IV.E.5 Foil Gas Bearing Supported High-Speed Centrifugal Anode Gas Recycle Blower

Giri Agrawal (Primary Contact),
Bill Buckley, Dennis Burr, Ali Shakil
R&D Dynamics Corporation
15 Barber Pond Rd.
Bloomfield, CT 06002
Phone: (860) 726-1204; Fax: (860) 726-1206
E-mail: agragiri@rddynamics.com

DOE Project Manager: Charles Alsup
Phone: (304) 285-5432
E-mail: Charles.Alsup@netl.doe.gov

Objectives

Demonstrate the feasibility of using a high-speed centrifugal foil bearing supported anode gas recycle blower (FBS-AGRB) to help members of the Solid State Energy Conversion Alliance (SECA) meet their solid oxide fuel cell (SOFC) goal of higher efficiency and lower overall system cost.

Accomplishments

- Substantial progress has been made, and a prototype FBS-AGRB unit has been designed and built meeting all SECA member requirements. The unit has the following features:
  - Low-cost design which incorporates "design for manufacturing and assembly" concepts
  - High temperature capability: >850°C
  - High-efficiency high-speed motor and centrifugal blower
  - Oil-free gas bearings
  - Compact
  - Scalability to larger sizes
  - No gas, sulfur, silica or heavy metal leakage
  - No purge gas required
  - No parasitic cooling required
  - Mechanical type seals were not required
  - Explosion-proof design
  - No corrosion/carbon deposition
  - 40,000-hour lifetime
  - Maintenance free
- The prototype FBS-AGRB unit is ready for testing at elevated temperatures.
- Initiated cost-reduced design. Conical gas bearing design and manufacturing is in progress for low-cost, high temperature capability and efficiency.

Introduction

The goal of the SECA is to develop commercially-viable ($400/kW) 3- to 10-kW SOFC systems by 2010. SOFC power generation systems are attractive alternatives to current technologies in diverse stationary, mobile, and military applications. SOFC systems are very efficient, from 40 to 60 percent in small systems and up to 85 percent in larger co-generation applications. The electrochemical conversion in a SOFC takes place at a lower temperature (650 to 850ºC) than combustion-based technologies, resulting in decreased emissions – particularly nitrogen oxides, sulfur oxides, and particulate matter. These systems all offer fuel flexibility, as they are compatible with conventional fuels such as hydrogen, coal, natural gas, gasoline, or diesel. Despite these advantages, advances in balance-of-plant component design must be developed before the SECA program goal can be realized.

SOFC systems that incorporate some recycling of the anode exhaust gas, which is mixed with incoming fresh fuel prior to entering the pre-reformer, have a higher efficiency and offer the potential for lower overall system cost. An anode gas recycle blower (AGRB) is an attractive solution to perform this task.

Approach

R&D Dynamics has focused on the design and development of a FBS-AGRB to achieve the goals set by SECA members. An innovative, cost-reduced, compact, high-temperature, high-speed centrifugal blower has been designed and built. The FBS-AGRB rotating assembly is supported on state-of-the-art proven foil gas bearing technology. The foil gas bearing technology and the high-speed permanent magnet (PM) motor design make the FBS-AGRB very promising for meeting the technical targets and cost. The integration of conical foil bearings into the FBS-AGRB will further drive down the blower cost.

The FBS-AGRB has been designed and built to meet the requirements of SOFC systems. The FBS-AGRB advances progress toward the goal of making economically viable and efficient SOFC systems because of its potential for:

- Low cost using simple design and materials.
- High temperature capability (>850°C) using foil gas bearings, and advanced high temperature magnets for PM motor.
- Highest blower efficiency via high-speed centrifugal impeller, foil gas bearings, PM motor and sensor-less controller.
- Contamination-free using oil-free foil gas bearings.
- High reliability requires no maintenance.
- Compactness and light weight.

Results

The FBS-AGRB has been designed and built for an inlet temperature of 600 to 850°C, atmospheric pressure, pressure rise of 4-10 inches of water, and a flow of 100 standard liters per minute (slpm), which is nominally composed of 46 slpm H_2O, 27 slpm CO_2, 20 slpm H_2 and 7 slpm CO. Overall efficiency exceeds 40% under aforementioned operating conditions. The unit has a variable speed control with a flow turndown ratio of 5 to 2. The blower unit will have a design life of >40,000 hours, with a 100% duty cycle and 10,000 hour maintenance interval. The unit will be able to tolerate at least 30 thermal cycles between operating and room temperatures over its design life. The unit cost of the blower for production rates of >50,000 units was estimated to be $100.

Design points for the FBS-AGRB are as follows:

Shaft speed	98,000 rpm
Pressure Ratio	1.025
Pressure Rise	25.4 cm of water (10 inches of water)
Inlet Pressure	1.01 bar (14.69 psia)
Outlet Pressure	1.08 bar (15.06 psia)
Inlet Temperature	850°C (1562°F)
Outlet Temperature	857.3°C (1575.2°F)
Gas Constant	0.369 J/Kg °C (68.64 ft-lbf/lbm R)
Specific Heat Ratio	1.274
Mass Flow	1.54 g/s (0.204 lbm/min)
Volume Flow	100 slpm
Impeller Isentropic Power	15.6 Watt

Figures 1 and 2 show the cut-section view and the manufactured blower assembly, respectively. Figure 3 shows the manufactured shaft assembly.

Key technologies were incorporated into the blower design, including state-of-the-art aerodynamics, foil gas bearings, PM magnet motor using advanced high temperature magnets, innovative fan design with fins mounted on the shaft assembly, thermal choke to separate the hot side from the cold side, and sensor-

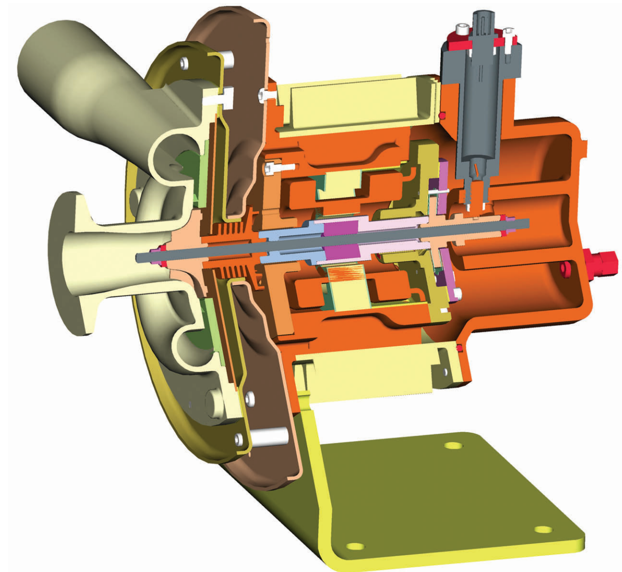

FIGURE 1. Cut-Section View of AGRB

FIGURE 2. View of the Manufactured FBS-AGRB Prototype Unit

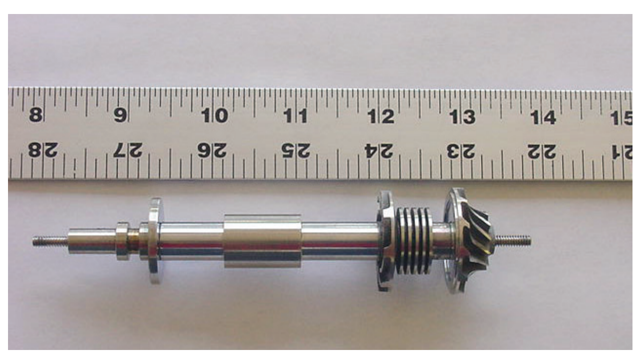

FIGURE 3. View of the Manufactured Shaft Assembly

less controller. Design analysis included performance prediction maps; preliminary design; finite element analysis including thermal, vibration and stress; computational fluid dynamics analysis; rotor dynamics analysis; cooling flow analysis; detailed design and drawings. Tests performed on AGRB components were load deflection on journal and thrust bearings, back electromotive force testing on motor rotor and stator, etc. A furnace will be used to heat the gas to 850°C for elevated temperature testing of the FBS-AGRB. The blower is ready for testing.

Technical feasibility of the conical bearing, proven in Phase I, has been extended to the manufacturing of the bearing and the test rig. The designed test rig is capable of testing many combinations of conical bearings at loads and speeds while measuring friction.

Conclusions and Future Directions

- Key blower technologies were proven by extensive design and analysis.
- A prototype unit has been designed and built which is ready for testing.
- The high-temperature blower design evolved to be a successful design which can achieve SECA goals.
- The blower cost was estimated to be $100 at a production volume of 50,000 units/year.

Phase II is in progress. Work needs to be continued in Phase II as follows:

- Test blower at high temperature conditions.
- Incorporate rigorous "design for manufacturing and assembly" techniques to further reduce cost.
- Build conical bearing rig, test bearings and incorporate bearings into blower design.
- Demonstrate blower to SECA members.
- Test blower in SECA member's fuel cell systems.

FY 2007 Publications/Presentations

1. "Foil Bearing Supported High Speed Centrifugal Blower" Progress Report Period 08/07/06 - 04/20/07, April 2007.

2. "Foil Bearing Supported High Speed Centrifugal Blower" Project Review Presentation, DOE NETL - Morgantown, WV, March 05, 2007.

3. "Foil Bearing Supported High Speed Centrifugal Blower" Progress Report Period 08/07/06 - 12/07/06, December 2006.