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
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

- Mating Ring
- Mating Ring Lift-off Spirals
- Permanent Magnet Assembly
Seal Ring Assembly

- Restrictive Orifice and Feed Groove
- Seal Ring Insert Segment
- Permanent Magnet Assembly

Design Features
Insert Segment Joints

Machined interlocking 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
Finite Element Analysis

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

Von Mises Stress Plot at 15,000 RPM (PSI)
Computational Fluid Dynamics (CFD) Analysis

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:
\[
\frac{\partial U}{\partial t} + \nabla \cdot (F - G) - S = 0
\]

Where:
\[
U = \begin{bmatrix} \rho \\ \rho v \\ \rho e \end{bmatrix}, \quad G = \begin{bmatrix} 0 \\ -pI + \tau \\ \tau \cdot v - q \end{bmatrix}, \quad F = \begin{bmatrix} \rho v \\ \rho vv \\ \rho vh \end{bmatrix}, \quad S = \begin{bmatrix} 0 \\ f \\ f \cdot v + q_s \end{bmatrix}
\]
Restrictive Orifice

Flow parameter:
\[ \phi = \frac{m\sqrt{T^*}}{\frac{1}{4} \pi d^2 p_{\text{Inlet}} K} \]

Total pressure loss ratio:
\[ \eta = \frac{p_{\text{Inlet}}^* - p_{\text{Exit}}^*}{p_{\text{Inlet}}^*} \]

Resulting Empirical formula:
\[ \eta = 0.02756 \phi + 0.1637 \phi^2 + 0.8978 \phi^3 - 0.4184 \phi^4 \]
Seal Face Coning

- Flat Rotor
- Negative Coning
- Positive Coning

Pressure Profile
Equivalent Forces

Rotor Face
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)
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 Repulsion Force vs Axial Separation

Comparison of Finite Element Analysis results to actual test results
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