

## **IV.H.6 Development and Testing of a Toroidal Intersecting Vane Machine (TIVM) Air Management System**

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### **Objectives**

- Develop a 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 barrier from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Compressors/Expanders

### **Approach**

- Demonstrate the basic performance of the TIVM concept as a compressor/expander.
- Test candidate materials for friction and wear using standard laboratory tribological 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 (ANL) for testing.

## Accomplishments

- Developed major innovation in TIVM design which eliminates transfer of significant work across vane-to-vane interface, thereby reducing friction very significantly; reduces pressure differential and leakage; and facilitates manufacturing. Submitted two patent applications.
- Significantly improved vane surface solution and automated implementation to machining process; increased pressure by 10 psig in feature test.
- Designed, fabricated and checked out Rotary Seal Test rig; initiated testing of candidate face seals for prototype.
- Completed detailed engineering analysis and an improved design of compressor/expander and released for fabrication.
- Fabricated improved prototype parts and initiated assembly for performance testing at Mechanology.
- Evaluated predicted performance of prototype, predicted to satisfy DOE performance targets for flow, pressure, and power.

## Future Directions

- Complete assembly and checkout of prototype TIVM compressor/expander.
- Measure performance compared to DOE targets.
- Refine design details and seal configuration based on test results to optimize performance.
- Engage subcontractor for motor design, fabrication, and testing.
- Design and fabricate integrated compressor/expander/motor (CEM) prototype.
- Measure CEM prototype performance at Mechanology.
- Deliver CEM prototype to DOE for independent testing.

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## 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 program, 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 2003, Mechanology focused on the use of simplified feature tests to allow rapid, efficient characterization of a broad range of design options

for later inclusion in a full TIVM device. The initial simplified tests used a Single Vane Test device to measure 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 is developing alternate mathematical approaches 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 (CEM) 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

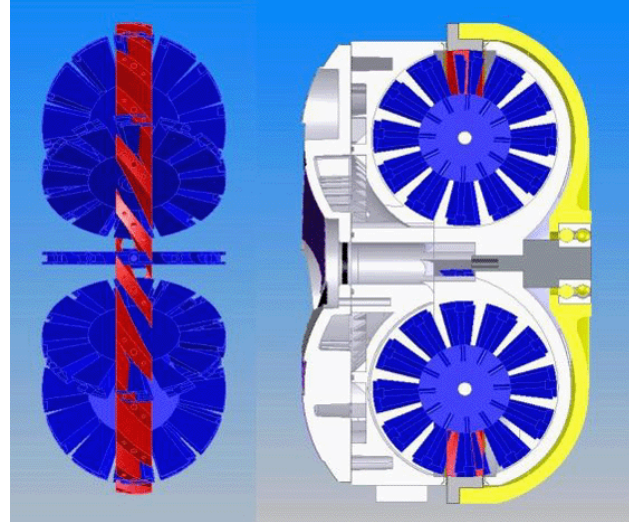


Figure 1. Improved TIVM C/E Design

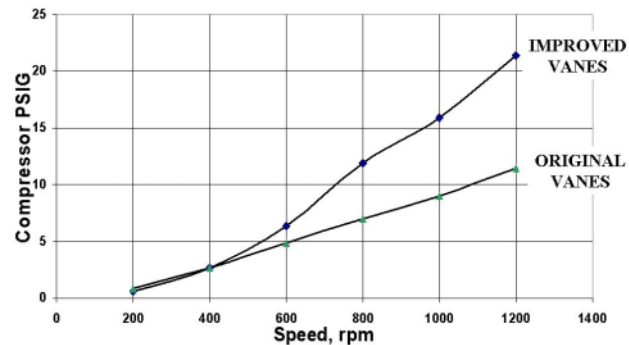
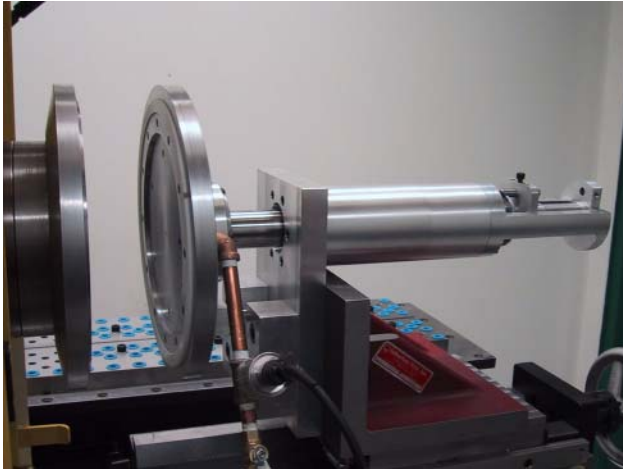


Figure 2. New Vane Solution Increases Pressure

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. This design is illustrated in Figure 1.

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 (CNC) machining. A feature test was performed to measure the impact of this single change in the generic prototype. As seen in Figure 2, the pressure increased by approximately 10 psig with



**Figure 3.** Rotary Seal Test Device

the improved surfaces because of reduced leakage across this interface.

To measure the leakage and friction performance of candidate face seals, Mechanology has designed, built and checked out a Rotary Seal Test rig, which is shown in Figure 3. This device interfaces with Mechanology's compressor/expander (C/E) test stand and uses its computer control, instrumentation, and data acquisition systems. Tests are conducted at prototypic operating conditions, including speed, pressure, and preload.

A detailed design of a TIVM compressor/expander prototype incorporating all of the improved features has been completed. The design process included detailed structural and thermal analysis across the operating range to accommodate structural deflections and differential thermal expansion. Rapid prototyping parts were produced and used to refine the design. Parts for this prototype have been fabricated, and initial assembly has begun. Figure 4 illustrates the partially assembled C/E TIVM prototype, which will be tested at Mechanology.

### **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



**Figure 4.** Partially Assembled TIVM C/E Prototype

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 2004 Publications/Presentations**

1. "Mechanology Technical Progress Review - TIVM Compressor/Expander/Motor Development and Demonstration", presented to the FreedomCAR Technical Team, March 17, 2004.
2. "Development and Test of the Toroidal Intersecting Vane Machine (TIVM) Air Management System", presented at the DOE Hydrogen and Fuel Cells 2004 Annual Merit Review, May 26, 2004.
3. "Development and Testing of a Toroidal Intersecting Vane Machine (TIVM) Air Management System, Annual Technical Progress Report" submitted June 30, 2003.