VII.H.3 Development and Testing of a Toroidal Intersecting Vane Machine (TIVM) Air Management System

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Objectives

- Develop a toroidal intersecting vane machine (TIVM)-based air management system that satisfies DOE's automotive fuel cell system requirements and is readily adaptable to alternate user requirements.
- Select and demonstrate design features to assure adequate sealing, minimum porting pressure loss, and low friction operation.
- Develop the TIVM design methodology to allow efficient application to alternate user requirements.
- Develop manufacturing processes to provide low cost for high volume production.
- Measure the performance of the TIVM compressor/expander across the operating range.
- Fabricate and deliver a compressor/expander/motor prototype for independent testing.

Technical Barriers

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

- E. Compressors/Expanders

Technical Targets

This project is developing an air management system comprised of an integrated compressor, expander, and motor. The products developed by this project will enable meeting the overall efficiency goals of the automotive fuel cell program. The key specific goals for the air management system are:

- Flow: 91 g/s for a 80 kWe system
- Compressor Pressure: 2.5 atm at full speed
- Power Required: 5.8 kWe at full speed

- Size: 15 liters
- Weight: 15 kg
- Noise: <65 db at full speed
- Cost: $400

Approach

- Demonstrate the basic performance of the TIVM concept as a compressor/expander.
- Test candidate materials for friction and wear using standard laboratory tribilogical methods.
- Test candidate seal and port designs as well as low friction materials in simplified test configurations to select the best performing options for the TIVM compressor/expander.
- Optimize the vane surface solution methodology to provide a more efficient design process.
- Fabricate a TIVM compressor/expander prototype using seals, porting, and materials selected from the simplified feature tests and evaluations.
- Conduct performance tests of the prototype covering the full operating range.
- Refine the prototype features as necessary to obtain optimal performance.
- Develop cost efficient manufacturing methods for high volume production.
- Integrate a high efficiency motor with the TIVM prototype and test the combined unit across the operating range.
- Deliver a TIVM compressor/expander/motor prototype to Argonne National Laboratory for testing.

Accomplishments

- Completed fabrication and assembly of TIVM compressor/expander with improved rotary valve design features.
- Performed initial break-in of clearance seals to provide desired clearances.
- Utilized improved vane surface solution for primary and secondary vanes.
- Performed low speed performance testing.
- Identified internal flow bypass behavior as primary limitation to achieving performance goals.
- Modified seal designs to minimize internal leakage and bypass flow.
- Retested flow and pressure performance and refined seal designs further.

Future Directions

- Refine design details and seal configuration based on test results to optimize performance.
- Design and fabricate integrated compressor/expander/motor prototype.
- Measure compressor/expander/motor (CEM) prototype performance at Mechanology.
- Deliver CEM prototype to DOE for independent testing.

Introduction

The Toroidal Intersecting Vane Machine (TIVM) is an innovative mechanical concept, invented and patented by Mechanology, which can be configured as an integrated, positive displacement compressor/expander or compressor/compressor. In FY 1999 DOE investigated the TIVM concept for potential application to automotive fuel cell systems and determined that the inherent efficiency, compactness and thermodynamic attributes of this concept might be of significant benefit. Mechanology developed a design specifically for the 50 kWe automotive system and evaluated its potential performance. Based on the encouraging results obtained, a first generation compressor/expander prototype was built and tested. The compressor/expander prototype tests indicated that the TIVM runs smoothly with no mechanical problems; however, improvements are required to limit air leakage. Additional tests using the generic prototype with temporary seals demonstrated the capability of the TIVM to produce the necessary flow and pressure. Based on these observations, the TIVM compressor/expander development plan is focused on development and demonstration of seals, ports and low friction materials. These are necessary to satisfy the functional performance requirements with low parasitic power. Although not the main focus of the current development project, the requirements for air management system packaging, noise, and cost are considered as critical for a successful TIVM based system and are carefully considered as development progresses.

Approach

The basic functions of the TIVM compressor/expander (kinematics, pressure, flow) have been demonstrated, however development and qualification of specific seals, flow ports and low friction materials are required to meet the performance requirements.

During the past year Mechanology focused on the integration of a broad range of design options into the hardware for a full TIVM device. The initial simplified tests from the single vane test provided a measure of the leakage and friction characteristics of candidate vane seal designs.

Definition of the vane surface configurations required for a specific TIVM can be accomplished through an iterative process developed by Mechanology. With sufficient iterations a very good meshing surface solution can be obtained, as evidenced by the generic TIVM prototype vanes. However, this process is quite time consuming. Mechanology has developed and applied an alternate mathematical approach to develop a more efficient surface design methodology and facilitate manufacturing.

Low friction materials are necessary for the intersecting vanes to realize the predicted energy efficiency of the TIVM compressor/expander. Additionally, these materials must have sufficiently low wear under the TIVM operating conditions to perform acceptably during a 6,000 hour lifetime. Several candidate material pairs and potential coatings have been identified based on published data. To qualify materials for the TIVM, standard laboratory friction and wear tests are being performed. Successful materials are being tested in the single vane test rig and subsequently the best materials will be used in a TIVM prototype.

In parallel with the specific technology development for the TIVM, Mechanology continues to evolve the overall design to reduce the operating speed and increase the efficiency. The improved design features will be incorporated into the subsequent prototypes.

One or more full TIVM compressor/expander prototypes will be fabricated by Mechanology and tested across the full operating range. Modifications will be made as necessary to optimize performance. Subsequently, a high efficiency electric motor will be integrated with the TIVM to form a complete compressor/expander/motor component. This unit will be tested by Mechanology and then delivered to ANL for independent testing.

Results

Mechanology developed a significant improvement in the TIVM arrangement that eliminates the transfer of the compressor work through the vane-to-vane interface and thereby reduces the friction dramatically. This arrangement also reduces the pressure drop across many of the potential leakage paths, which reduces leakage inefficiency. The design of low pressure drop ports is also enhanced by this innovation as well as fabricability and ease of assembly. The thin secondary rotors that implement this design concept are shown in Figure 1 with the surrounding housing.

The improved design uses *layer cake* architecture rather than the *pie segment* arrangement used in previous prototypes. This arrangement significantly improves the manufacturability of the

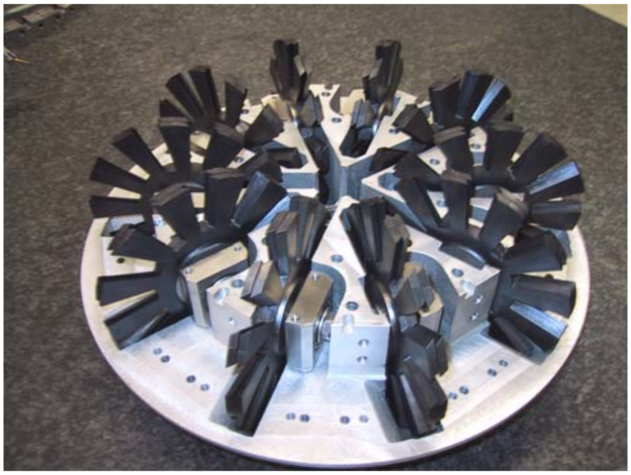

Figure 1. Secondary Rotors as Dynamic Valves in Housings

Figure 2. Hardware in *Layer-Cake* Architecture

TIVM and reduces the need for precision assembly. The layers that comprise this architecture are shown in Figure 2.

The vane surface solution has been improved by mathematical modeling of the TIVM vane interactions and a methodology has been developed that provides an automated path to computer numerical control machining. A feature test performed to measure the impact of this single change in the generic prototype demonstrated a pressure increase of approximately 10 psig with the improved surfaces because of reduced leakage across this interface. Figure 3 illustrates the primary vanes with the improved surfaces installed in their housings.

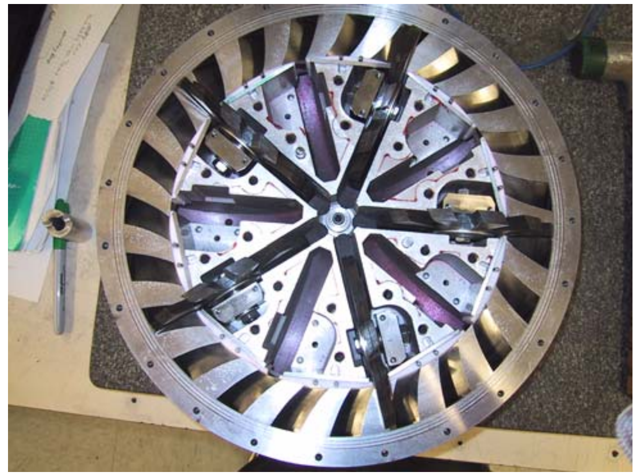

Figure 3. Primary Vanes with Improved Surfaces in Housings

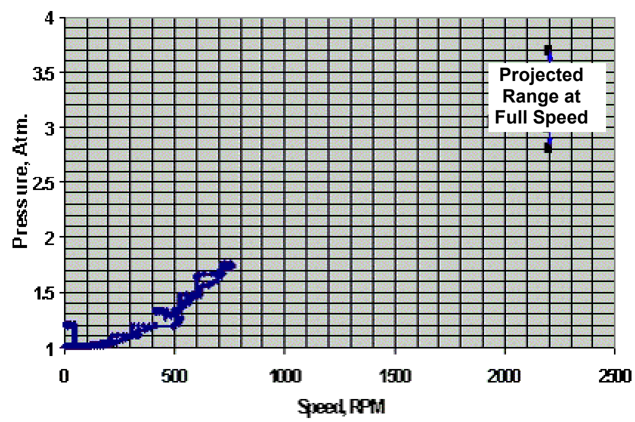

Figure 4. Pressure versus Speed for TIVM Prototype

A prototype TIVM compressor/expander has been designed, fabricated, and assembled incorporating all of the improved features described above. Initial testing has begun using clearance seals. The testing strategy is to start with very close clearances and to run the TIVM at low speeds to wear in the seals by using higher and higher speeds. As the speed has been increased the friction between the seals and the housings has increased as the material temperature increased. Extended operation at speed has produced the desired seal wear and reduced the operating friction. The pressure as a function of speed for the initial tests is shown in Figure 4. Projection of the low speed data to full speed indicates that the TIVM should meet the DOE compressor outlet pressure target.

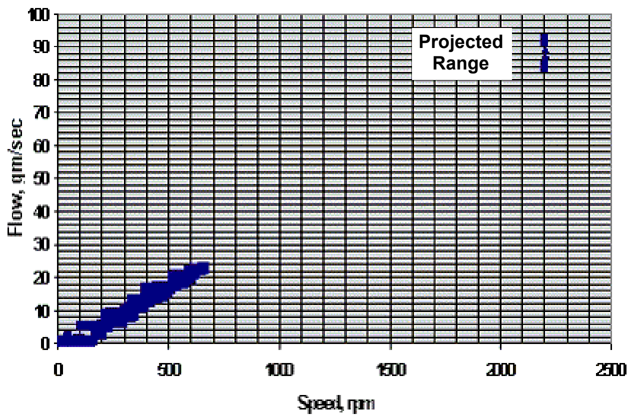

Figure 5. Flow versus Speed for TIVM Prototype

The compressor inlet flow as a function of speed is illustrated in Figure 5. Projection of this curve to full speed indicates that the TIVM will satisfy the DOE performance goal.

Detailed analysis of the test results and diagnostic testing has identified several specific areas of leakage paths that have been modified to improve performance. A series of tests with iterations of small design improvements are in process with performance tests to determine the integral effects. These design evolutions are expected to provide a TIVM compressor/expander that meets all of the DOE performance requirements.

Conclusions

The design, analysis, and feature testing performed by Mechanology over the past year continues to indicate that the innovative TIVM air management system for fuel cell cars has the potential to meet or exceed the DOE targets. Completion of prototype integral performance measurements and integration of a high efficiency motor will provide car and fuel cell power system original equipment manufacturers with a superior air management solution.

FY 2005 Publications/Presentations

1. "Mechanology Technical Progress Review - TIVM Compressor/Expander/Motor Development and Demonstration", presented to the FreedomCAR Technical Team, February 23, 2005.
2. "Development and Test of the Toroidal Intersecting Vane Machine (TIVM) Air Management System", presented at the DOE Hydrogen and Fuel Cells 2005 Annual Merit Review, May 25, 2005.