FOIL GAS BEARING SUPPORTED HIGH-SPEED CENTRIFUGAL BLOWER

Sponsor: Department of Energy

Participants: R&D Dynamics
SECA Members

Presented by: Dr. Giri L. Agrawal

BLOWER NEEDED FOR

✓ Recycling SOFC Anode Exhaust Gas Back To Pre- Reformer

Resulting In ----

- Increased SOFC System Efficiency
- Potential for Lower Overall System Cost

HIGH-SPEED CENTRIFUGAL BLOWER PROVIDES

- ✓ High Efficiency
- ✓ Potential for Low Manufacturing Cost
  - Less material
  - Few components
- ✓ Part Load Capability / Variable Speed

FOIL BEARING PROVIDES

- ✓ Oil Free Operation
- ✓ High Rotational Shaft Speed
- ✓ Maintenance Free
- ✓ High Reliability
- ✓ High Temperature Capability

TECHNICAL ISSUES

- ✓ Design for Low Cost Manufacturability
- ✓ Design for scalability
- ✓ No gas leakage
- ✓ No sulfur leak into fuel stream
- ✓ No free silica exposure into fuel stream
- ✓ No heavy metal leakage into fuel stream
- ✓ DC voltage operation flexibility below 150 VDC
- ✓ Design for 40,000 hour lifetime
- ✓ Flexible on maintenance interval ~ 10,000 HRS.

TECHNICAL ISSUES (Cont.)

- ✓ No cooling available from system other than process fluid
- ✓ All power consumption needs to include cooling
- ✓ Purge gas is undesirable
- ✓ Blower shaft temperature may be below water dew point
- ✓ Mechanical type seals do not last
- ✓ Hydrogen around motor may be safety concern
- ✓ Corrosion/carbon deposition issues with high temperatures
- ✓ Metal out gassing at high temperatures e.g. chrome

R&D OBJECTIVES

- ✓ Design and Demonstrate a Foil Gas Bearing High-Speed Centrifugal Blower that Resolves All Technical Issues.

PHASE I OBJECTIVES

- ✓ Preliminary Design of Prototype Blower
- ✓ Breadboard Testing of Key Technology

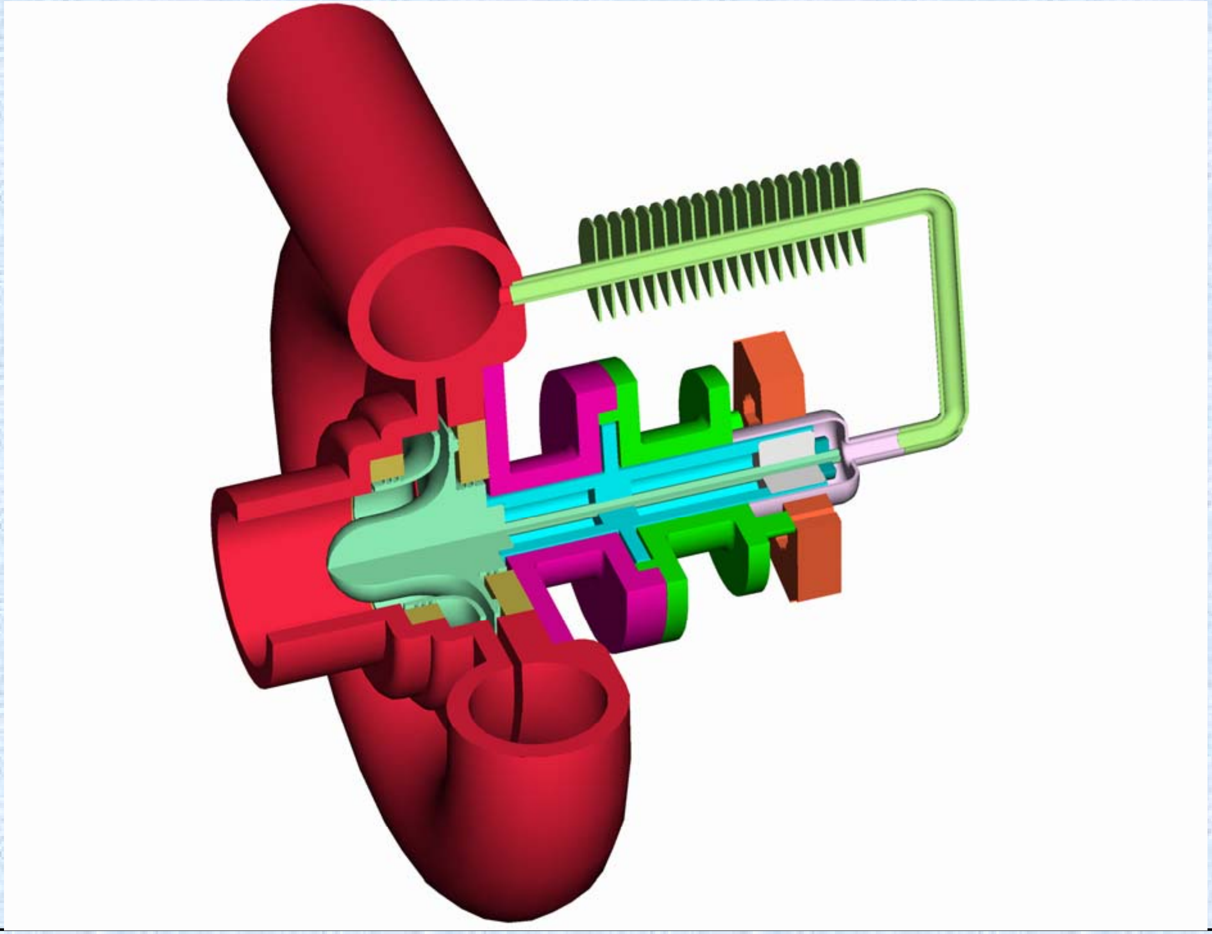
PHASE II OBJECTIVES

- ✓ Detailed Prototype Design
- ✓ Manufacture Prototype
- ✓ Test Prototype

PRELIMINARY SPECIFICATION

✓ Inlet Temperature	600 to 850°C
✓ Inlet Pressure	Atmospheric
✓ Pressure Rise	4 to 10 in. of H_2O
✓ Flow	100 slpm
✓ Nominal Gas Composition	46 slpm H_2O, 27 slpm CO_2, 20 slpm H_2, 7 slpm CO
✓ Overall Efficiency	$\geq$ 40%
✓ Turn-down Ratio	5 to 2 (Variable Speed)
✓ Thermal Cycles	> 30
✓ Unit Cost (50,000 units/year)	Low

PROTOTYPE BLOWER CONCEPT



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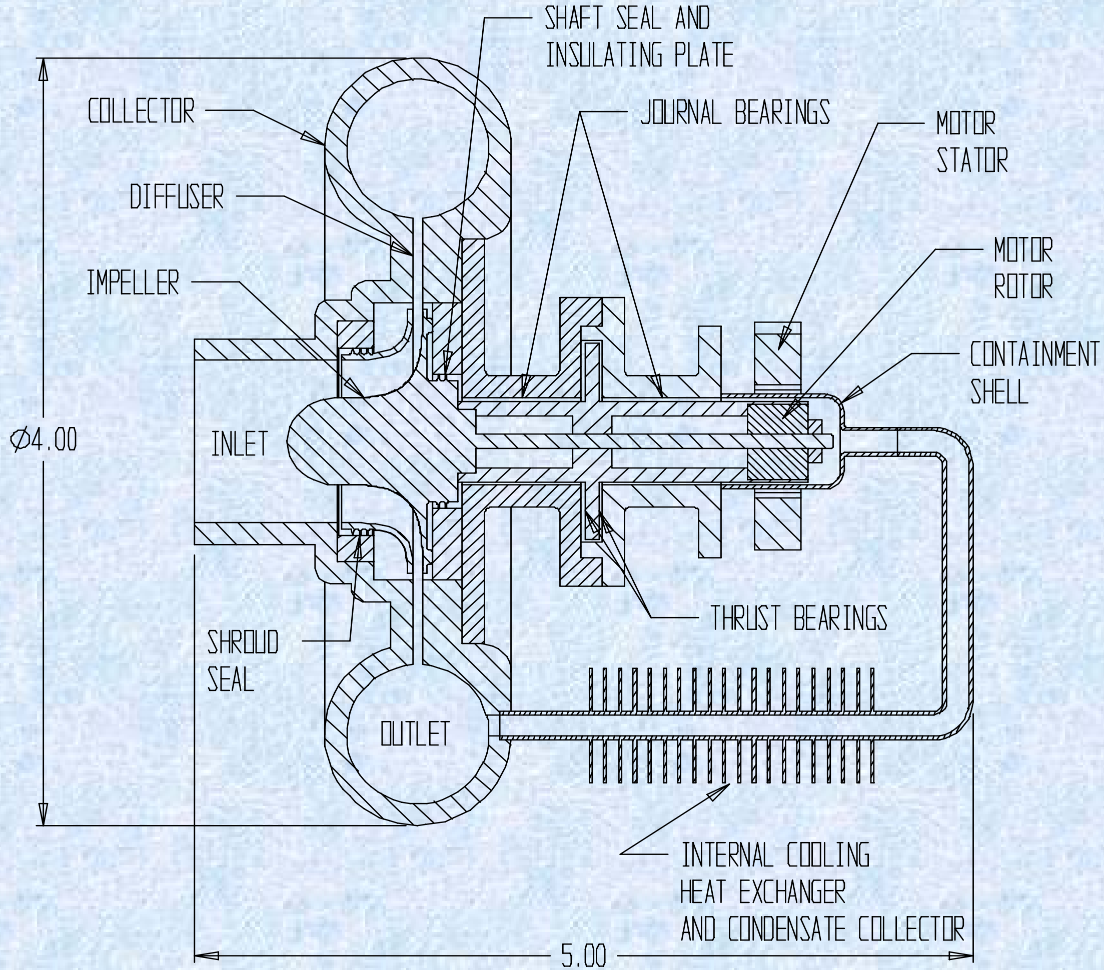

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FEATURES OF CONCEPT

- ✓ Sealed Rotor
- ✓ Shaft System Supported Radially by Pair of Hydrodynamic Foil Journal Bearings
- ✓ Aerodynamic and Applied Thrust Loads Borne by Pair of Opposing Hydrodynamic Foil Thrust Bearings
- ✓ Motor Driven by an Integrated Variable Frequency Drive (inverter)
- ✓ Internal Process Gas Cooling

PHASE I WORK PLAN

- ✓ Prototype Unit
  - Preliminary design
  - Motor design
  - Rotor design
- ✓ Breadboard Unit
  - Test sealed rotor motor design

ACCOMPLISHMENTS

- ✓ Prototype Unit Concepted
- ✓ Breadboard Unit
  - – Existing hardware identified
  - – Sealed rotor motor design in progress

PROTOTYPE UNIT
MOTOR DESIGN

Number of Poles	2	
Rated Output	100	watts
Rated Speed	75,000	rpm
Rated Voltage	24	V_{rms}
Rated Torque	.013	N*m
Rated Current	4.5	A_{rms}
Stator Resistance	.066	ohms L-L
Stator Inductance	.067	mH

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PROTOTYPE UNIT
MOTOR DESIGN (cont.)

- Motor Rotor
  - Magnet Inside Diameter 0.170 in
  - Magnet Outside Diameter 0.650 in
  - Sleeve Thickness 0.030 in
  - Radial Air Gap 0.020 in
  - Magnet Length 0.600 in
- Stator
  - Stator Can Thickness 0.010 in
  - Lamination Inside Diameter 0.770 in
  - Lamination Outside Diameter 2.500 in
  - Stack Length 0.600 in

PROTOTYPE UNIT
MOTOR DRIVE (cont.)

DC Supply Voltage	40-190 Vdc
Peak Current	25 amps
Maximum Continuous Current	12.5 amps
Minimum Load Inductance	250 μH
Switching Frequency	22 kHz $\pm$15%
Bandwidth	2.5 kHz
Temperature Range	0° to 65°C
Rotor Position Feedback	Hall Effect Sensor
Over-Voltage Shutdown	195 Vdc
Over-Temperature Shutdown	>65°C
Size	7.35 x 4.40 x 1.00 inches
Weight	1.5 lb.

PROTOTYPE UNIT ANALYSIS in PROGRESS

- Critical Speed Analysis
- Forced Response
- Internal Cooling
- Thrust Balance
- Heat Transfer
  - Conduction
  - Convection
  - Radiation
- Motor Magnetic Analysis

PROTOTYPE UNIT
IMPELLER AERODYNAMIC DESIGN

Pressure Ratio	1.025
Isentropic Power	16 watts
Compressor Isentropic Efficiency	78 %
Compressor Power	21 watts
Speed	75,000 rpm
Specific Speed	80
Flow Coefficient	.0496
Pressure Coefficient	.551

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PROTOTYPE UNIT
INTERNAL COOLING FAN AERODYNAMIC DESIGN

Inlet Temperature	277	°F
Inlet Pressure	14.7	psia
Mass Flow Rate	0.5	g/s
Pressure Rise	6.6	in. of H_2O
Isentropic Power	1.2	watts
Compressor Isentropic Efficiency	78	%
Compressor Power	1.6	watts
Impeller Outside Diameter	0.70	in
Speed	76,000	rpm
Specific Speed	80	

APPLICABILITY to SOFC COMMERCIALIZATION

- 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
- Superior Blower Technology
  - No Maintenance
  - Oil Free
  - Efficient
- Cost Competitive
  - Less then $50 per SOFC kW

PLANNED ACTIVITIES for NEXT 6 MONTHS

- Complete Prototype Unit Design
- Complete Breadboard Design
- Fabricate Breadboard
- Test Breadboard
- Prepare Phase II Project Plan
- Final Report

SUMMARY

- Foil Gas Bearing Supported High-Speed Centrifugal is the Best Technology for SOFC

- This Technology
  - Will resolve key technical issues
  - Will help SECA members
    - to achieve high system efficiency
    - to obtain low cost blower