ANALYSIS AND DESIGN OF A DOUBLE-DIVERT SPIRAL GROOVE SEAL

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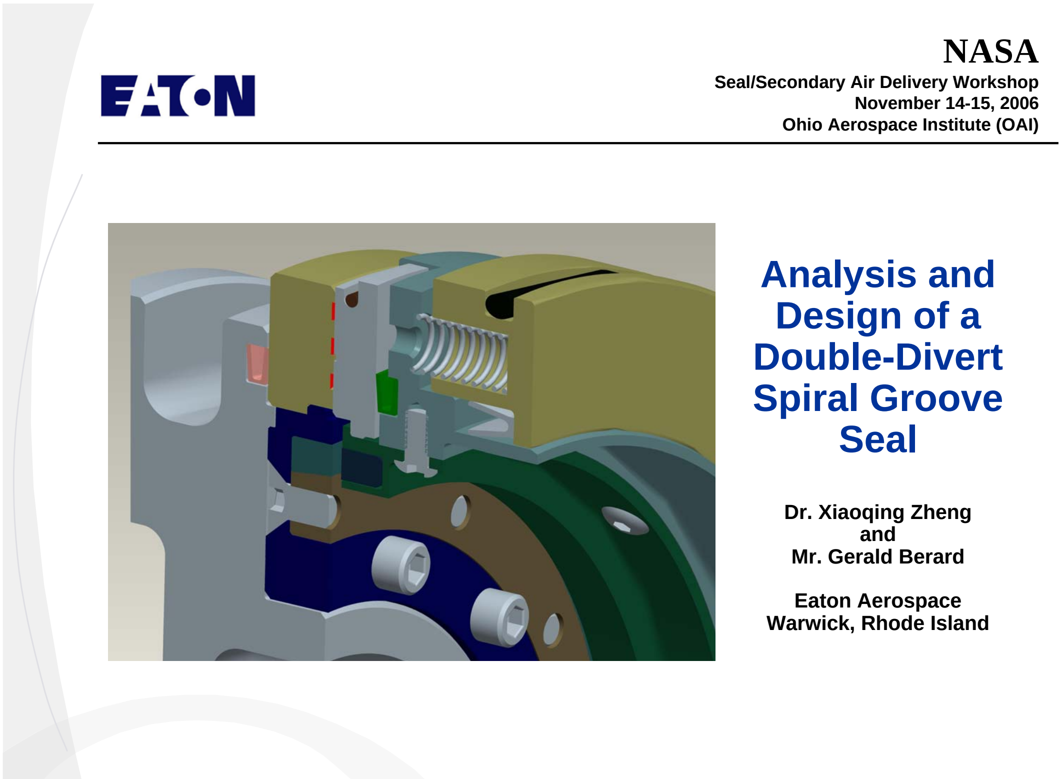

Double Spiral Design Features

- Non-Contacting seal faces during static and dynamic operation
  - → High temperature permanent magnets to prevent contact at startup/static conditions
  - → Outwardly pumping spirals allow for self-correcting dynamic axial seal face tracking during seal face coning/dynamic conditions
- Insert segmentation with low leakage joints to accommodate larger sizes and enhance axial tracking and compliance
- Center feeding restrictive orifices allow insert segments to be adaptive to local waviness and coning

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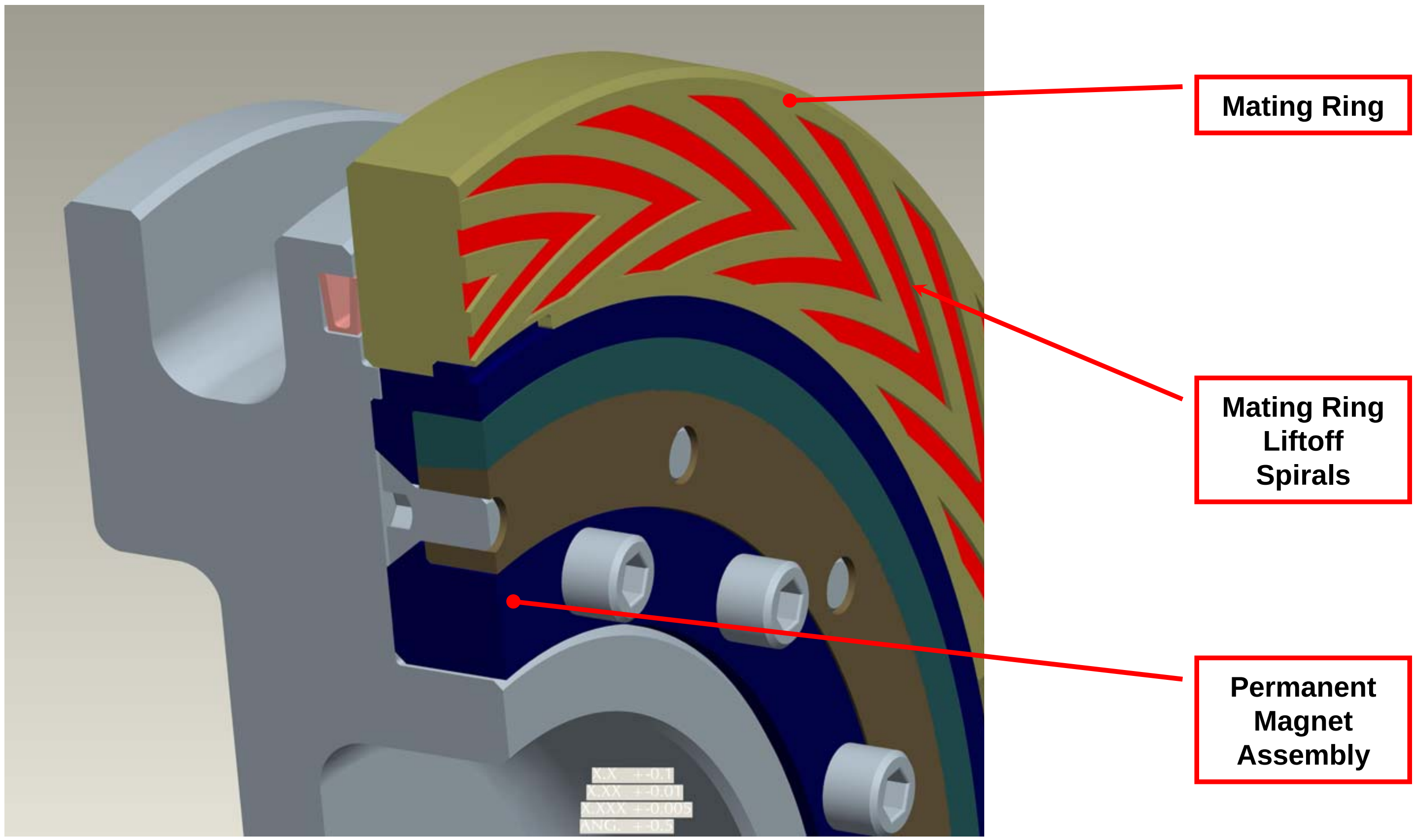
Double Spiral Operational Features

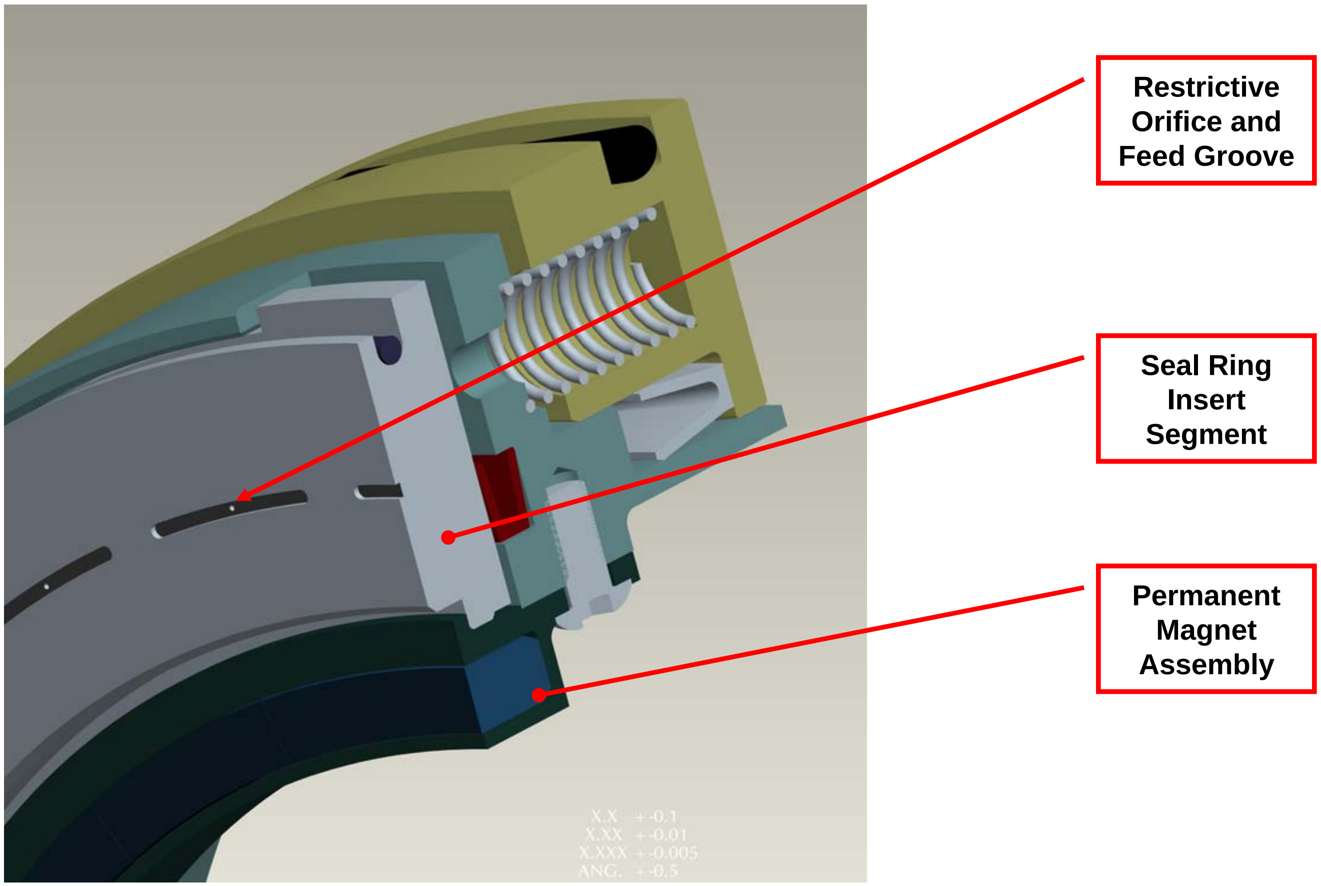
- Low Leakage – Approximately 10 times less than a new brush seal
- Seal is always non-contacting therefore no wear and long life
- Low heat generation
- High speed capabilities

Mating Ring/Rotor Assembly



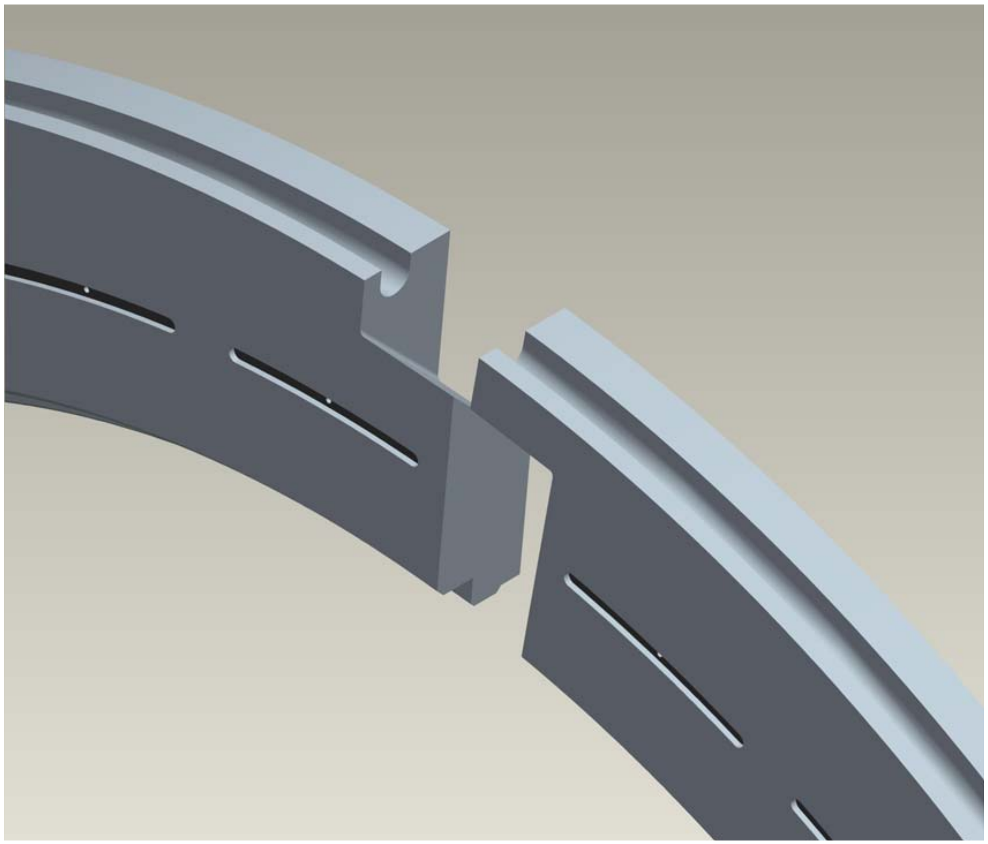
Design Features

Seal Ring Assembly



Design Features

Insert Segment Joints



Machined inter-locking joints to minimize leakage and provide adaptability to larger diameters as well as provide axial compliance to rotor waviness

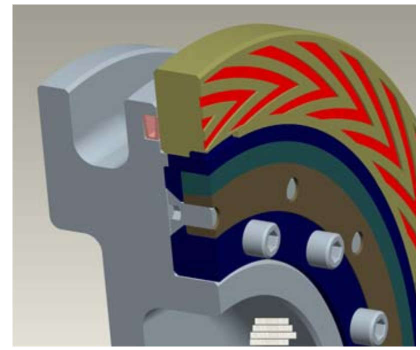
Design Features

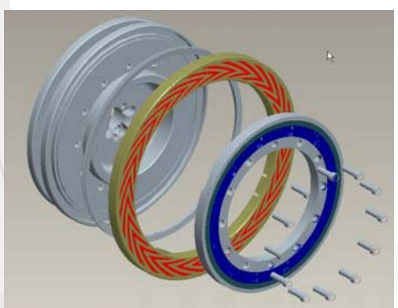
Rotor Assembly
Completed Prototype Parts

Titanium Rotor/
Shaft Adapter

Titanium/
Samarium Cobalt

Magnet Housing

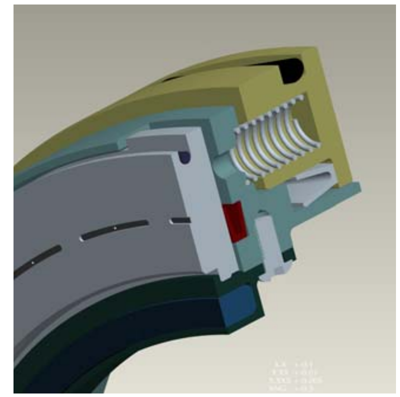




Stainless Steel
Mating Ring

Seal Assembly
Completed Prototype Parts

Stainless Steel Seal Ring Shell Assembly



Stainless Steel/ Samarium Cobalt Magnet Housing

Aluminum Seal Ring

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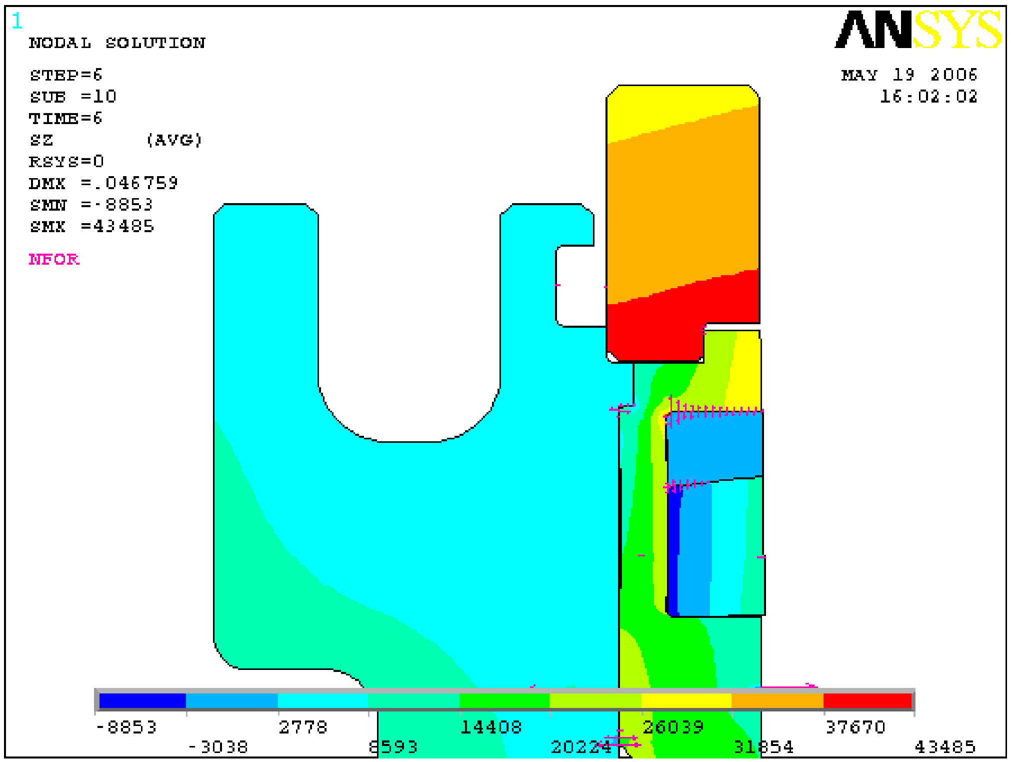
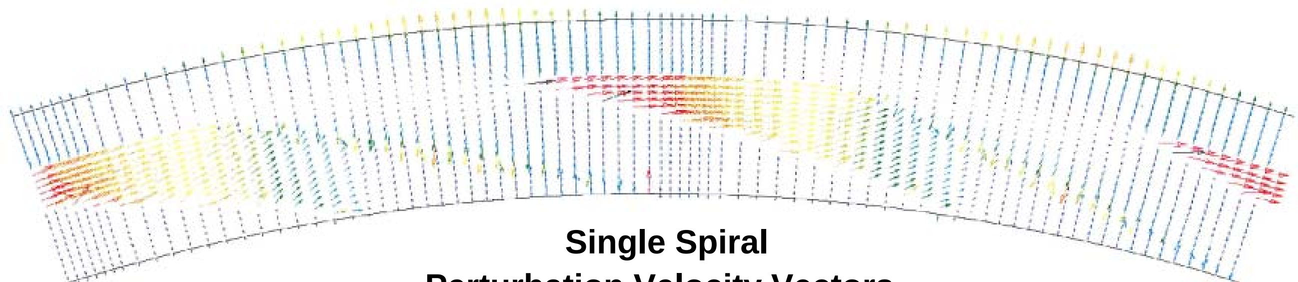
Finite Element Analysis



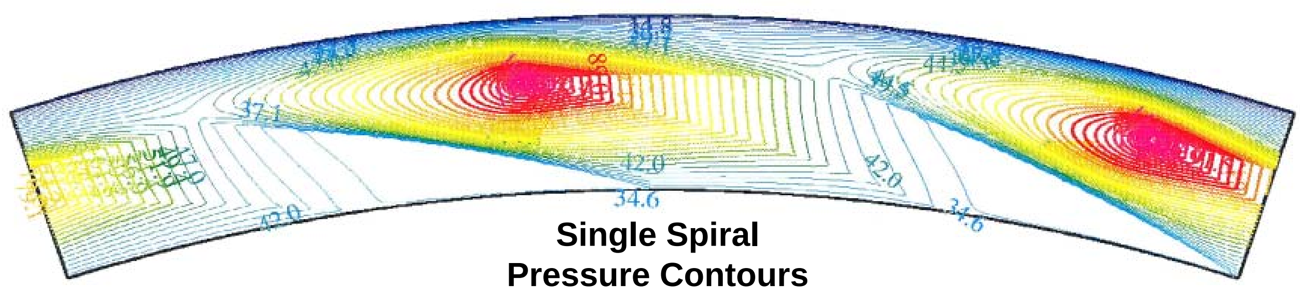
Von Mises Stress Plot at 15,000 RPM (PSI)

The Mating Ring/Rotor assembly were analyzed using ANSYS, a general purpose finite element analysis program

Computational Fluid Dynamics (CFD) Analysis



Single Spiral
Perturbation Velocity Vectors



Single Spiral
Pressure Contours

Seal face liftoff is calculated using Adina and a custom CFD code

Restrictive Orifice Design

1. Purposes:
   - Control leakage
   - Extend the range of high film stiffness
   - Improve film stiffness

2. Calculation of effectiveness
   - Empirical formula
   - Detailed CFD simulation
   - Integrated into double-spiral groove seal design code

Orifice CFD Model

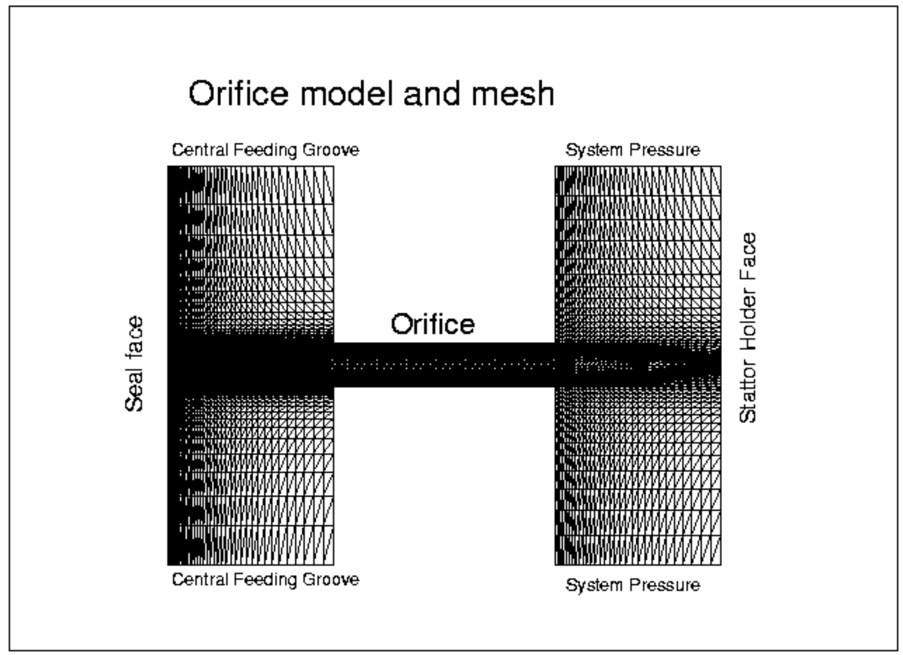
Governing Equation:

$$\frac{\partial U}{\partial t} + \nabla \bullet (F - G) - S = 0$$

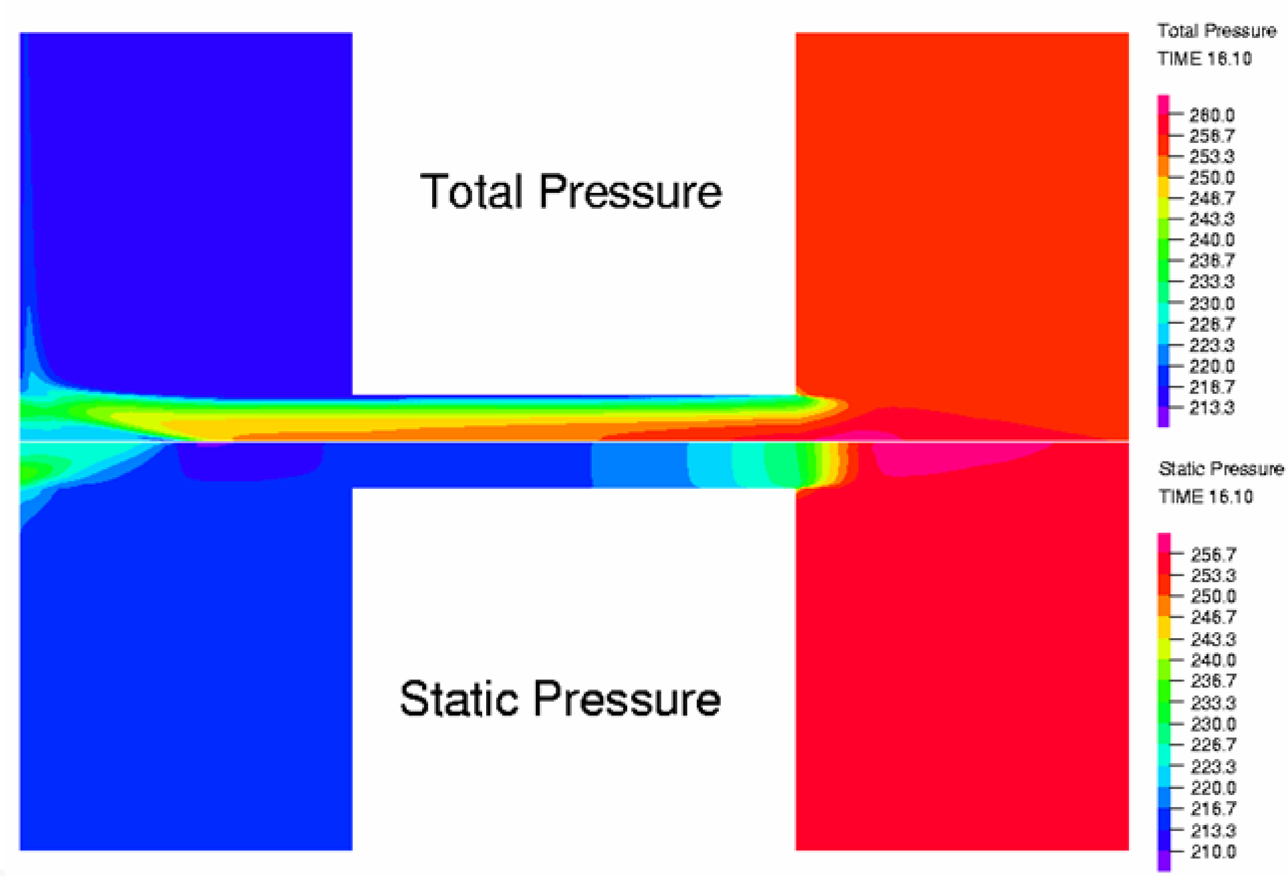
Where:

$$U = \begin{bmatrix} \rho \\ \rho v \\ \rho e \end{bmatrix} \qquad G = \begin{bmatrix} 0 \\ -pI + \tau \\ \tau \bullet v - q \end{bmatrix}$$

$$F = \begin{bmatrix} \rho v \\ \rho v v \\ \rho v h \end{bmatrix} \qquad S = \begin{bmatrix} 0 \\ f \\ f \bullet v + q_s \end{bmatrix}$$



Orifice Results



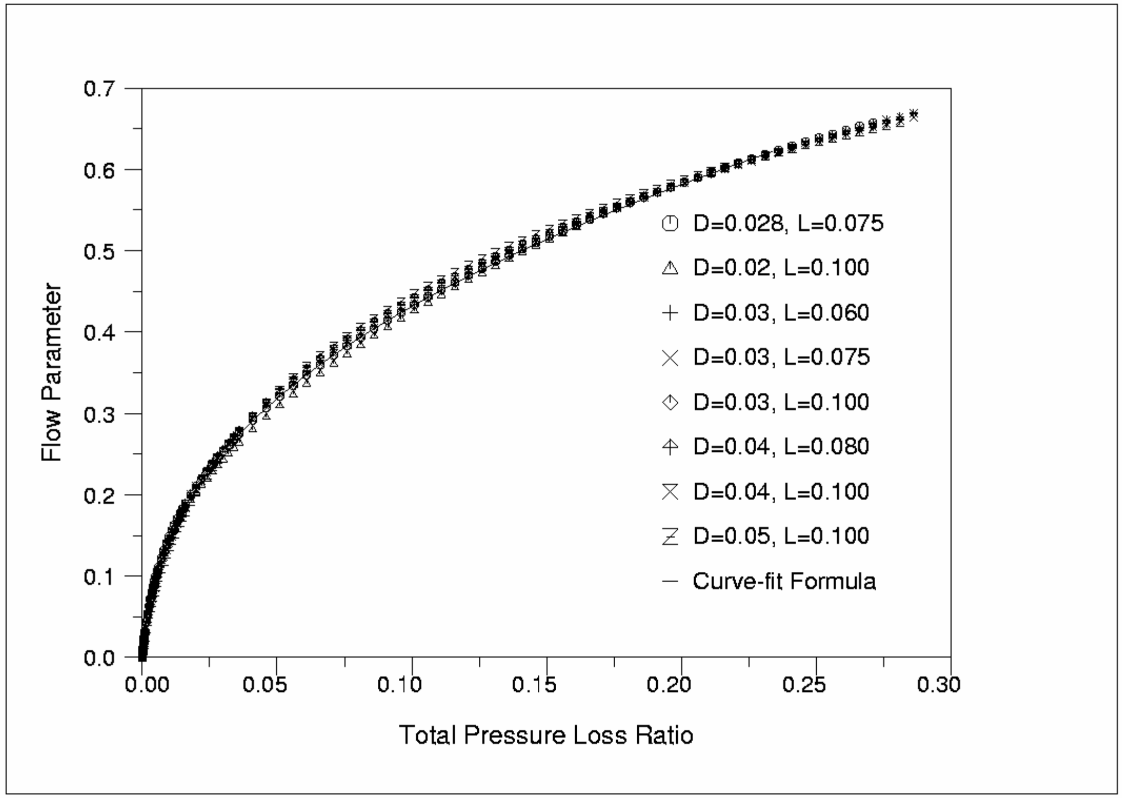
Restrictive Orifice

Flow parameter:

$$\phi = \frac{\dot{m}\sqrt{T^*}}{\frac{1}{4}\pi d^2 p^*_{Inlet} K}$$

Total pressure loss ratio:

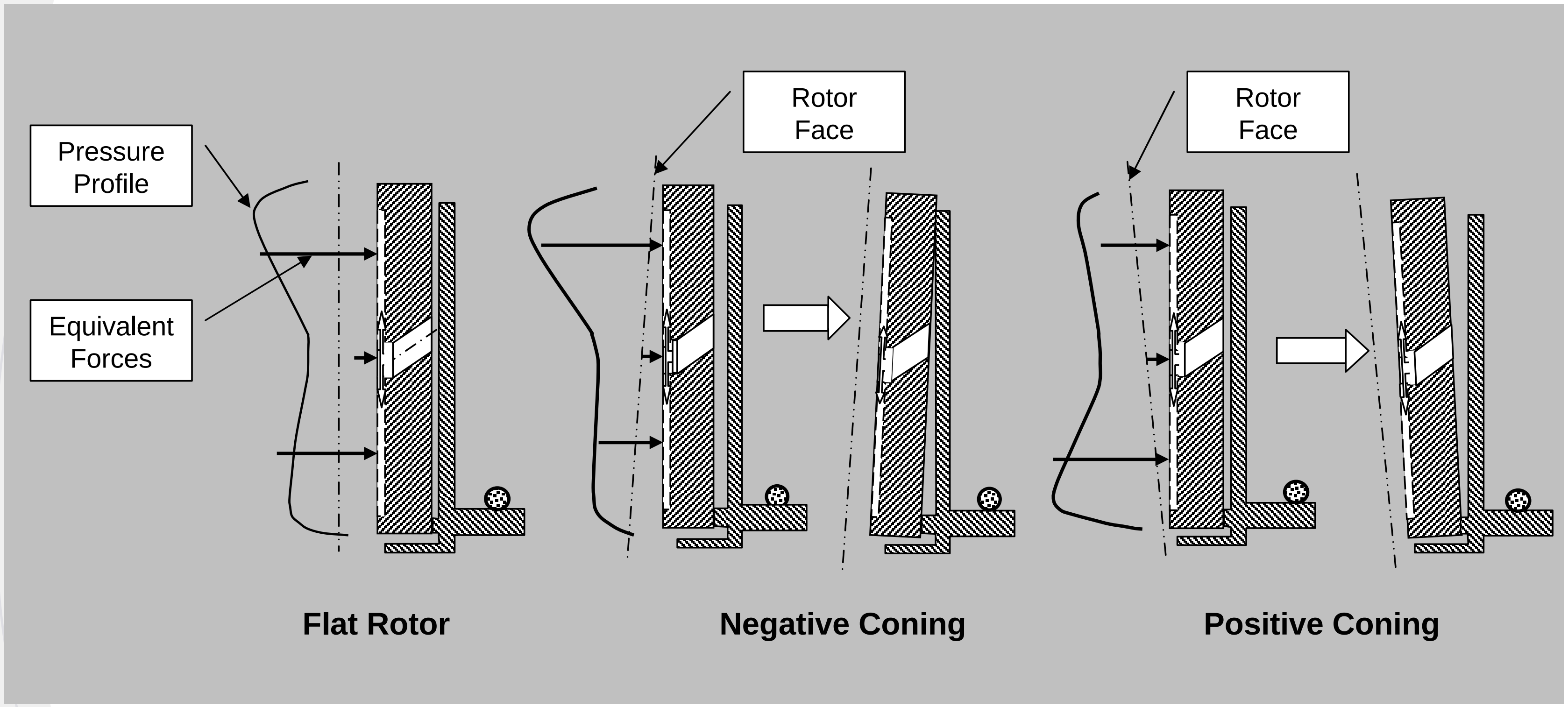
$$\eta = \frac{p^*_{Inlet} - p^*_{Exit}}{p^*_{Inlet}}$$



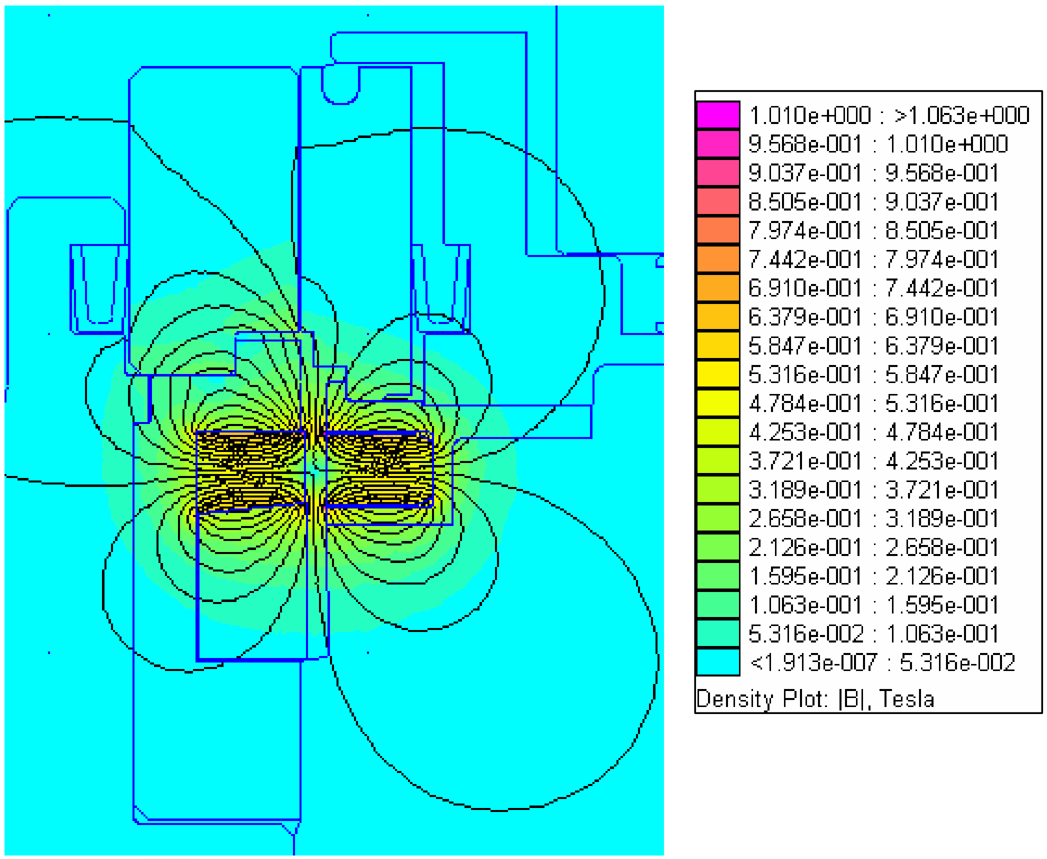
Resulting Empirical formula:

$$\eta = 0.02756\ \phi + 0.1637\ \phi^2 + 0.8978\ \phi^3 - 0.4184\ \phi^4$$

Seal Face Coning



Permanent Magnet Analysis



Magnetic Analysis was conducted using various high temperature rare earth Samarium Cobalt with a maximum operating temperature of 550°C (1022°F)

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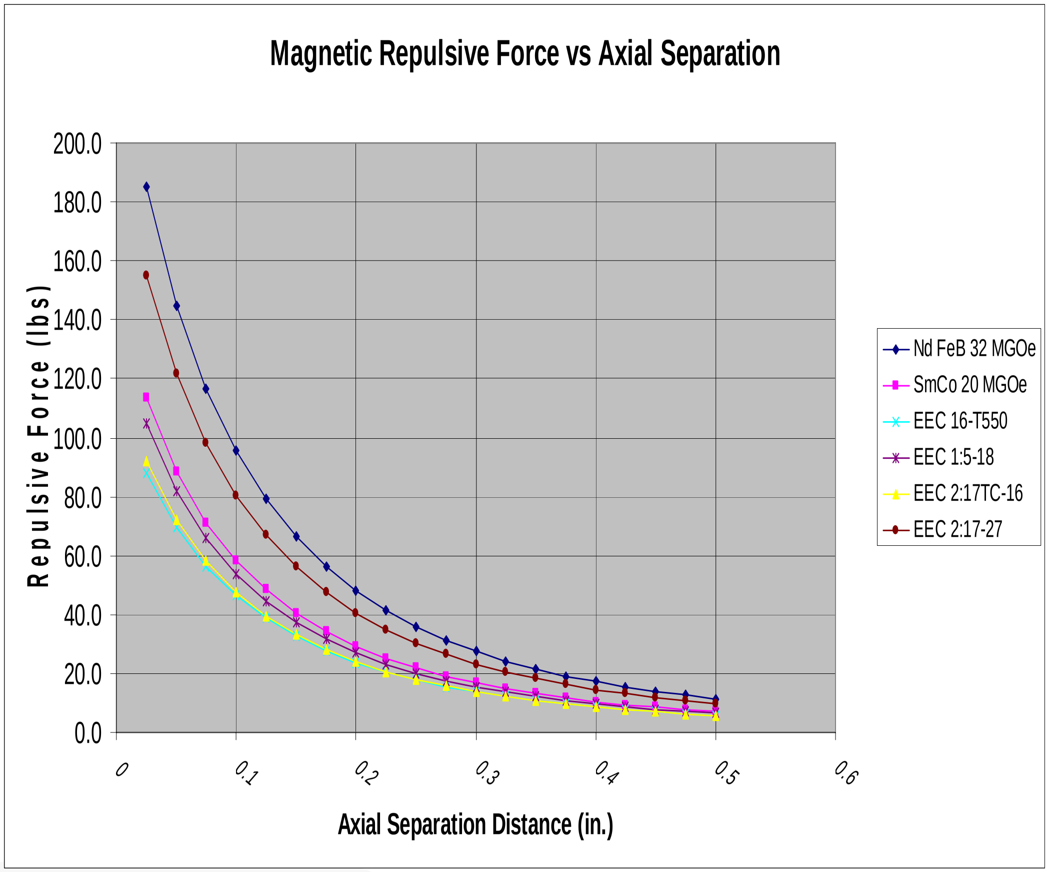
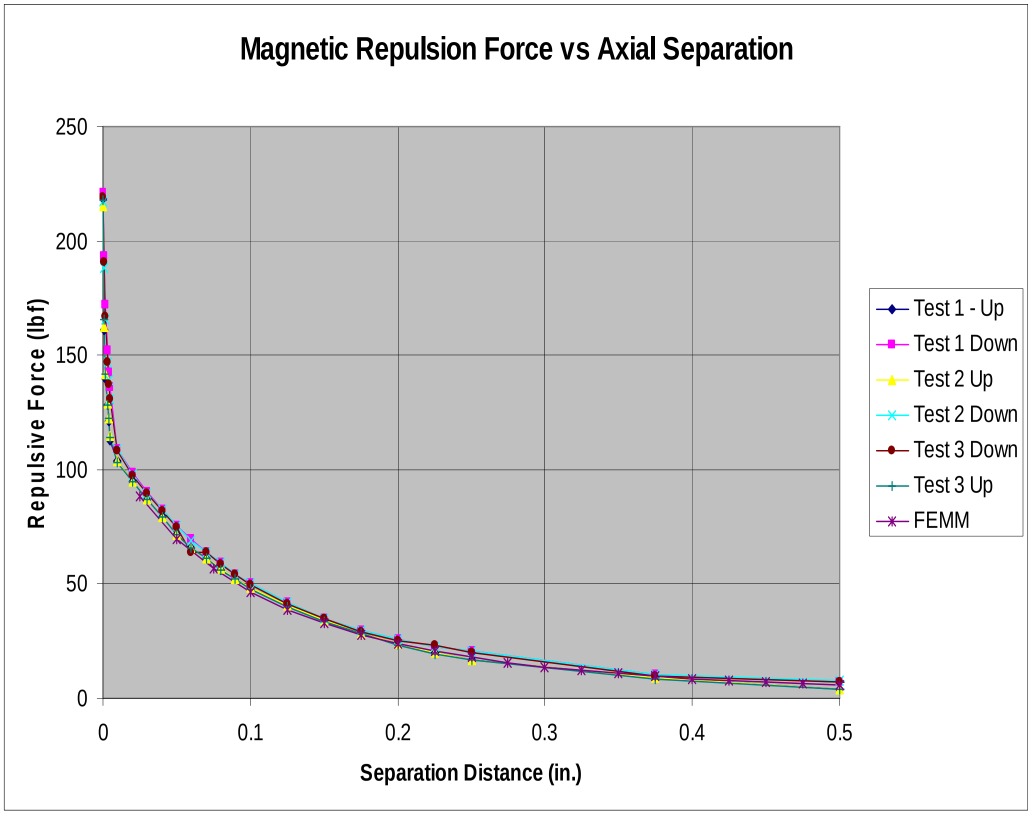
Magnetic Repulsive Force



Why Magnets?

Magnetic Repulsive Force is non-linear therefore the force dissipates significantly with increasing gap distance

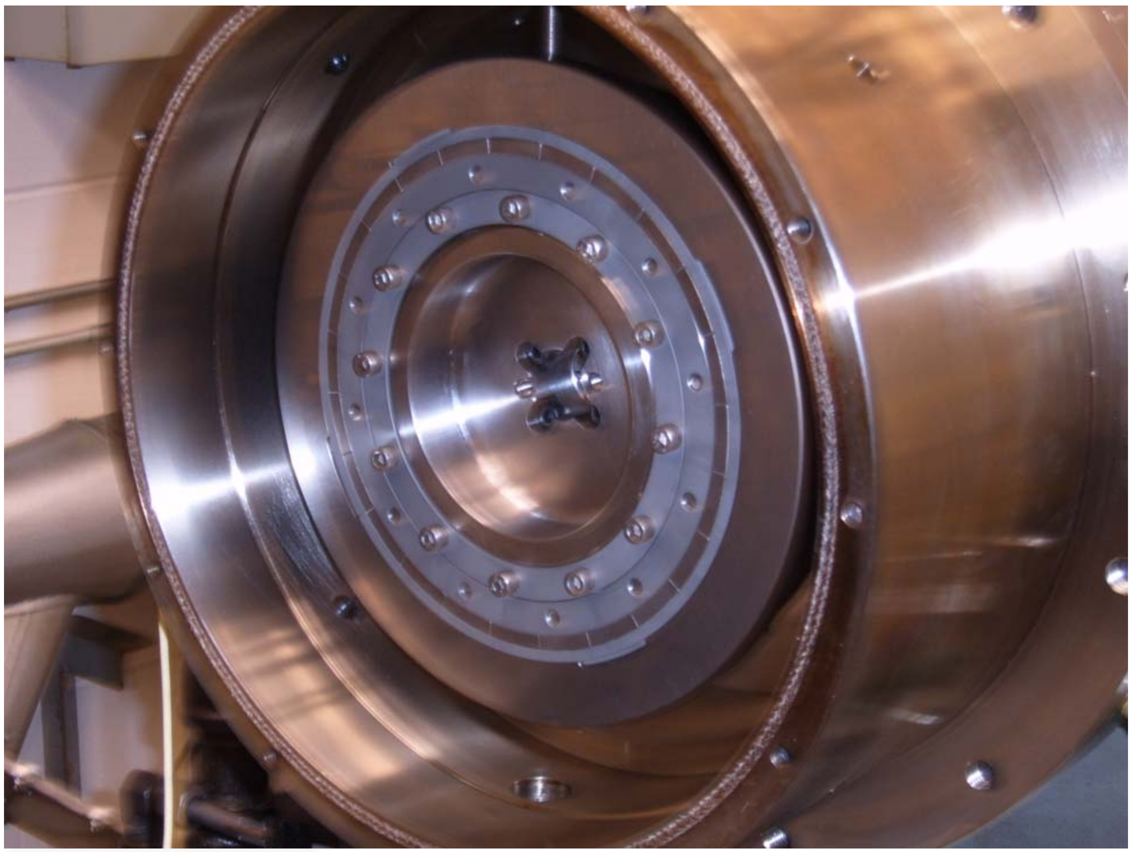
Magnetic Repulsive Test Results



Magnetic
Test Results

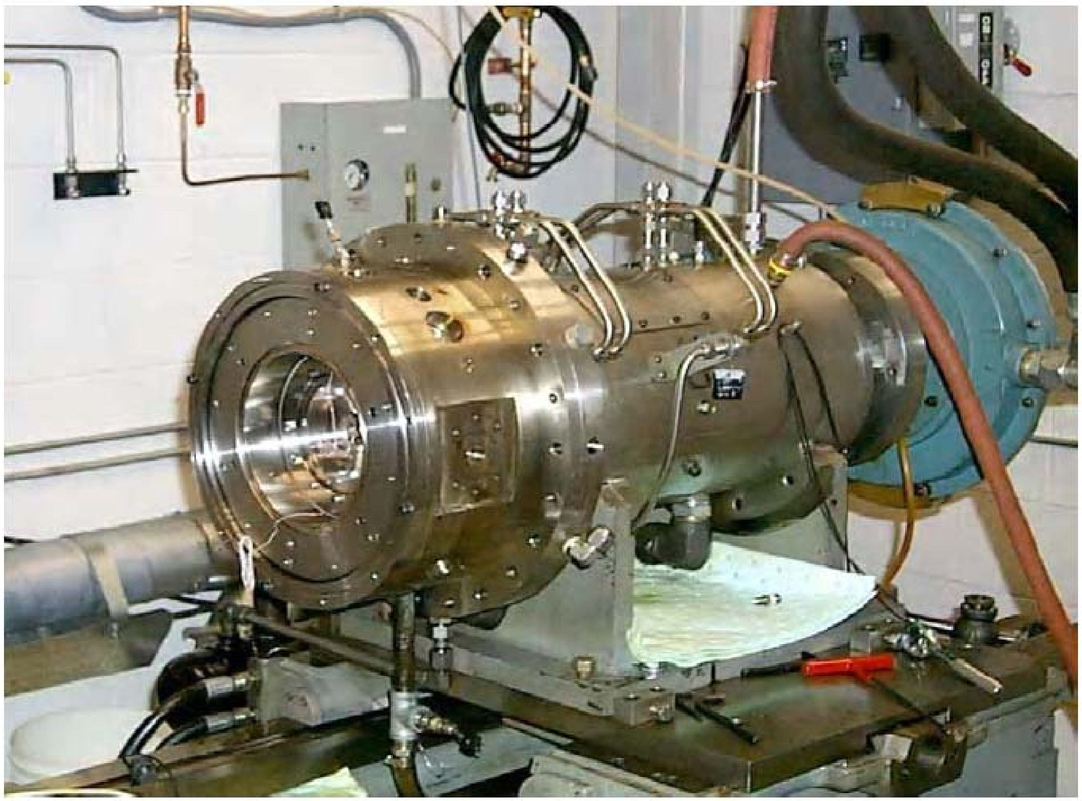
Comparison of Finite Element Analysis results to actual test results

Spin Testing



18,000 RPM Spin Test was conducted on the rotor/magnet assembly

Testing and Validation



- **Testing and validation will be accomplished on the Warwick Aerospace Test Rig which has a 24,000 RPM, 1,000°F, 120 PSI capability**