Anode and Cathode Blower Systems for SOFC

Mark C. Johnson

Phoenix Analysis & Design Technologies

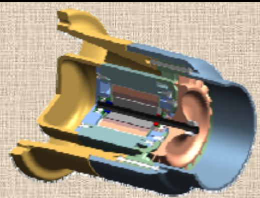
Agenda

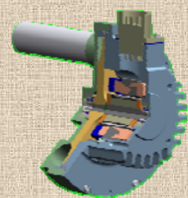
- PADT Background
- Summary of HARB program
- Transition from DG to FutureGen
- HARB II for FutureGen
- Component Development
- New blower: Small Multi-stage (SMS) blower
- Conclusions

Who is PADT?

- **Incorporated in March 1994**
  - Specialty blowers
  - Simulation services
  - Rapid prototyping
  - Medical instruments
  - Semiconductor equipment
  - **Facilities**
  - 24,000 ft^2 at ASU Research Park in Tempe, Arizona
  - 60% Office
  - 40% Shop & Lab
- **People**
  - 50 Employees

PADT Fuel Cell Programs





1998-2000

- 5 Roots Cathode blowers delivered
- 6 Axial Cathode blowers delivered

2001-2002

- VGEN, TURBOMIX, TRILOBE designed
- 18 blowers delivered

2003

- 28 blowers delivered

2004

- New HRB, SECA,TURBORAD developed
- 60 blowers delivered

2005

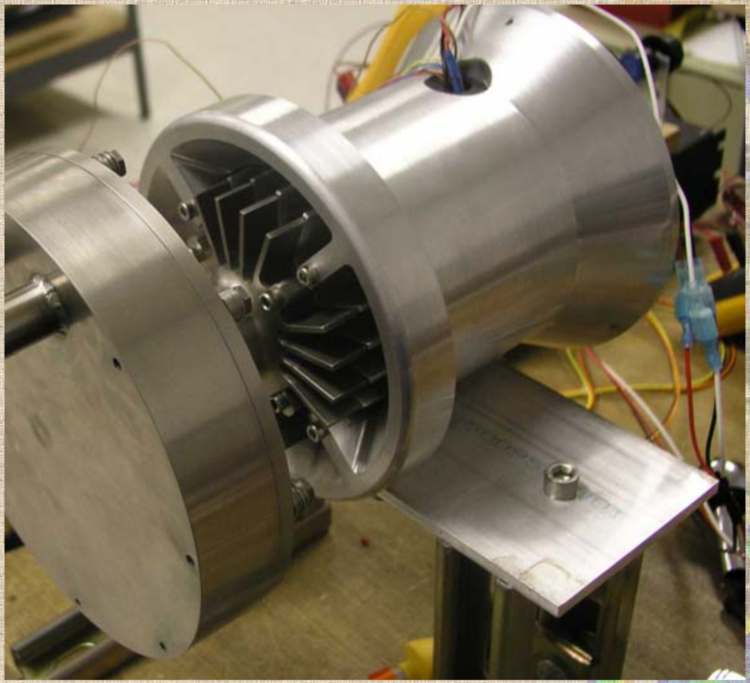
- HARB developed
- 120 blowers delivered

2006

- MINIRAD developed
- 150 blowers delivered

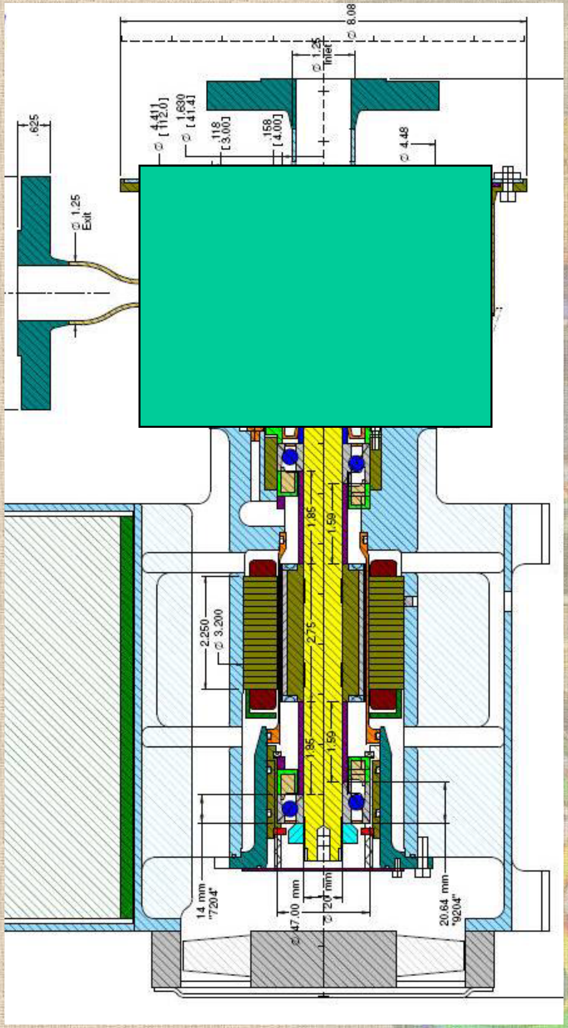
Summary of HARB Development

- Hot Anode Recycle Blower (HARB)
- HARB I POC built and tested
  - Thermal segregation proven
  - Tested to ~ 600 C
  - Low efficiency, ~ 25%
- Transition to FutureGen
  - Program slowed down
  - Specifications reassessed
- Component development
  - BLDC Motor
  - Bearings
  - Pumphead evaluation
- HARB II Designed for FutureGen



FutureGen Approach: HARB II

- Consulted with most SOFC developers
  - Support from DOE
- Design Drivers for FutureGen
  - Robustness
  - Cost Control
  - High performance
  - Flexible
- Approach for HARB II
  - 700 C inlet
  - Scalable, serves 50 kWe – 500 kWe
  - Low cost mfg processes
  - Moderate RPM 10k – 20k RPM
  - 18” long x 10” dia.
  - Good efficiency ~ 55%, DC to fluid
- Patents being evaluated
  - Pumphead, bearings, cooling



HARB II: Risk Assessment

- Motor exposure to High Voltage/Temperature/Moisture
  - Potting with silicone/epoxies/urethanes help some
  - Canned motor is best solution
- Motor Hall sensor failure
  - Work towards sensorless control
  - Keep sensors out of process flow
- Condensation in bearing/ motor cavity
  - Anode gases are ~ 50% mole fraction H_2O
  - Bearing/motor cavity may be below dew point
- Bearing Failure
  - Continual progress is being made (e.g. SiN balls)
  - Proper mounting and lubrication
- Impeller Creep
  - Control temps and stress
- Pumphead Corrosion, Chromium contamination
- Feedback: High temps add more risk

HARB II: Cost Assessment

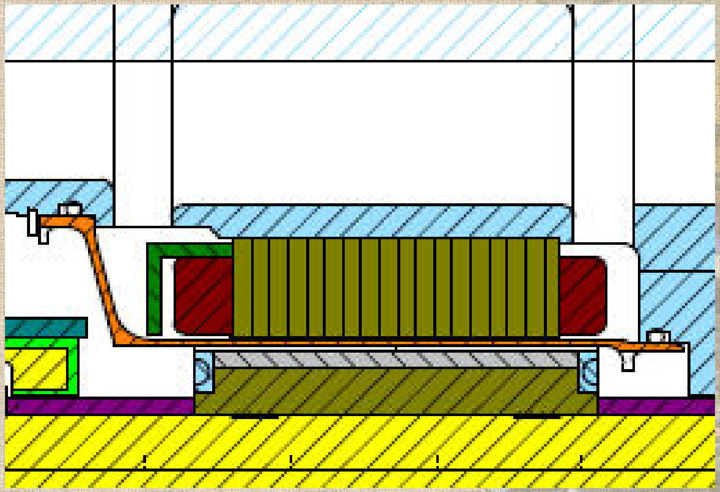
- **Bottom up cost estimate complete for HARB II**
  - **Based on quotes, scales, and estimates**

- **Feedback: Cost Drivers**
  - **Pressure Rise drives cost, higher stage count**
  - **Also higher power levels drive motor/controller cost up**
  - **Big benefit if inlet temp is below 500C. Enable SS solutions**

SUMMARY OF HARDWARE COSTS	PERCENT
Cool static component costs	12%
Cool rotating component costs	11%
Hot static component costs	31%
Hot rotating component costs	14%
Motor/Conroller costs	32%

HARB II: BLDC Canned Motor

- Motor now being tested in PEM based HRB system
- Cost Control
  - Keep RPM down
  - Avoid nickel-iron laminations
  - Use silicon steel laminations
  - Injection moldable can designs
- Testing in fuel cell environment
  - High temperature, Water, Hydrogen, Voltage
  - Pressure cycling for 38368 cycles over 632 hours
- Thermal Shock Testing
  - -40 C to 140 C, 300 cycles
- Overpressure to ~ 8 Bar with no issues



HARB II: Motor Can Testing

Fuel Cell Chamber

	HIPPIES Test			HIPPIES Test			HIPPIES Test	
	Initial Test			304 hrs, 14199			632 hrs, 38368	
	2/9/2007			2/22/2007			3/9/2007	
Material	Measured Leak Rate (cc/sec)	Measured Leak Rate (cc/hr)		Measured Leak Rate (cc/sec)	Measured Leak Rate (cc/hr)		Measured Leak Rate (cc/sec)	Measured Leak Rate (cc/hr)
	-	-		-	-		-	-
Ultem 30% filled	1.50E-05	0.054		2.40E-05	0.086		2.00E-05	0.072
Ultem (unfilled)	1.50E-05	0.054		3.10E-05	0.112		2.00E-05	0.072
Peek (unfilled)	1.50E-04	0.54		1.20E-05	0.043		7.40E-06	0.027

THERMAL SHOCK

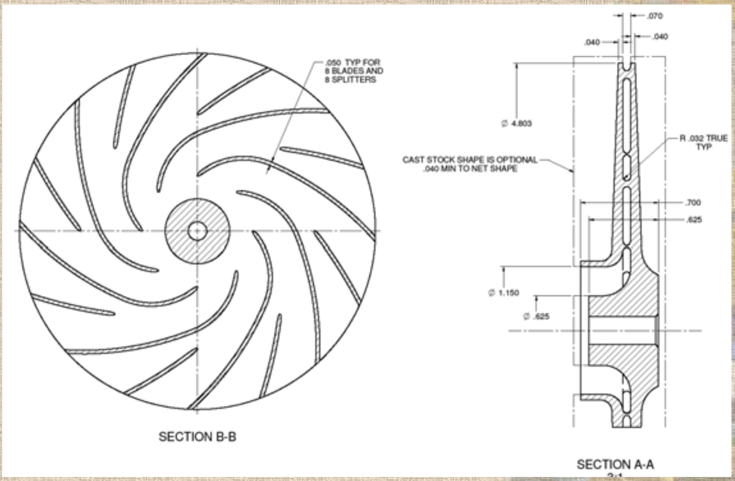
	Thermal Shock			Thermal Shock	
	Initial Test			300 cycles	
	2/13/2007			4/9/2007	
Material	Measured Leak Rate (cc/sec)	Measured Leak Rate (cc/hr)		Measured Leak Rate (cc/sec)	Measured Leak Rate (cc/hr)
	-	-		-	-
Ultem 30% filled	1.50E-05	0.054		1.80E-05	0.065
Ultem (unfilled)	1.50E-05	0.054		2.20E-05	0.079
Peek (unfilled)	6.75E-05	0.243		8.20E-06	0.03

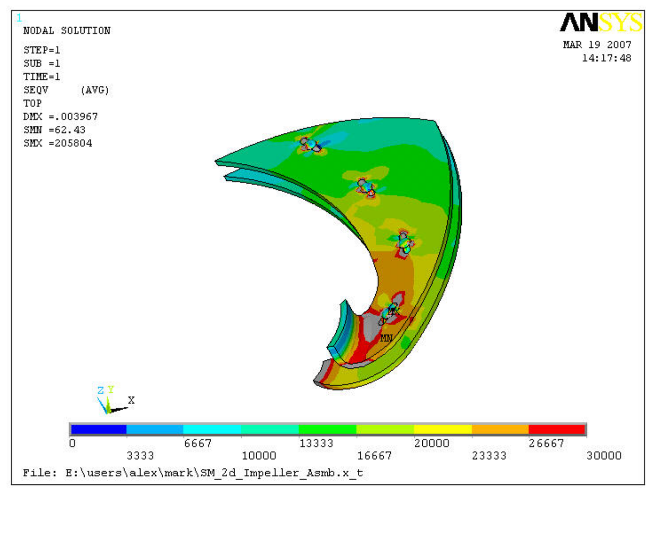
HARB II: Bearing Development

- 2 Bearing Rigs built
  - Running non-stop
- Accelerated life testing
  - Need 40000 hrs of life
  - 2 year program
- Working with industry veteran
  - 40 years of experience
- An additional 2 rigs now being built
  - 4 rigs total

Impeller Selection

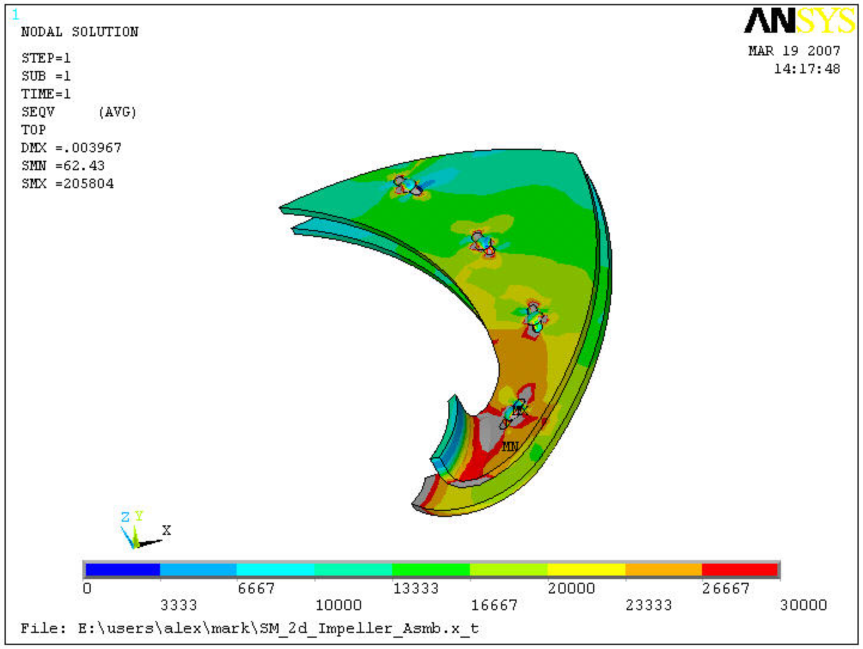
- **4 Configurations considered**
  - Cast regenerative
  - Cast single stage centrifugal
  - Single stage sheet metal centrifugal
  - Multi-stage sheet metal centrifugal
- **Regenerative is inefficient**
  - Axial clearance is critical
  - Temperatures, transients
- **Cast approach slow/expensive**
  - Got 2 Quotations(Howmet, Miller)
  - Casting cost over $2000 in low volume
  - Post machining greater than $2000
  - Long lead times, ~ 6 months

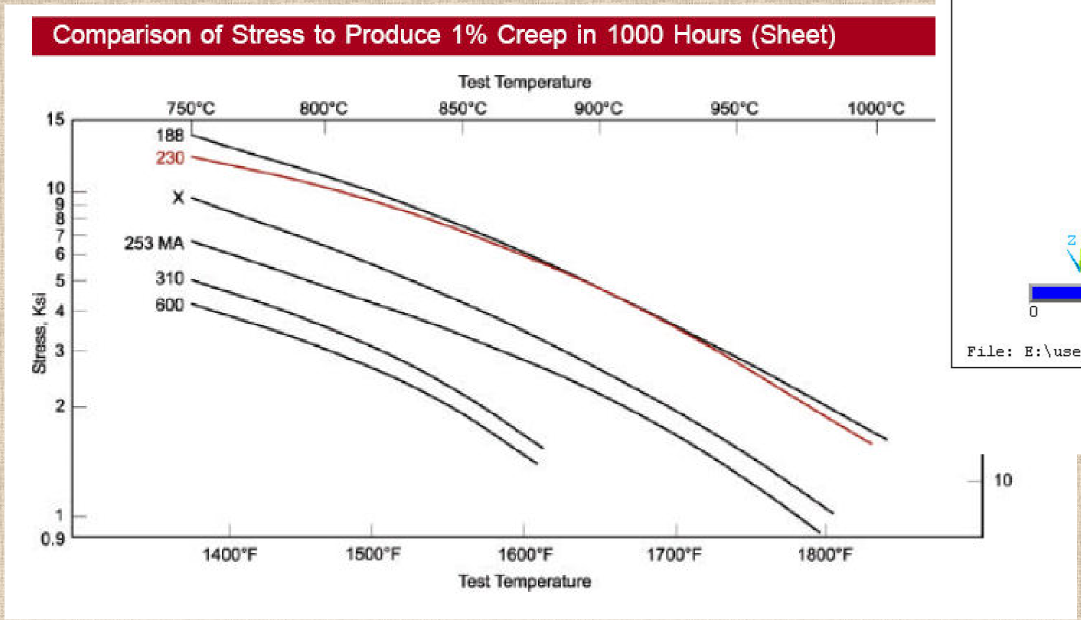




Impeller Selection

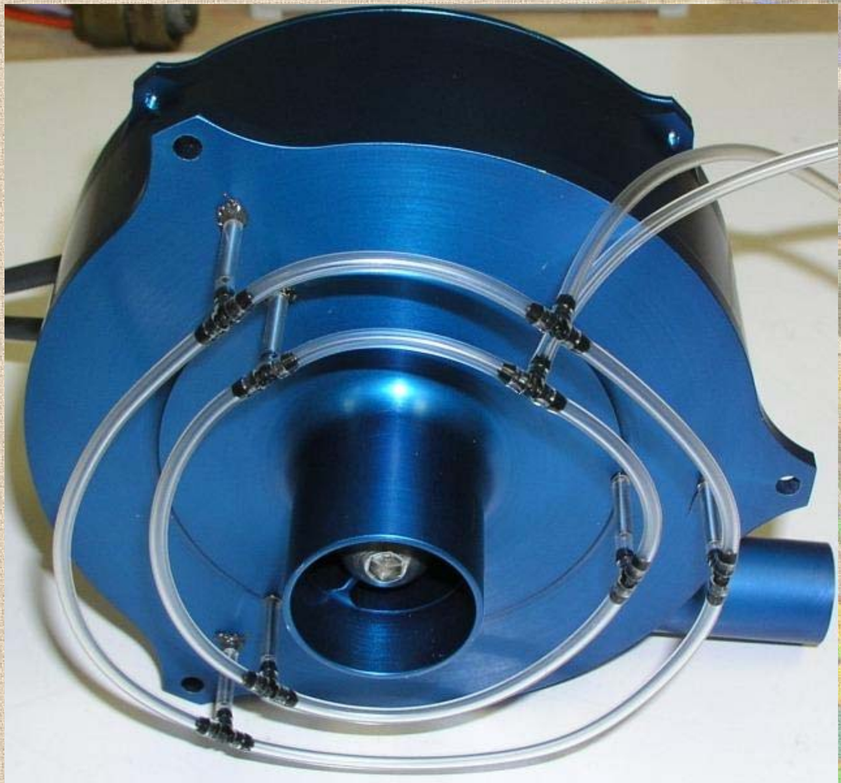
- **Single stage sheet has high stresses**
  - **High tip speed required to make DP**
  - **Bore stresses exceed 30 ksi**
  - **Haynes 230 will have limited life**





Multi-Stage Impeller Selected

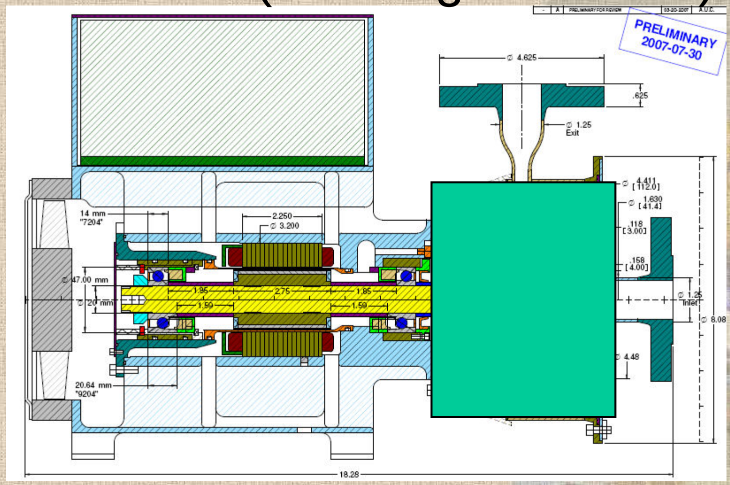
- **Multi-stage Impeller offers solution**
  - Tip speed way down. Quiet.
  - Bore stresses lower than 10 ksi
  - Flexible: Stage count easy to change
  - Very low cost
- **Efficiency proven on MINIRAD program**
  - ~ 43% overall efficiency
  - Expect ~55% for HARB II
  - Patent under evaluation



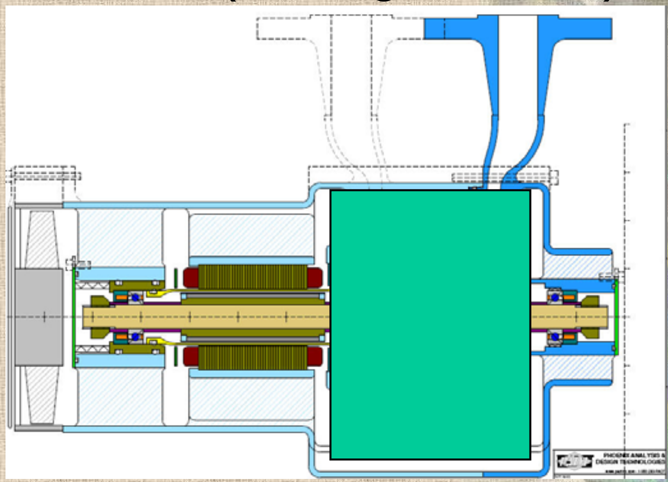
New Developments

- PADT has chosen to split program
  - HARB II for FutureGen
  - Small Multi-Stage (SMS) blower for DG
  - Both blowers will use same pumphead technology
- HARB II now in final design
  - Hardware in ~ 6 months
- SMS Blower
  - Will provide anode recycle
  - ~ 200C
  - Same multi-stage approach
  - Same motor approach
  - Design restricted to very low cost mfg processes
  - Flexible

HARB II (18" long x 10" dia.)



SMS (9" long x 6" dia.)



Acknowledgements

- SOFC developers
- NETL support
  - Chuck Alsup
  - Travis Schultz
  - Heather Quedenfeld
- UCI
  - Jack Brouwer
- Dawnbreaker Commercialization Assistance
  - Jenny Servo, Bob Larsen, Patty Heckman
- PADT Blower development team