (output H_2 pressures of 6,500 and 15,000 psi), diaphragm materials, as well as technical details that need to be considered when designing and operating diaphragm compressors. Using the compressor design and operational information provided by PDC Machines, Inc., PNNL developed a preliminary finite element model using ANSYS software to understand the diaphragm deformation and stresses as a function of gas compression. Materials characterization effort was also initiated using the diaphragm materials provided by PDC Machines. This involved surface characterization via roughness and residual stress measurements, microstructure characterization using optical and electron microscopy and fracture surface analysis using electron microscopy. On the basis of work performed to date and discussions with PDC Machines, Inc., the project accomplishments are:

- Contamination/debris in the H_2 gas and improper priming procedures when restarting a compressor after stopping have been identified as two important factors that adversely affect the life of the diaphragm. Figure 1 shows a picture of a used PDC diaphragm that was taken out of service owing to cracking. The diaphragm shows the ring of black deposit, suspected to be a cause in reducing the diaphragm life and generated by the impurities in the incoming H_2 gas.
- A finite element model of the diaphragm was developed and used to predict the location on the diaphragm where maximum contact sliding occurs relative to the compressor process head (see Figure 2). This location is close to the ring of black deposit in Figure 1, which could potentially be a site for fretting damage and subsequent failure, especially in the presence of any debris. It is pointed out that this result is consistent with the location of actual failures observed in the diaphragms of PDC's compressors.
- Initial examination of the cracked diaphragm showed the primary crack was approximately perpendicular to the radial direction, suggesting that radial stresses played a role in the diaphragm failure. Multiple cracks were also observed adjacent to the primary crack and at places the top surface of the diaphragm appeared to stretch across the primary crack, suggesting significant plastic deformation associated with the failure (see Figure 3).

Additional analysis of the diaphragm behavior via finite element modeling and microstructural examination is underway. Therefore, this project has enabled us to begin developing a fundamental understanding of design, materials and operational issues that affect the diaphragm life. We anticipate that this partnership and information and knowledge exchange between the industry and a national laboratory will be critical in helping DOE achieve its targets

FIGURE 1. Picture of a PDC diaphragm taken out of service, showing the ring of black deposit suspected to be a cause in reduced diaphragm life. The location of the crack, where the diaphragm leaked, is circled with a black marker.

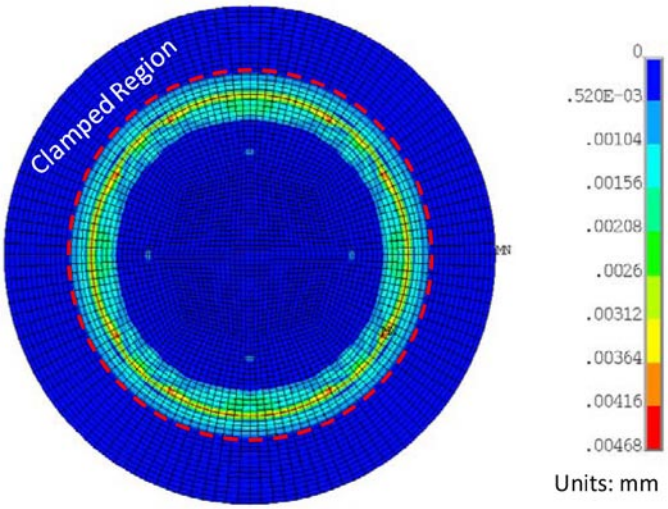

FIGURE 2. Finite element model predicted relative sliding between the diaphragm and the process head. The yellow contour band indicates the radial location of maximum sliding, which coincides with the ring of black deposit in Figure 1.

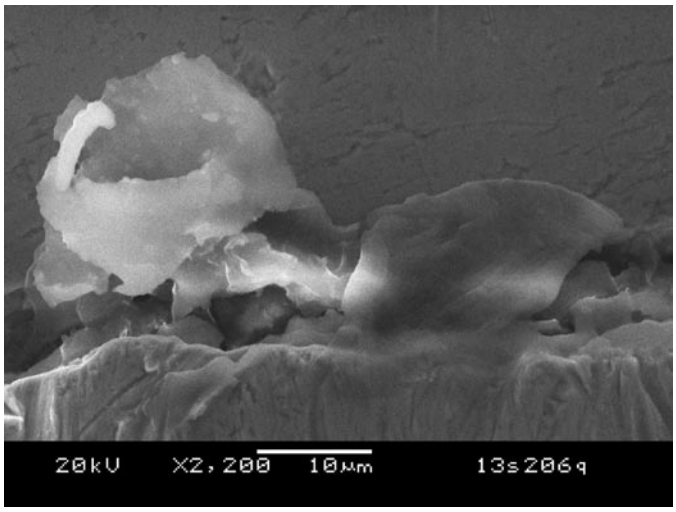

FIGURE 3. A scanning electron microscope image of a portion of the crack (from diaphragm shown in Figure 1) showing a thin layer of the diaphragm material "bridging" the primary crack, as well as numerous small surface cracks formed in the material adjacent to the crack.

for improving compressor reliability, increase diaphragm life and reduced maintenance costs.

FUTURE DIRECTIONS

The following are three potential areas for further research to enable long life for H_2 compressors:

- Understanding the role of diaphragm microstructure in controlling its operational life.
- Design tools for evaluating interactions between compressor design, fluid flow, and diaphragm response.
- Effect of impurities and debris on fatigue life of the diaphragm.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. DOE July 2013 Milestone Report

2. DOE August 2013 Milestone Report

3. Project Review technical presentation to PDC Machines, Inc.

4. Project Review technical presentation to Fuel Cell Technology office, DOE