

## V.B.4 Cost and Performance Enhancements for a PEM Fuel Cell Turbocompressor

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Contract Number: DE-FC36-02AL67624

Start Date: December 2002

Projected End Date: September 2008

### Objectives

- Develop an optimum turbocompressor configuration by working with fuel cell system manufacturers.
- Reduce turbocompressor/motor controller costs while increasing design flexibility.
- Develop and integrate the turbocompressor/motor controller into a fuel cell system.

### Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section (3.4.4) of the Hydrogen, Fuel Cells & Infrastructure Technologies Multi-Year Research, Development and Demonstration Plan:

(F) Air Management

### Technical Targets

See Table 1 for the fuel cell turbocompressor update.

### Approach

- Use of automotive and aerospace turbomachinery technology to develop a low-cost and low-weight/volume design.
- Build upon previous turbocompressor experience.
- Use variable nozzle turbine (VNT) inlet geometry for improved performance across the desired flow range.
- Use a mixed flow type compressor for improved low flow performance.
- Use contamination/oil free and zero maintenance compliant foil air bearings.
- Use a modular approach to improve design flexibility.
- Use a high-efficiency, low-cost two-pole motor.
- Use a low-cost, no-sensor-required variable speed motor-controller topology design.

### Accomplishments

- Structural integrity and detailed design have been completed.
- All parts have been received.
- A fully instrumented unit has been assembled.
- Integration of the turbocompressor and motor controller has been completed.
- Mapping of the compressor and VNT turbine has been completed.
- Three additional demonstration units for use by system developers have been assembled and acceptance tested.

### Future Directions

- Complete mapping of the motor/bearing cooling.
- Complete mapping of the motor and motor controller power.



### Introduction

The objective of this work is to develop an air management system to pressurize an automotive fuel cell system with contaminant-free air. The turbocompressor is a motor-driven compressor/expander operating on air bearings that pressurizes the fuel cell system with contaminant-free air and recovers subsequent energy from the high-pressure exhaust streams. Under contract

**TABLE 1.** Fuel Cell Turbocompressor Update

<b>Table 3.4.10. Technical Targets: Compressor/Expanders (C/E) for Transportation Fuel Cell Systems</b>					
<b>Characteristic</b>	<b>Units</b>	<b>2005 Status</b>	<b>2010</b>	<b>2015</b>	<b>2007 Honeywell Estimates</b>
Input Power <sup>a,b</sup> at Full Load, 40°C Ambient Air (with Expander / without Expander)	kW <sub>e</sub>	6.3/13.7 <sup>b</sup>	5.4/12.8	5.4/12.8	11.0/15.7 <sup>g</sup>
Overall Motor/Motor Controller Conversion Efficiency, DC Input	%	85	85	85	87
Input Power <sup>a</sup> at Part Load, 20°C Ambient Air (with Expander/without Expander)	kW <sub>e</sub>	5.2/12.4 <sup>b</sup>	4.4/11.6	4.4/11.6	1.3/14.3 <sup>g</sup>
Compressor/Expander Efficiency at Full Flow (C/E Only) <sup>c</sup>	%	75/80 <sup>d</sup>	80/80	80/80	70/77
Compressor/Expander Efficiency at 20-25% of Full Flow (C/E Only) /Compressor at 1.3 PR/Expander at 1.2 PR	%	55/45 <sup>d</sup>	60/50	60/50	65/65
System Volume <sup>e</sup>	liters	22 <sup>b</sup>	15	15	15
System Weight <sup>e</sup>	kg	22 <sup>b</sup>	15	15	22
System Cost <sup>f</sup>	\$	1,500 <sup>b</sup>	400	200	1,500 <sup>h</sup>
Turndown Ratio		10:1	10:1	10:1	10:1
Noise at Maximum Flow (excluding air flow noise at air inlet and exhaust)	dB(A) at 1 meter	65	65	65	TBD
Transient Time for 10-90% of Maximum Airflow	sec	1	1	1	2-3

<sup>a</sup> Input power to the shaft to power a compressor/expander, or compressor only system, including motor/motor controller with an overall efficiency of 85%. 80 kW<sub>e</sub> compressor/expander unit for hydrogen/air flow – 90 g/sec (dry maximum flow for compressor, compressor outlet pressure is specified to be 2.5 atm. Expander (if used) inlet flow conditions are assume to be 93 g/sec (at full flow), 80°C and 2.2 atm.

<sup>b</sup> Projected

<sup>c</sup> The pressure ratio is allowed to float as a function of load. Inlet temperature and pressure used for efficiency calculations are 20-40°C and 2.5 atm.

<sup>d</sup> Measure blade efficiency.

<sup>e</sup> Weight and volume include the motor and motor controller.

<sup>f</sup> Cost targets based on a manufacturing volume of 100,000 units per year, includes cost of motor and motor controller.

<sup>g</sup> Input power includes leakages, bearing losses, additional flow to cool the motor rotor and bearings, motor and motor controller losses. Testing will have to be completed to determine if the additional flow can be reduced or recovered in the turbine inlet to reduce the input power at the 40°C and 20°C ambient air conditions to 8.6/15.7 kW<sub>e</sub> and 7.3/14.3 kW<sub>e</sub>, respectively.

<sup>h</sup> The estimate is in 2005 dollars. The estimate is for hardware only and does not include labor, testing, nonrecurring engineering or capital equipment costs. The turbomachinery, motor and motor controller costs are estimated at approximately 90%, 5.5% and 4.5% respectively of the total costs noted.

TBD - to be determined

by the Department of Energy, Honeywell designed and developed the motor-driven compressor/expander and evaluated performance, weight and cost projection data. As compared to positive displacement compressor/expander technology, the turbocompressor approach offers high-efficiency, reliable and low-cost potential, in a compact and lightweight package.

## Approach

The turbocompressor design currently underway for the 'Cost and Performance Enhancements for a PEM Fuel Cell Turbocompressor' project consists of a mixed flow compressor impeller, a VNT, and motor magnet rotor incorporated onto a common shaft operating up to a speed of 110 krpm on compliant foil air bearings. A motor controller drives and controls the motor, which is capable of driving the turbocompressor to the maximum design speed. The air bearings are lubrication-free in addition to being lightweight and compact. The bearings

are also self-sustaining therefore no pressurized air is required for operation.

The turbocompressor operates by drawing in ambient air and compressing it, then delivering it to the fuel cell stack, and fuel processor where applicable. The exhaust streams are then expanded through the turbine to aid in the overall turbocompressor/fuel cell system efficiency. The design is modular to enhance system developer flexibility. In addition to the liquid-cooled motor stator and motor controller, the motor and bearing cavities are air-cooled. The motor is of the two pole toothed type and the motor controller will incorporate controls that do not require separate sensors for operation, both of which are conducive to low cost and improved packaging.

Both the mixed flow compressor impeller and VNT improve system performance by improving the flow, pressure ratio and power characteristics of the turbocompressor over the flow range. The mixed flow

compressor impeller design comes from various aerospace applications and the VNT variable nozzle turbine from the automotive turbocharging division, Transportation Systems.

## Results

After working with various system developers, the DOE and the FreedomCAR Tech Team, a set of specifications was completed for the 'Cost and Performance Enhancements for a PEM Fuel Cell Turbocompressor' project. The detailed analyses and design have been completed for the turbocompressor, motor and motor controller. All parts have been fabricated, received and units have been assembled as shown in Figures 1 and 2.

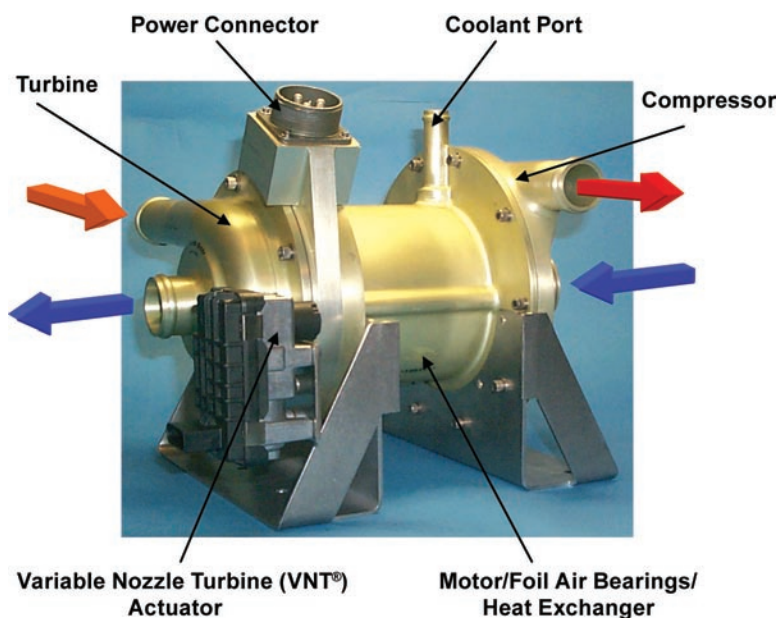
The testing of the integrated turbocompressor and motor controller has been initiated with the compressor and VNT turbine maps completed. Mapping of the motor/bearing cooling and the motor/motor controller power will be completed in 2008.

## Summary

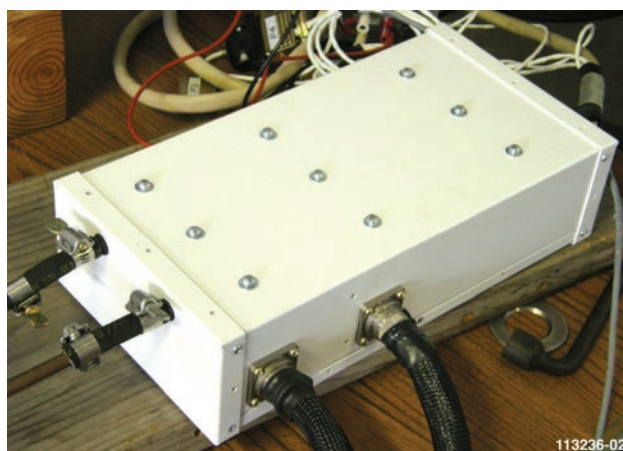
- All detailed analysis and design has been completed.
- All hardware has been fabricated, received and assembled.
- A fully instrumented unit has been assembled and performance characterization initiated.
- Three demonstration units have been assembled, tested and are ready for delivery to system developers.

## Future Directions

- Complete mapping of the motor/bearing cooling.
- Complete mapping of the motor and motor controller power.
- Complete final technical report.



**FIGURE 1.** Turbocompressor for the DOE/Honeywell Cost and Performance Enhancements for a Proton Exchange Membrane (PEM) Fuel Cell Turbocompressor Project



**FIGURE 2.** Motor Controller for the DOE/Honeywell Cost and Performance Enhancements for a PEM Fuel Cell Turbocompressor Project