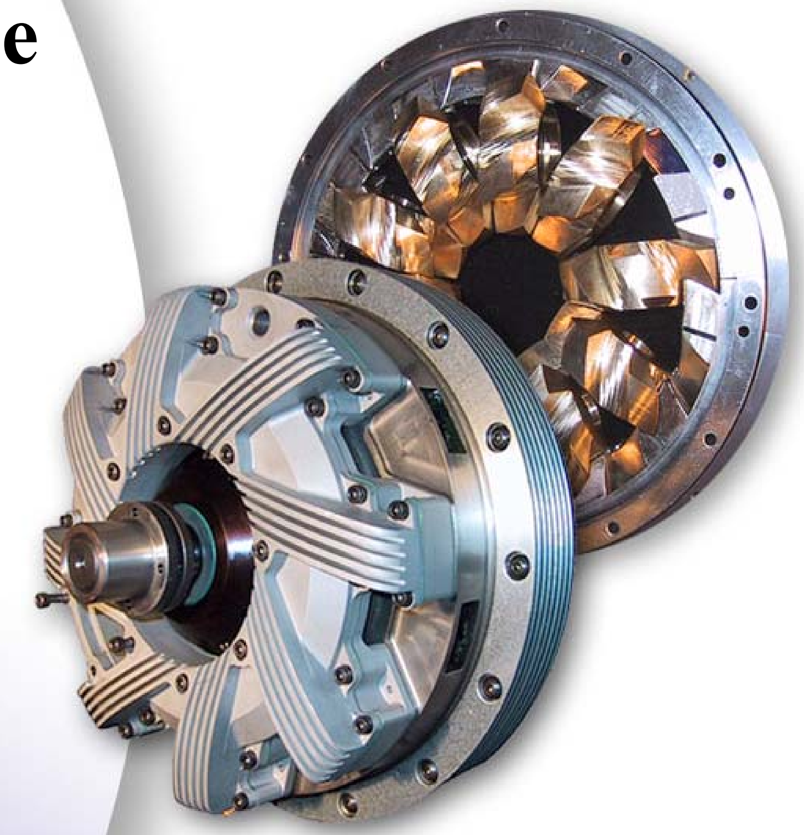
MECHANOLOGY

Development and Test of the Toroidal Intersecting Vane Machine (TIVM) Air Management System



Sterling Bailey Ph.D., P.E.

May 26, 2004

This presentation does not contain any proprietary or confidential information

TIVM Air Management System Development Objectives

- The overall objective of this program is to develop the innovative TIVM concept into working compressor/expander/motor hardware that satisfies the FreedomCAR Guidelines – and is easily adaptable to individual car system requirements – and to measure the TIVM air management system performance

- Objectives for the past year - building on the prior demonstration of the basic functionality of the TIVM:
  - Develop a compressor/expander design concept to limit friction, air leakage, and porting losses to meet FreedomCAR power and efficiency targets
  - Develop a detailed design for a prototype compressor/expander
  - Begin fabrication of the prototype compressor/expander with the selected features

TIVM C/E/M Development and Test Budget

- Total funding - $2,736,900
- DOE share - $2,000,000
- Mechanology Cost Share - $736,900 i.e. 26.9%
- GFY03 funding - $450,000

Air Management Technical Barriers

The Objective of Mechanology's TIVM CEM Development and Test project is to overcome the following Transportation Systems Barrier identified in the HFCIT Program Multi-Year Program Plan:

"**Compressors/Expanders.** Automotive-type compressors/expanders that minimize parasitic power consumption and meet packaging and cost requirements are not available. To validate functionality in laboratory testing, current systems often use off-the-shelf compressors that are not specifically designed for fuel cell applications. These result in systems that are heavy, costly, and inefficient. Automotive-type compressors/expanders that meet the FreedomCAR technical guidelines need to be engineered and integrated with the fuel cell and fuel processor so that the overall system meets packaging, cost, and performance requirements. "

2010 Technical Targets for Compressor/Expanders

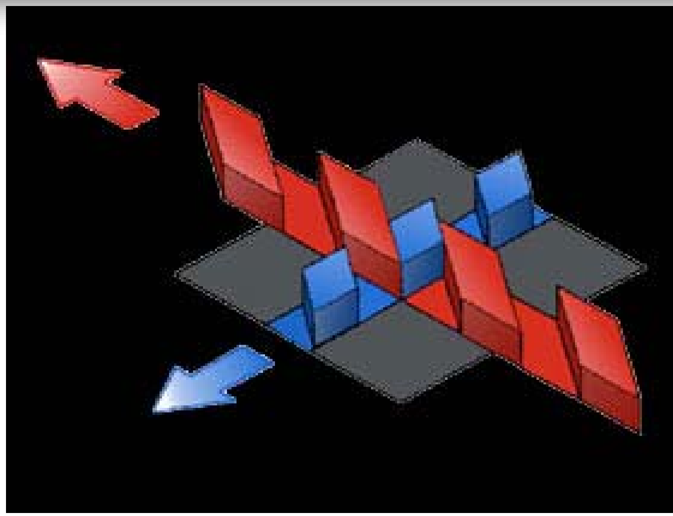
80-kW Unit Hydrogen with Expander 40^0 C Ambient Air

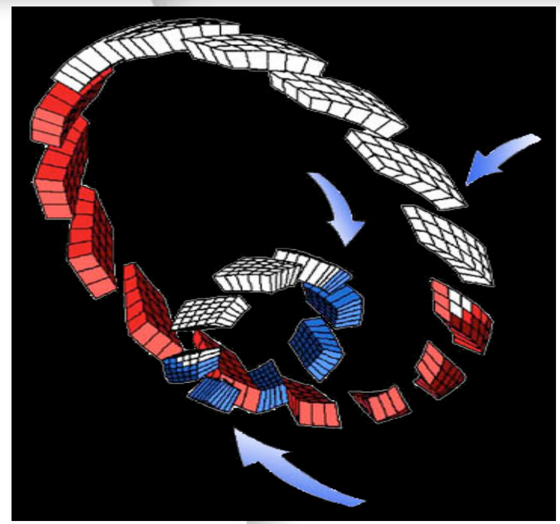
Requirement	Value
Flow	91g/s
Pressure	2.5 atm
Power	5.8 kW
Size	15 liters
Weight	15 kg
Noise	<65 db
Cost	$400
Turndown Ratio	10
Durability	5000 Hours

TIVM Development Technical Approach

- TIVM Description and Unique Features
- Prior Technical Status – Demonstrated Basic Functionality
- Identify Key Technical Challenges to Meet DOE Targets
- Develop Key Components Through Feature Testing and Analysis
- Integrate Features Into C/E Prototype Conceptual Design
- Develop Detailed Design with Engineering Analysis Support
- Fabricate and Test C/E Prototype for Integral Performance
- Refine C/E Prototype as Needed to Satisfy DOE Targets
- Integrate Motor with Compressor/Expander
- Fabricate, Test, Deliver CEM to DOE for Independent Testing

The Toroidal Intersecting Vane Machine Concept





Toroidal Intersecting Vane Machine Characteristics

Positive Displacement

- Compressor/Expander

- Compressor/Compressor

- Blower

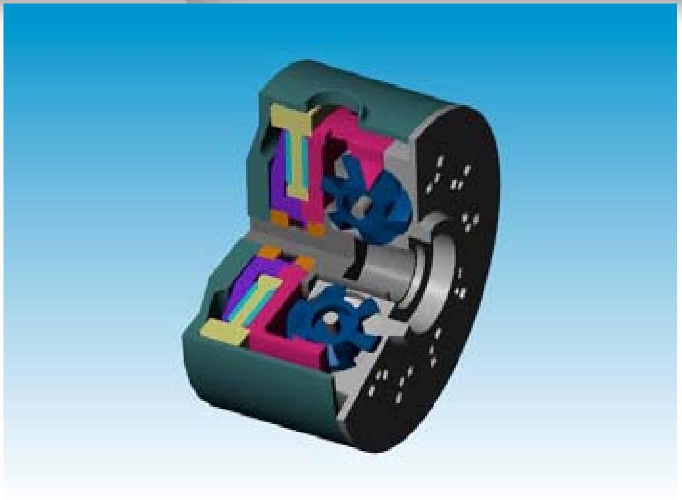
High Flow

High or Low Pressure

Small Volume

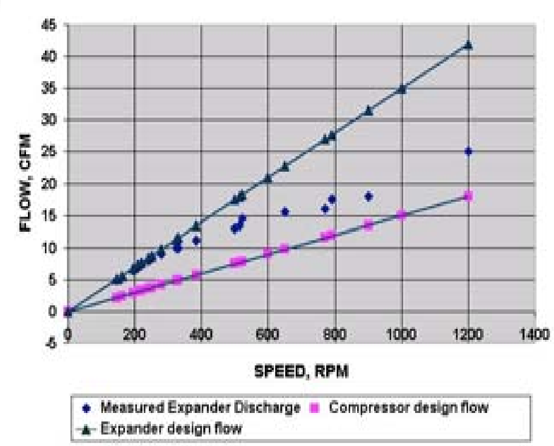
Low Production Cost

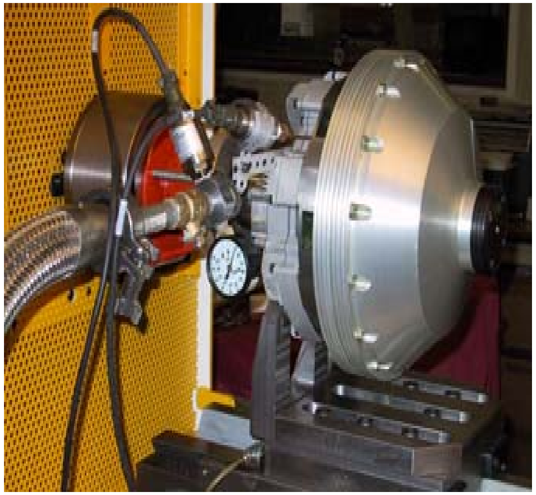
Many Spin-off Products

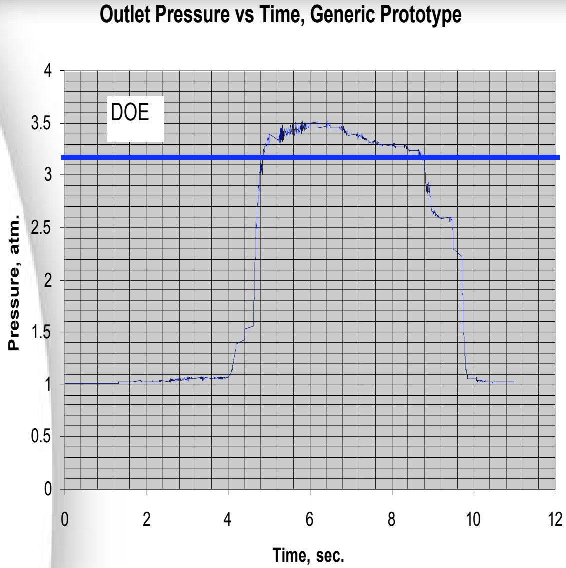


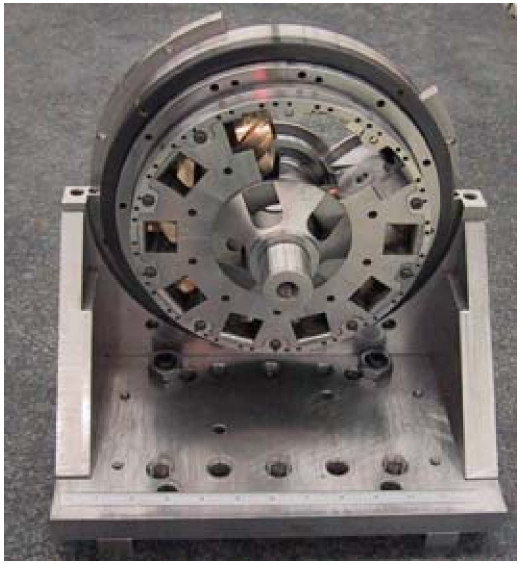
TIVM Attributes Provide Efficient Operation as an Integral Compressor/Expander for Automotive Fuel Cell Applications With Very Good Performance at High Turndown Ratios

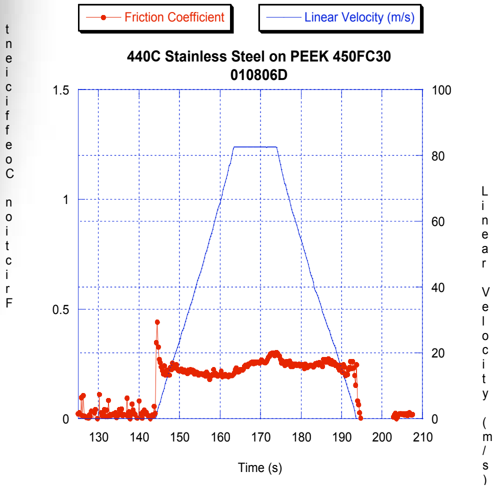
The Basic Viability of the TIVM Has Been Proven Through Hardware and Tests











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Three Key Performance Issues Needed to Satisfy the Power Requirement

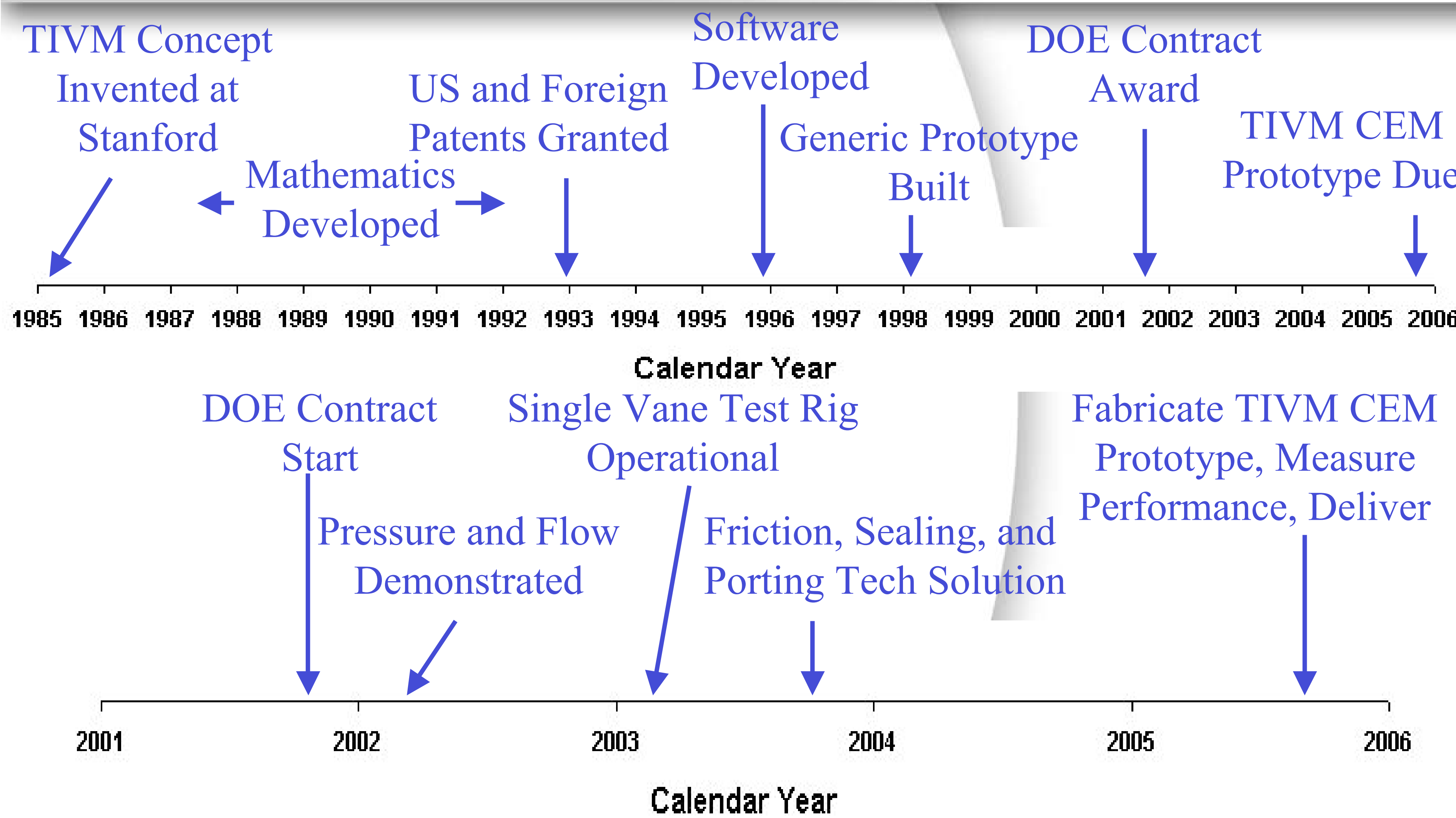
- Seals to limit air leakage without adding excessive friction
- Porting to assure low pressure drop, and power loss, across the compressor and expander inlet and discharge paths
- Confirmation of coefficient of friction for meshing vane interface – including high humidity environment

These are not unusual engineering tasks that require inventions or new materials. Solid, disciplined engineering development will provide the required solutions

Safety

- Failure modes and effects analyses will be used to identify and evaluate potential TIVM air management safety risks
- Fault trees will be constructed and evaluated
- Potential hazards include operation of rotating equipment at ~2000 RPM with potential mechanical failure
  - Robust design and large margins mitigate this risk
- Materials of construction could pose risk
  - No hazardous materials identified to date

TIVM Development Timeline



Technical Accomplishments/Progress

- Major innovation in TIVM conceptual design developed, patents submitted
- Significantly improved vane surface solution – performance impact tested
- Rotary Seal Test Machine built for qualifying face seals
- Detailed Compressor/Expander design and analysis completed
- Fabrication of prototype begun

New TIVM Design Concept and Patents

TIVM New Architecture (TIVM DV) Uses Basic TIVM Configuration with Secondary Rotors Acting as Dynamic Valves Rather Than as Compression Chambers

Primary Rotors and Vanes Now Perform Both Compression and Expansion

Eliminates Transfer of Significant Work Through the Sliding Vane Interface, and Thus the Major Source of Friction.

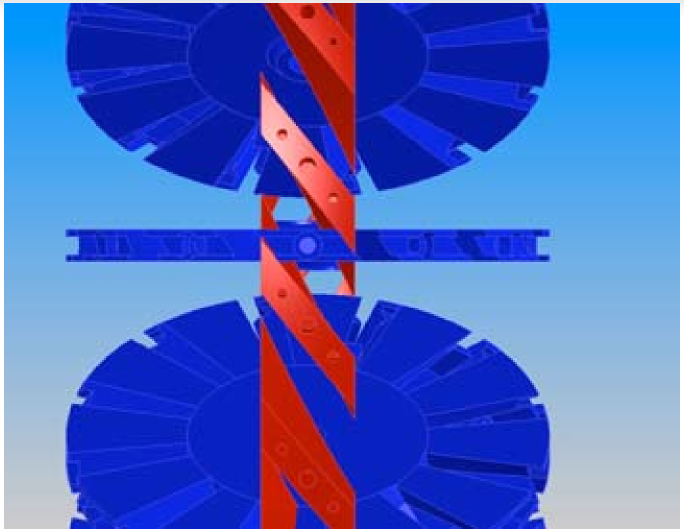
Significantly Reduces Pressure Differential Across Air Leakage Paths – Eases Sealing Challenge

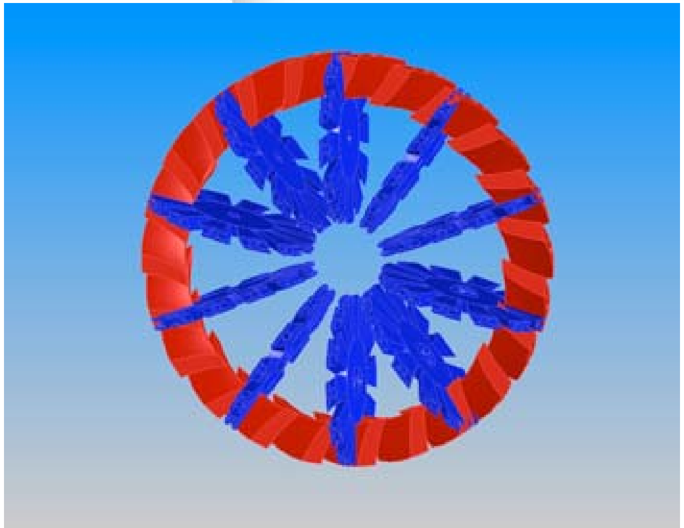
Simplifies Porting Design – Provides Generous Flow Area

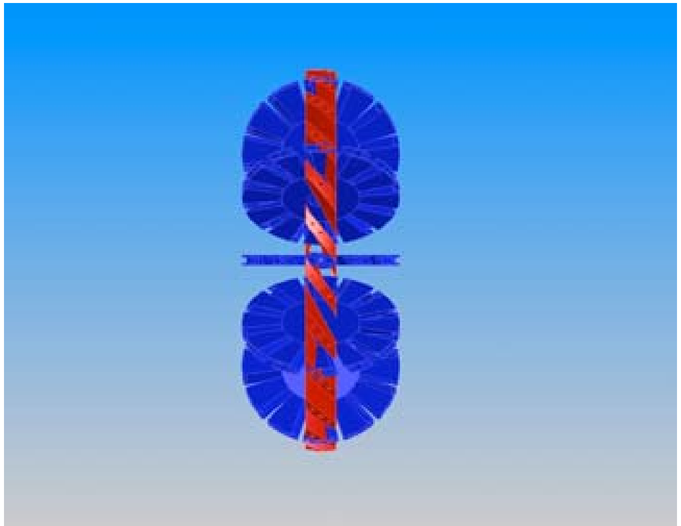
Simplifies Thermal Management

Simplifies Fabrication – Reduces Cost Challenge

New TIVM Design Concept and Patents





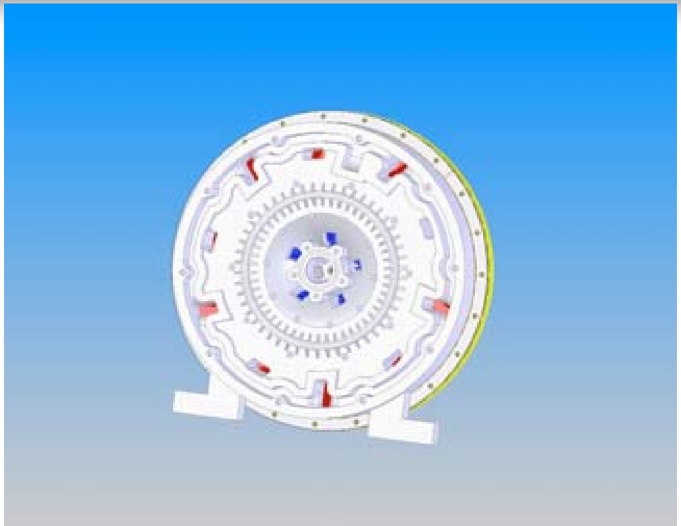


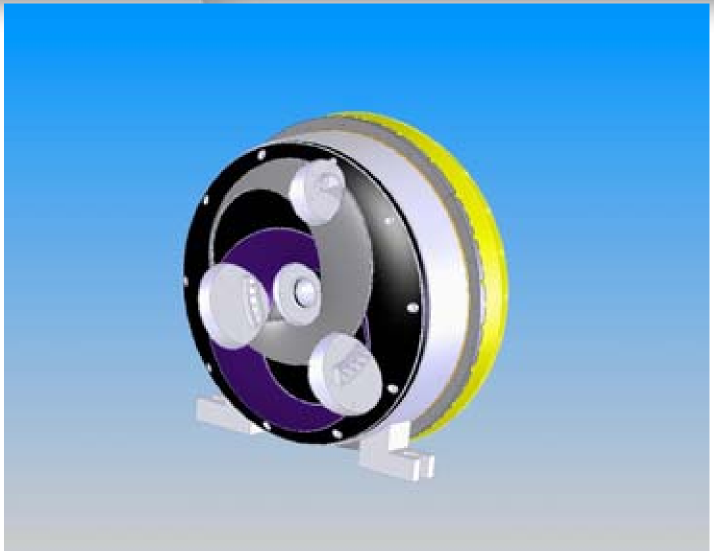
Patent Applications Submitted:

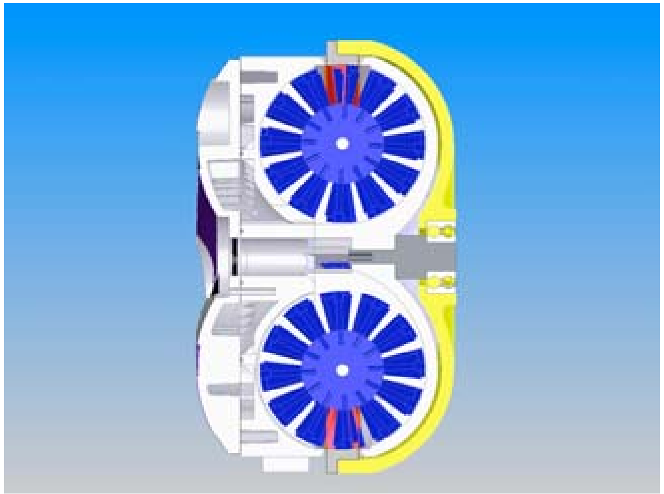
10/744230 and 10/744229

On December 22, 2003

New TIVM Design Concept and Patents



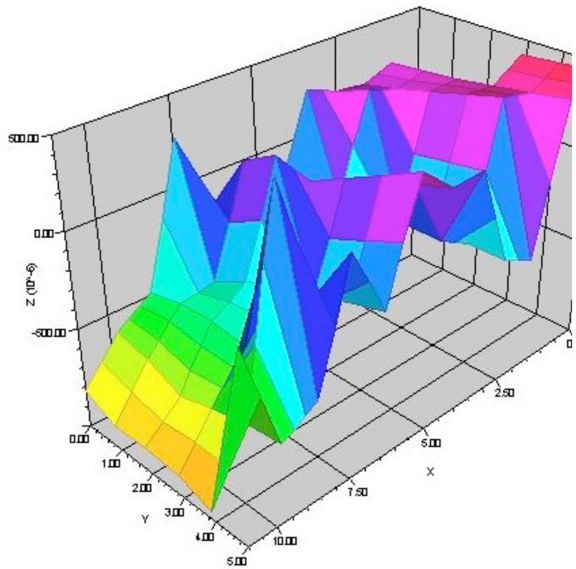


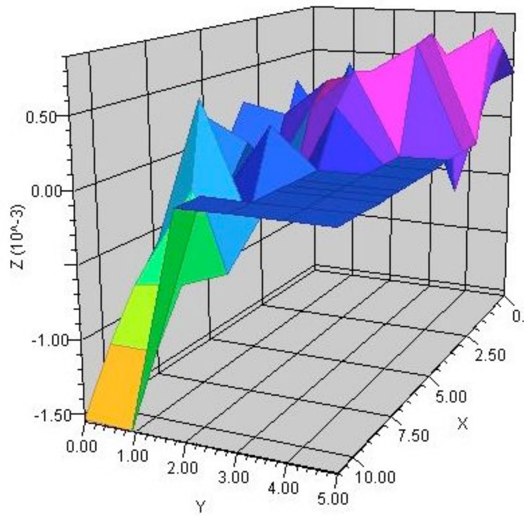


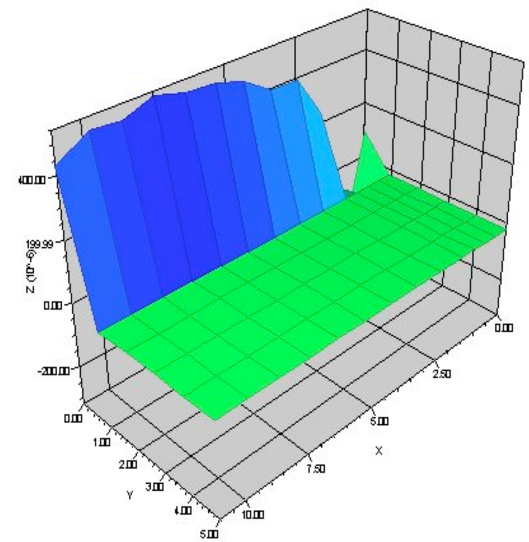
TIVM DV C/E Prototype is Being Fabricated for Testing in Third Quarter of GFY 2004

Uses "layer cake" rather than "pie segment" housings

Rigorous Meshing Surface Mathematical Solution





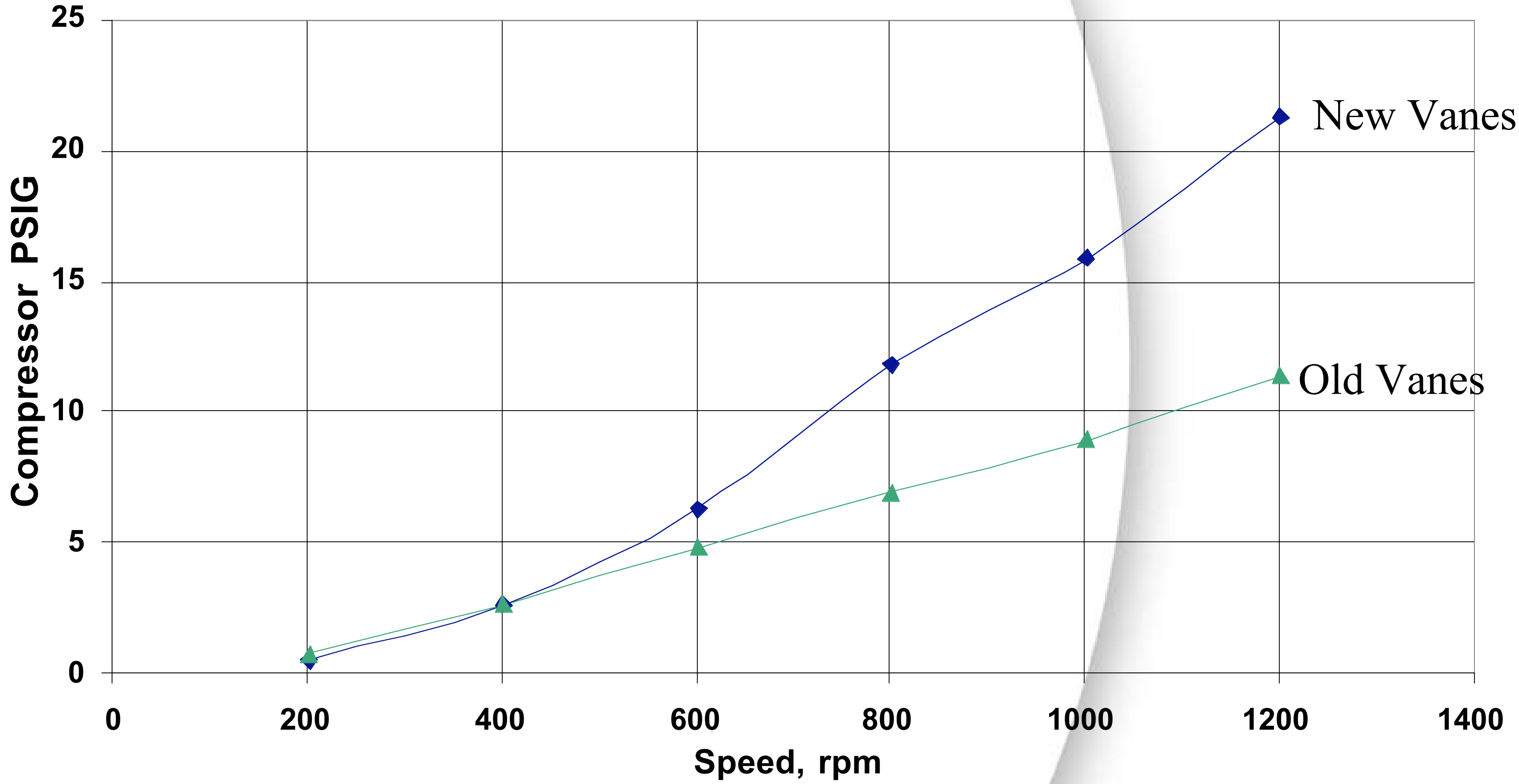


New Surface Solution Provides Vane Interface Gaps Well Less Than 0.001" Across Complete Meshing Surface

New Primary Vanes and Rotors for Generic Prototype Testing

New Vanes and Plastic Rotors Have Produced 3.9 atm Pressure with No Seals In Generic Prototype at 1000 RPM

Initial Test Data with New Surface Solution Vanes Without Seals

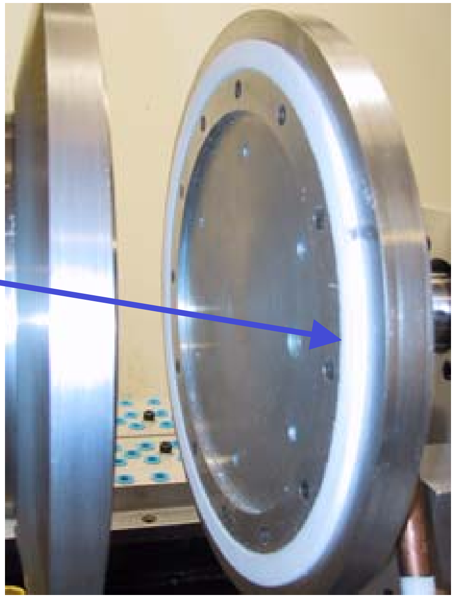


Rotating Seal Test Machine

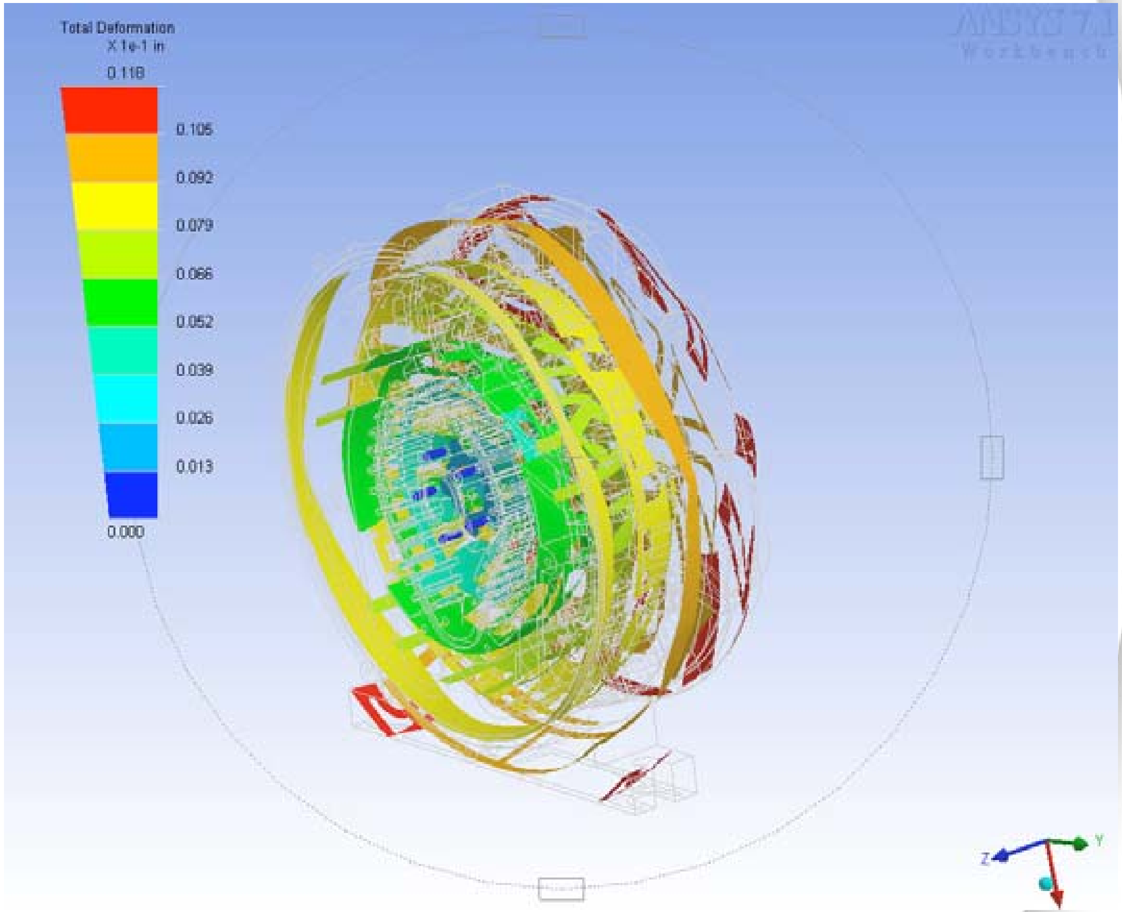
Rotating Seal Test Machine Features

- Designed for Development of Primary and Secondary Rotor Seals
- Preserves Dimensional Scale of 80 kW TIVM / CE
- Leverages Existing Test Stand Hardware and Instrumentation
- Fast Turn Around Time for Test Specimens
- Dynamic Sealing at Operating Speed
- Gas Pressure Transducer
- Preload Load Cell
- Seal Friction via Torque Meter

Candidate Face Seal

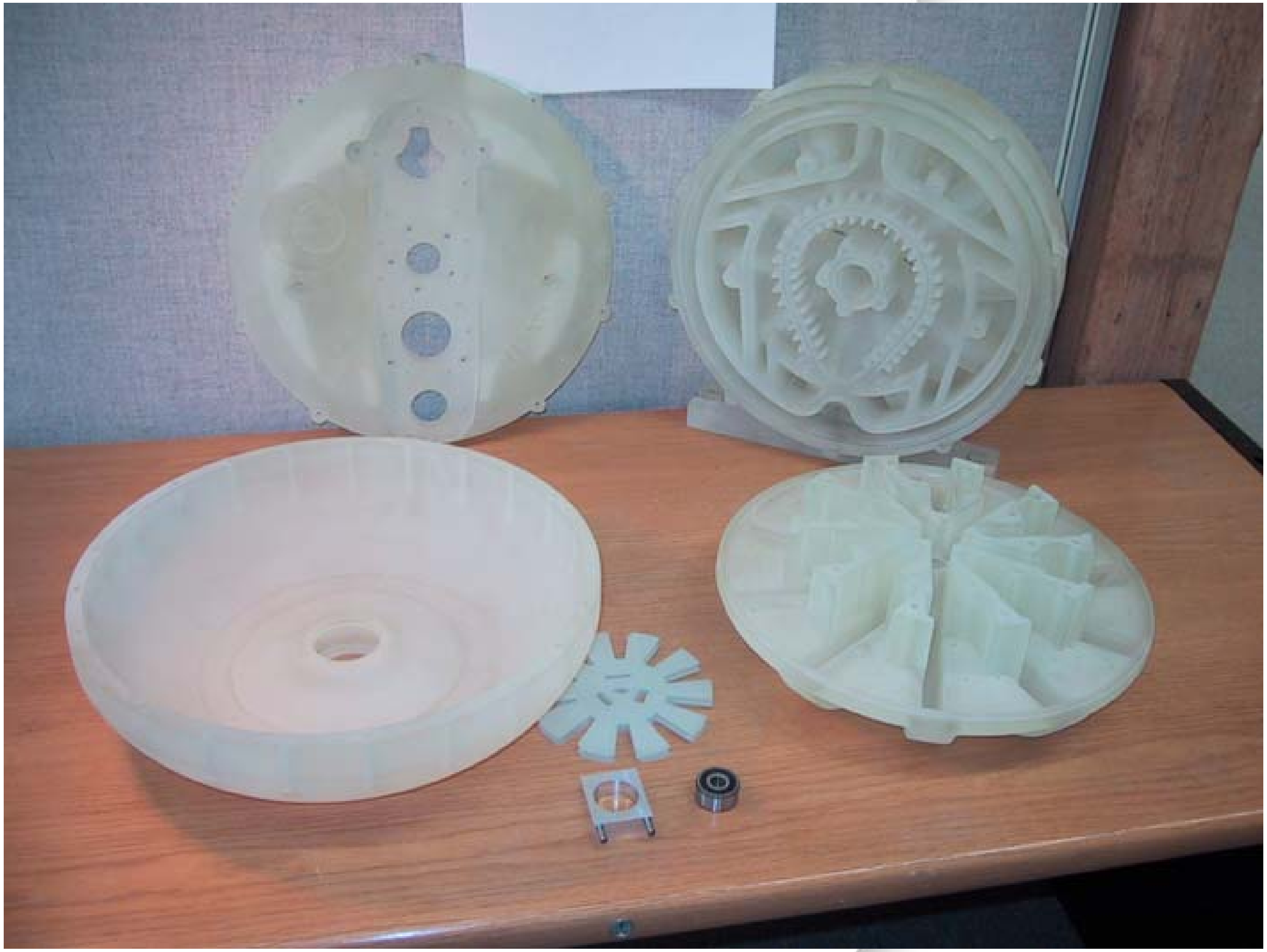


Detailed Structural and Thermal Analysis of TIVM C/E Prototype Design is in Process



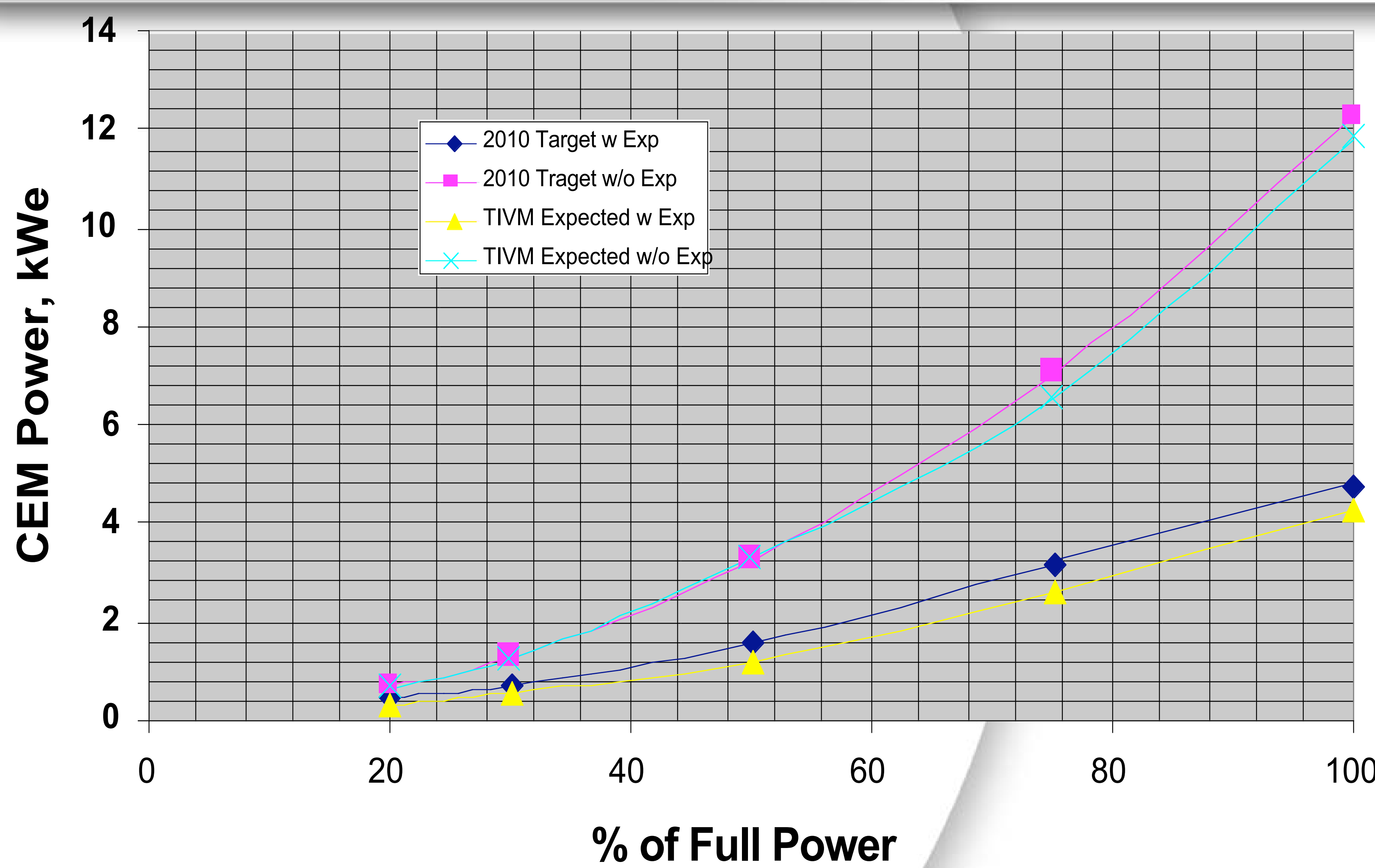
Example of Thermal Analysis for Differential Expansion

SLA Parts Have Been Fabricated and Used for Design and Fabrication Refinement



Prototype Compressor/Expander Metal Parts

Expected 80 kW Unit Hydrogen CEM Power vs % Power



Expected Performance Matrix for TIVM Compressor/Expander

Requirement	Value	Comment	Expected
Flow	91g/s For 80 kWe	Flow consistent with design flow demonstrated with temporary seals - as expected for positive displacement device	Designing for 100 g/s
Pressure	2.5 atm	3.5 atm pressure demonstrated with temporary seals - as expected for positive displacement device	Capability Beyond Requirement
Power	5.8 kW	Key remaining performance issue – requires low friction effective seals	<5.5 kW - Remains to be Demonstrated
Size	15 liters	Acceptable to car makers and OEMs	20-25 liters Acceptable
Weight	15 kg	Acceptable to car makers and OEMs	20-25 kg Acceptable
Noise	<65 db	Use of polymer parts and compliant seals will mitigate	To Be Demonstrated
Cost	$400	Cost estimates based on vendor quotes Give several $100's in high volume	Expected to be acceptable

Interactions and Collaborations

- Mechanology has completed due diligence and negotiations and has entered into a development contract to introduce an industrial TIVM product into a substantial existing market in the near term
- This provides independent conformation of the TIVM technology and provides manufacturing and distribution capability
- DOE's funding of Mechanology and the TIVM technology is paying off as a high leverage investment leading to many valuable energy sector products in addition to a successful automotive fuel cell compressor/expander/motor component

Hardware Fabrication and Testing Plans

Use Rotary Seal Test Rig to Select Face Seals and Measure Performance – May 2004

Complete Fabrication and Initiate Testing of TIVM DV Prototype with Complete Set of Seals - Third Quarter GFY 2004

Refine TIVM DV Prototype Details Based on Test Results to Optimize Performance

Engage Subcontractor for Motor Design, Fabrication, Testing

Begin TIVM DV CEM Prototype Fabrication with Integrated Motor Fourth Quarter GFY 2004

Complete TIVM DV CEM Fabrication Second Quarter GFY 2005

Test CEM at Mechanology Third Quarter GFY 2005

Deliver TIVM DV CEM to DOE Fourth Quarter GFY 2005 – On Schedule