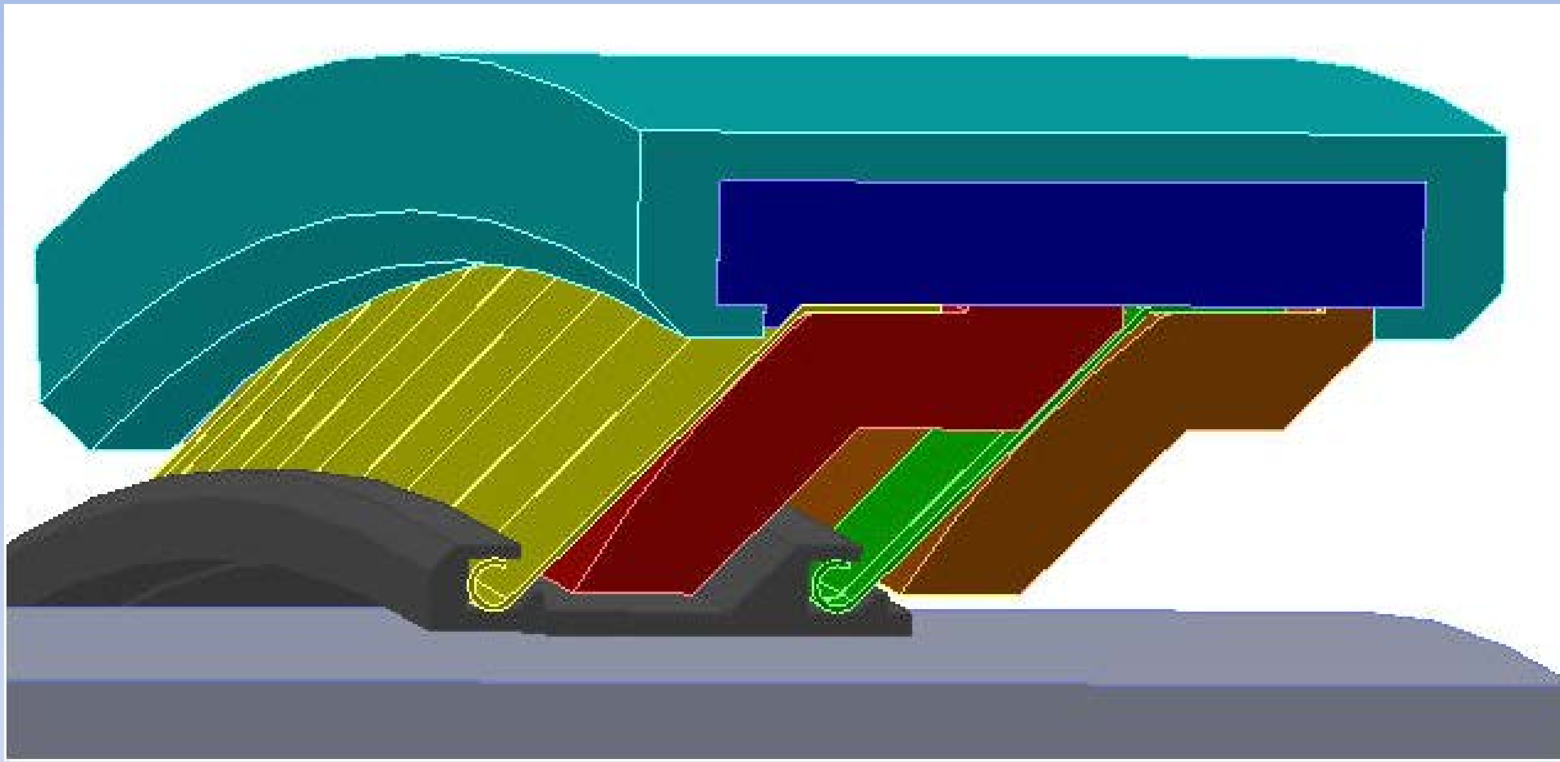
FILM RIDING LEAF SEALS

FOR IMPROVED SHAFT SEALING



Authors - Clayton M. Grondahl and James C. Dudley.

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Power for Land, Sea and Air

June 14-18, 2010, Glasgow, UK.

ASME GT2010-23629

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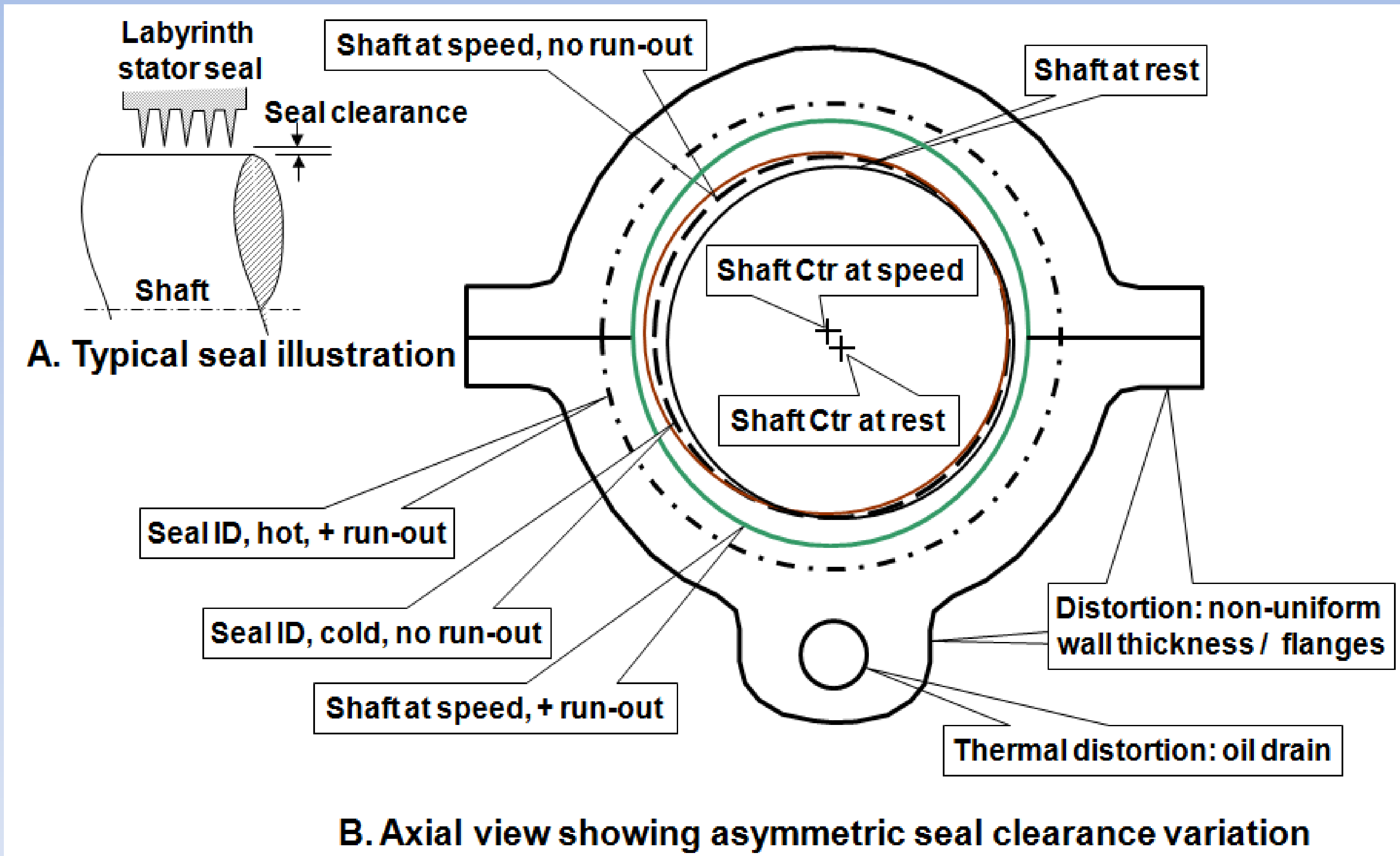
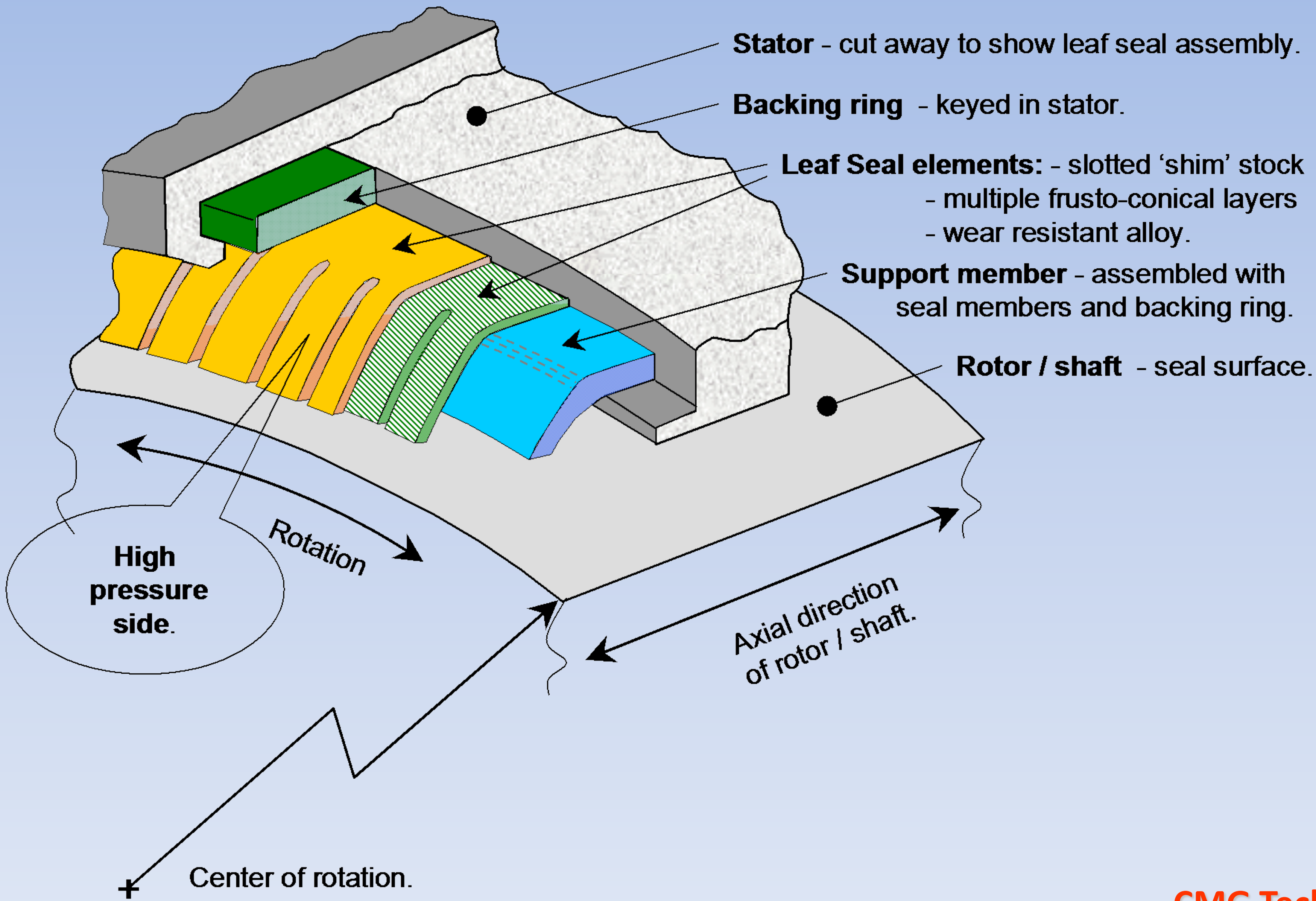
Seal operating environment and need for a film riding seal:



FILM RIDING PRESSURE ACTUATED LEAF SEALS

Pressure Actuated Leaf Seal structure incorporated in FRPALS.



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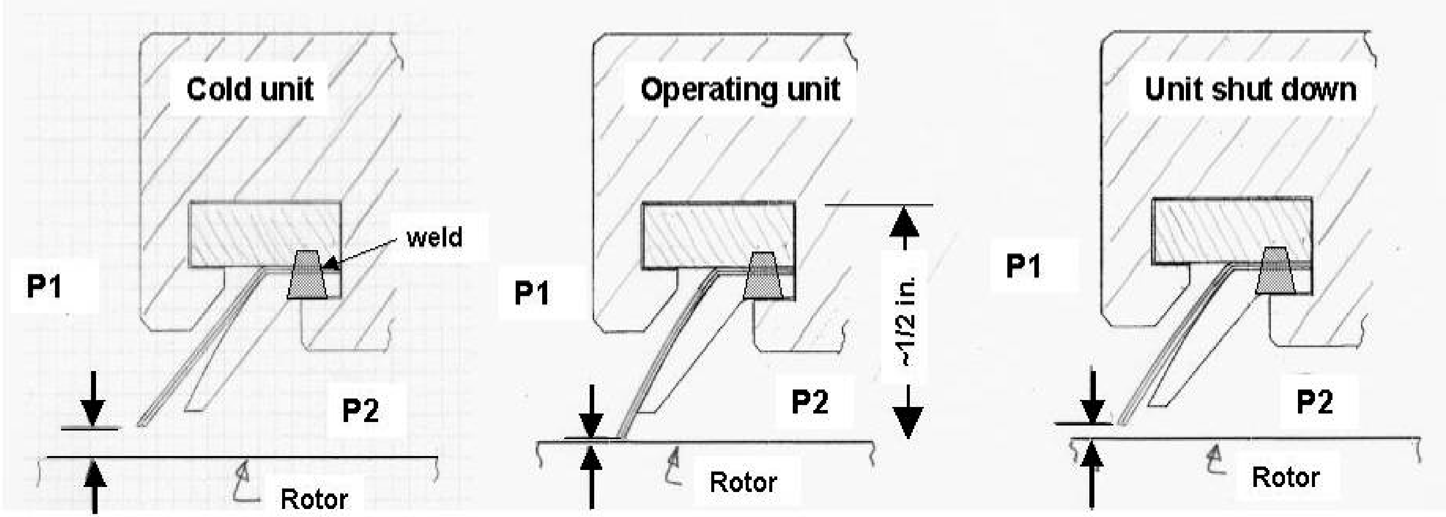
FILM RIDING PRESSURE ACTUATED LEAF SEALS

Basic PALS passive closure.



Cold clearance - <u>large.</u>
- **P1 = P2**
- **Seal elements *<u>not in</u>* contact with support.**
- **Seal rubs avoided.**

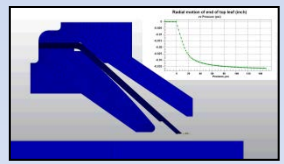
Operating clearance - <u>small</u>.
- **P1 >> P2**
- **Seal elements *<u>in</u>* contact with support.**
- **Leakage minimized, for performance gain.**

Shutting down clearance - <u>increasing.</u>
- **Δ P decreasing with RPM.**
- **Seal elements *<u>retract</u>* from support.**
- **Seal rub damage avoided.**

Large startup & shut down clearance: → ***<u>Rub avoidance.</u>***

Minimum operating clearance: → ***<u>Performance gain</u>*.**

Non-contacting operation: → ***<u>Long seal life.</u>***



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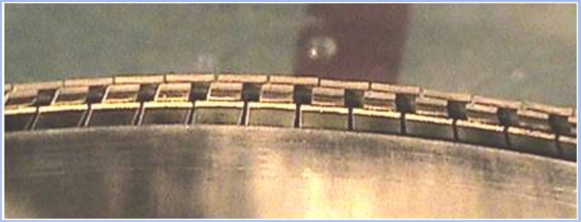
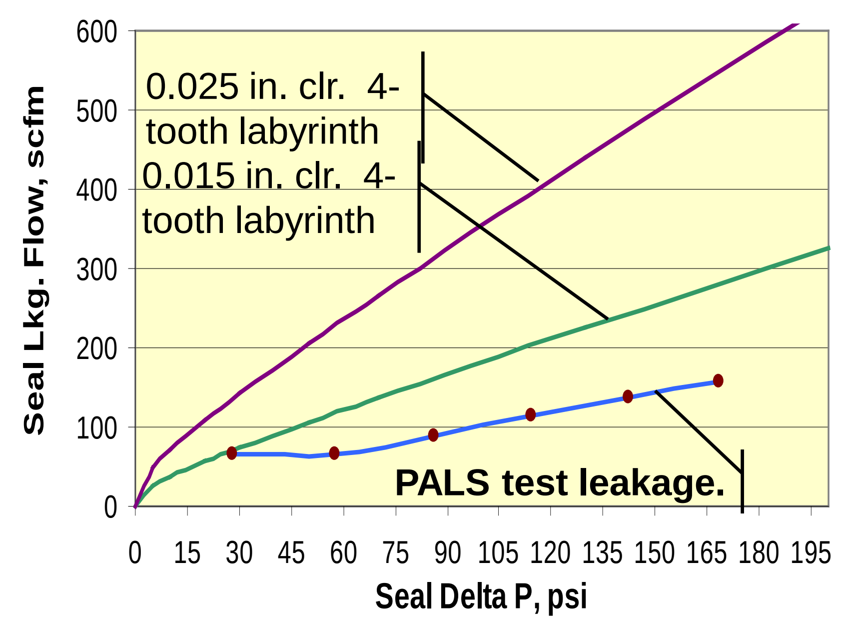
Pressure Actuated Leaf Seal (PALS) test seal and leakage:





Large startup & shut down clearance → ***rub avoidance.***

Minimum operating clearance → ***performance gain*.**

Non-contacting operation & rub tolerance → ***long seal life.***

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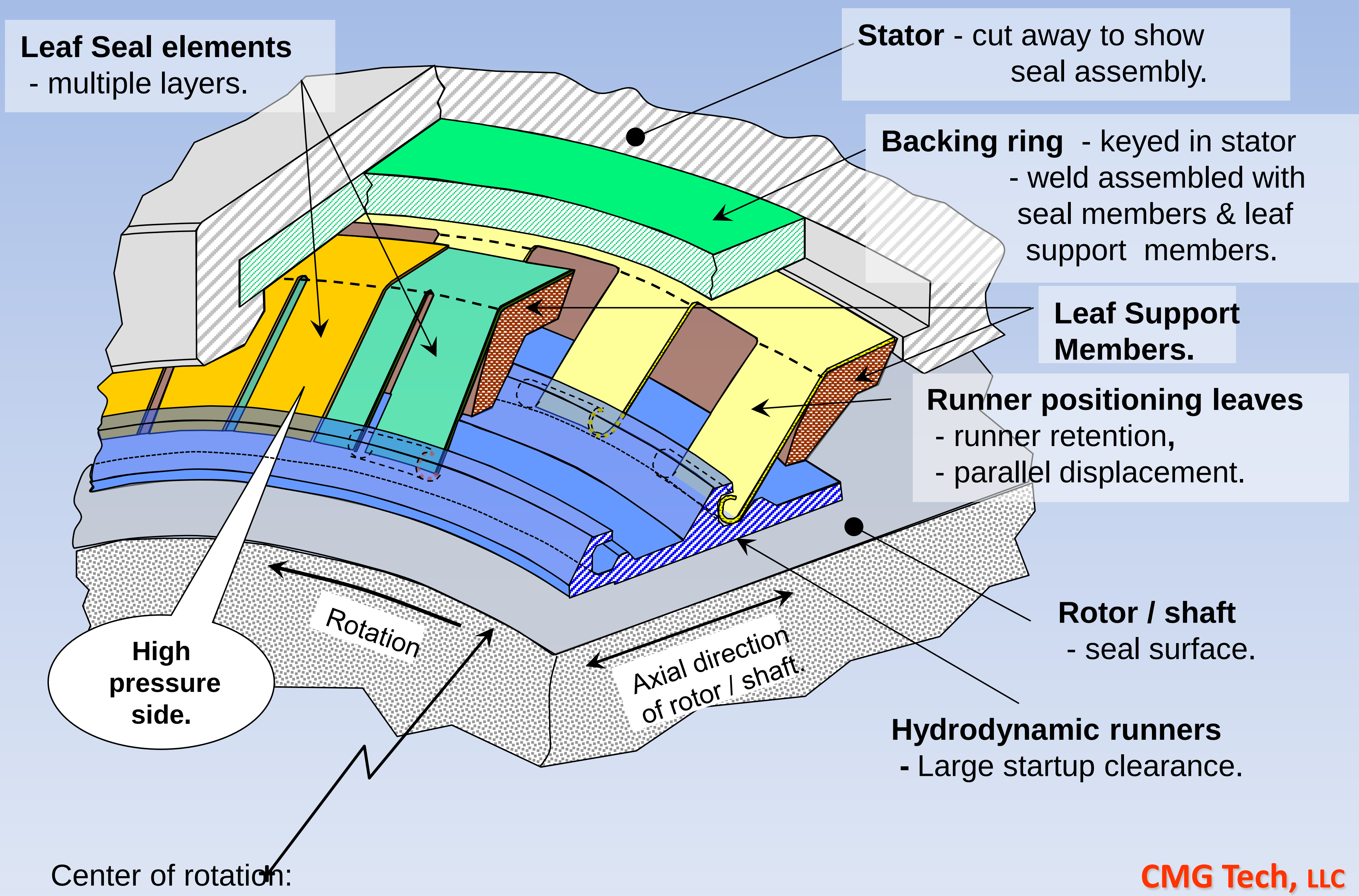
FILM RIDING PRESSURE ACTUATED LEAF SEALS : Isometric view.



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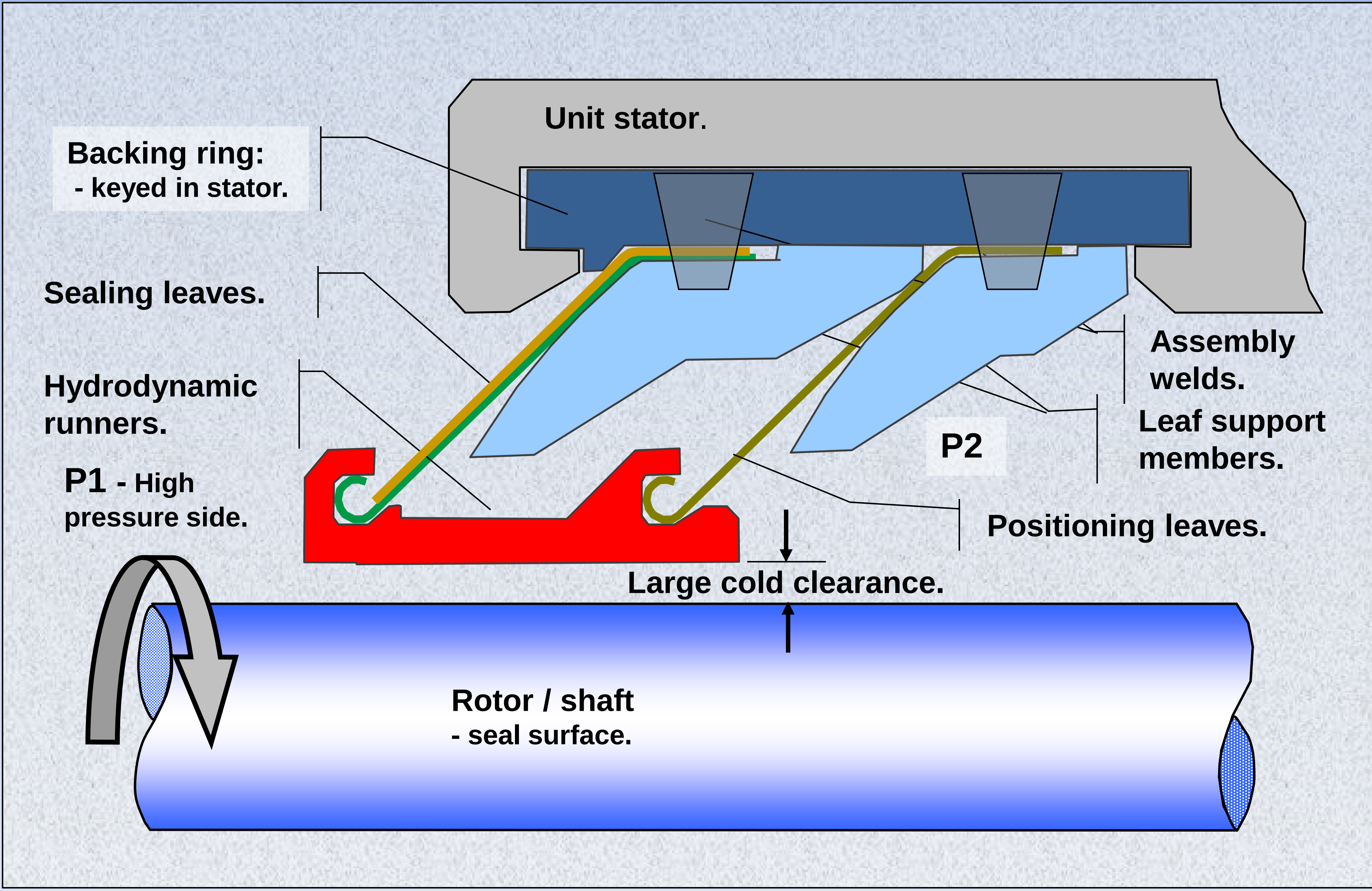
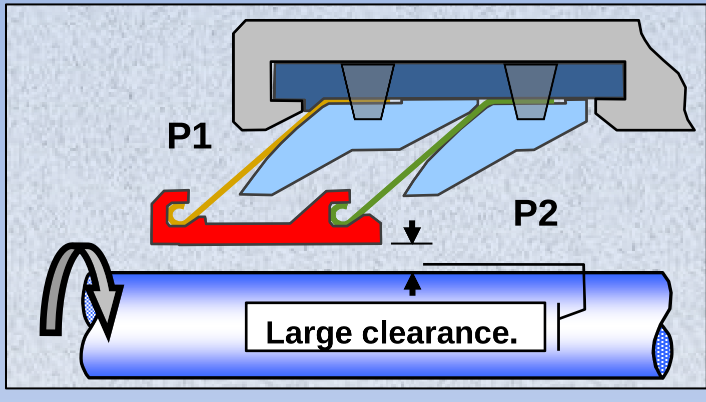
FILM RIDING PRESSURE ACTUATED LEAF SEALS : Section view.



FILM RIDING PRESSURE ACTUATED LEAF SEALS : Function.

Startup:

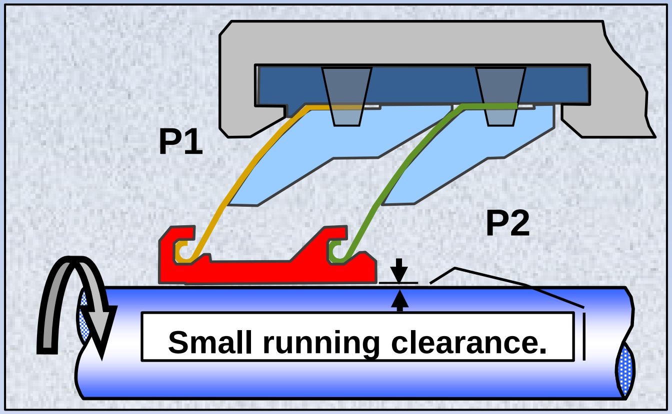
- P1 ~ P2
- Straight leaves.
- Large clearance.



Startup rub avoidance.

Normal operation:

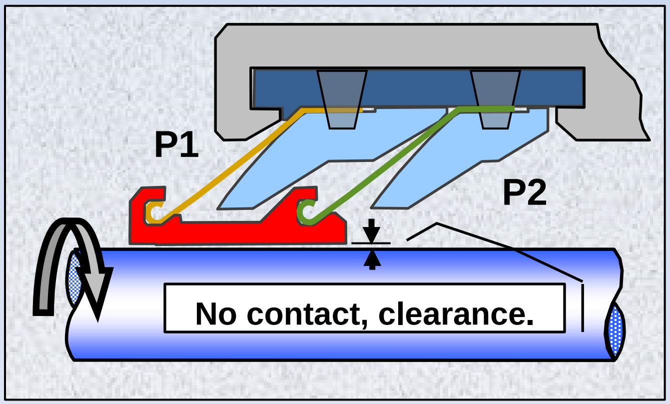
- P1 > P2
- Leaves deflect.
- Compliant, forces balanced.
- Small clearance, low leakage.



Operating Performance gain.

Eccentric rotor:

- P1 > P2
- Leaves deflected from support.
- Runners ride on hydrostatic / hydrodynamic film.



Rub avoidance: Non-contacting clearance

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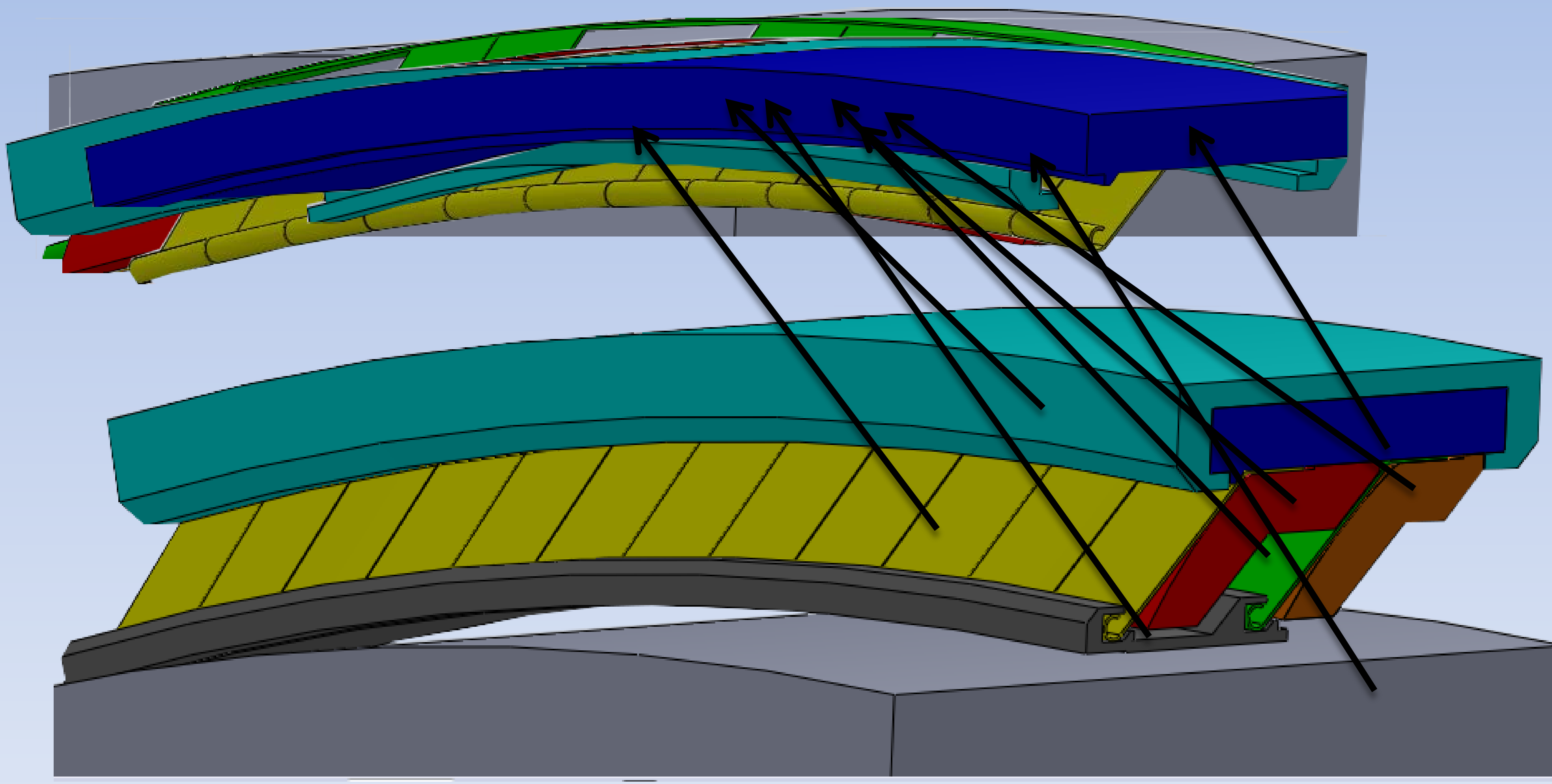
FILM RIDING PRESSURE ACTUATED LEAF SEALS : Components.



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FILM RIDING PRESSURE ACTUATED LEAF SEALS

Seal application for hydrodynamic-hydrostatic analysis:

Rotor seal diameter	60.0 in.	1.52 m
Runner segment angle	18.0 deg.	0.314 rad
Temperature	1000 F	538 K
Speed	3600 RPM	3600 RPM
Ambient pressure	50.0 psig	345 kPa
Pressure differential	40.0 psi	276 kPa

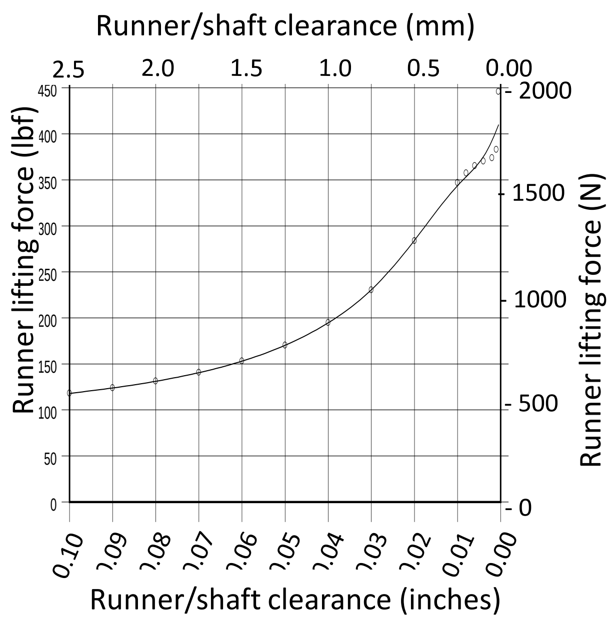
Seal analysis goals: < 2 lbs/sec (0.91 kg/s) seal leakage, rotor centered.
+ / - 0.100 inches rotor eccentricity.
< 50°F (28°C) temperature rise. .

Film analysis by Wilbur Shapiro using NASA Industrial code GCYLT.

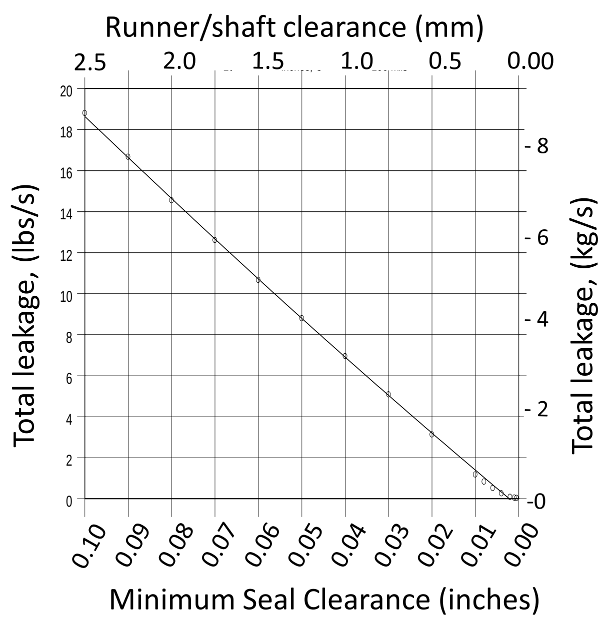
Seal film geometry selected to meet performance goals:

Runner axial length	1.500 inch	38.1 mm
Inlet Rayleigh step height	0.010 inch .	0.254 mm
Inlet Rayleigh step length	0.300 inch	7.62 mm
Runner inside radius	30.100 inch	0.76454 m

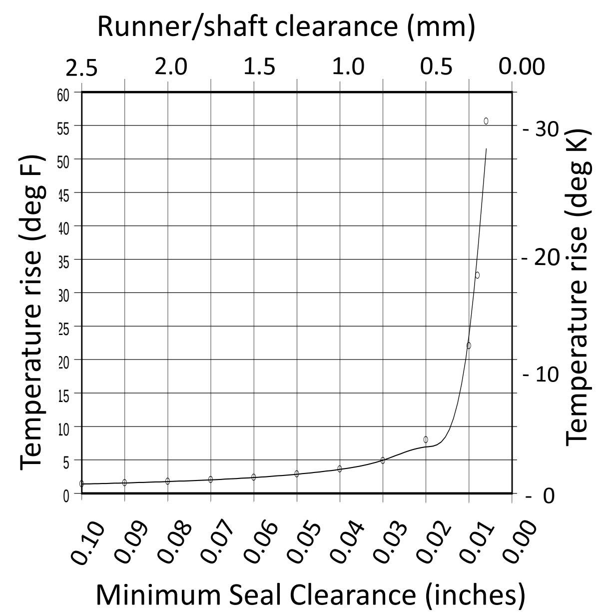
FILM RIDING PRESSURE ACTUATED LEAF SEALS : Film analysis.



Runner Segment Lifting Force.



Seal Leakage Under All Runners.



Seal Leakage Temperature Rise.

Evaluation studies:	Hydrodynamic contribution at 3600 RPM vs 0 RPM	Operating temperature of 1000F vs RT
Lifting force	No significant change	No significant change
Leakage	~10% less at 0 RPM.	~ 200% increase at RT

Expect meaningful static test results at room temperature.

Additional film analysis calculations:

- cross coupled stiffness and damping coefficients,
- power loss and
- center of film force.

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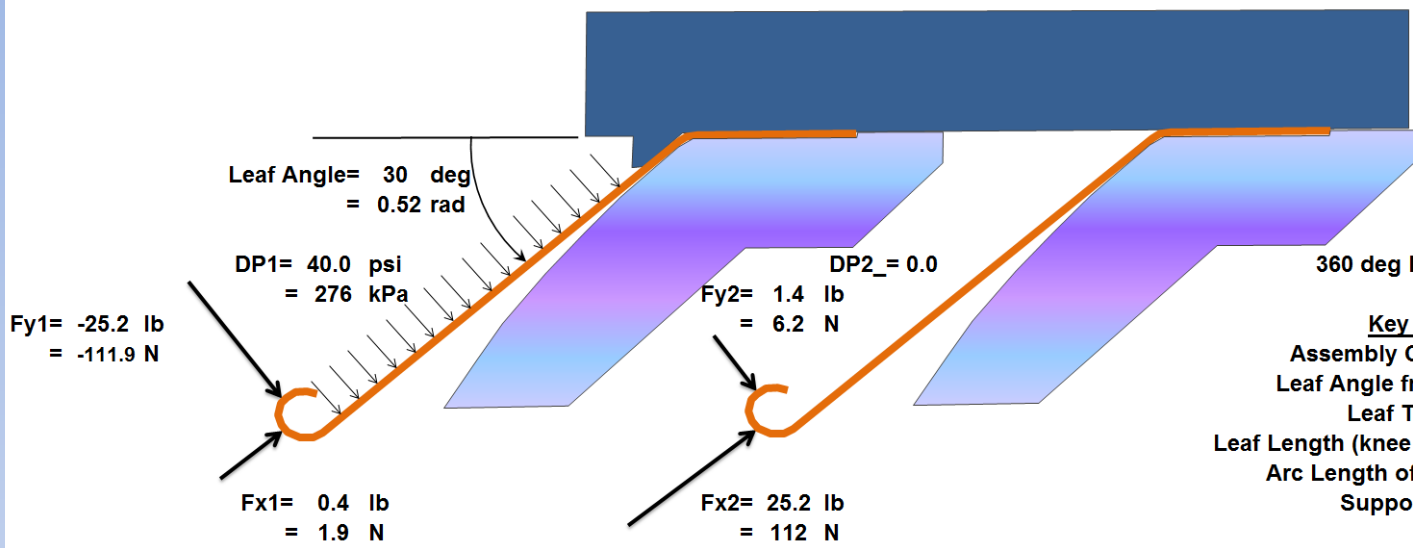
FILM RIDING PRESSURE ACTUATED LEAF SEALS : Force analysis.



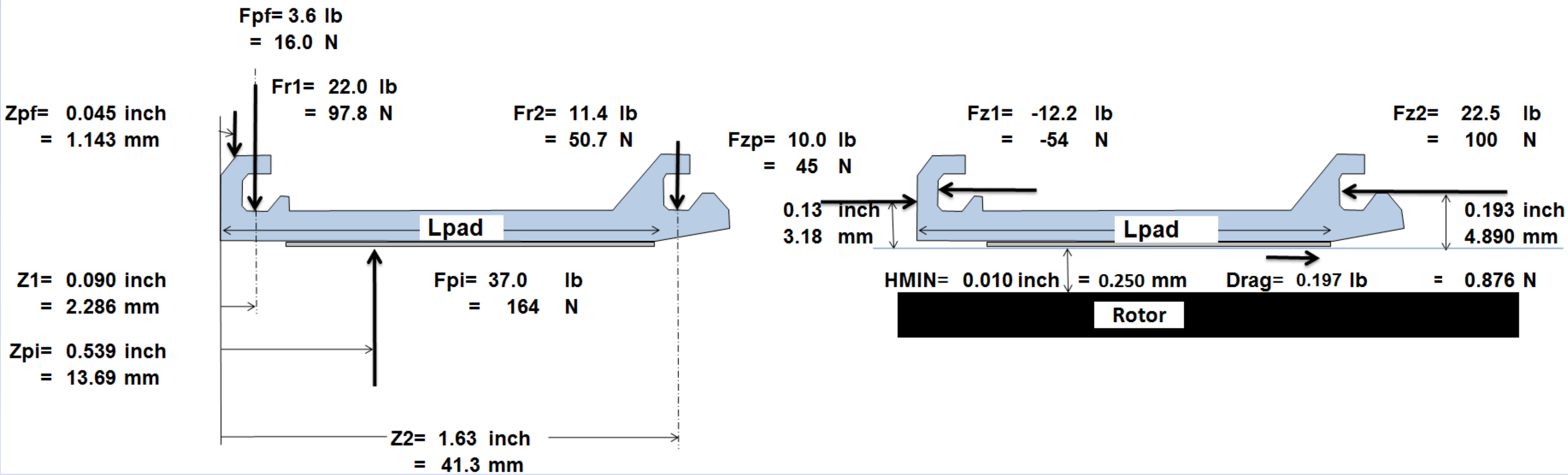
Runner conditions when rotor is centered

Lpad	1.500 inch	38.1 mm
Lstep	0.300 inch	7.62 mm
Step	0.010 inch	0.25 mm
HMIN=	0.010 inch	0.25 mm
ALPHA=	-0.001 radians (ccw positive)	
LOAD=	347.7 lbf (one 18 deg pad)	
Zpi=	0.539 inch	13.7 mm
360 deg Leakage=	2.280 lbm/s	1.03 kg/s

Key Design Parameters

Assembly Clearance	0.120 inch	3.05 mm
Leaf Angle from Axial	30.0 deg	0.52 rad
Leaf Thickness	0.029 inch	0.74 mm
Leaf Length (knee to ankle)	2.000 inch	50.8 mm
Arc Length of Support	1.600 inch	40.6 mm
Support Radius	4.500 inch	114 mm

Forces are all per inch (25.4 mm) of circumference.



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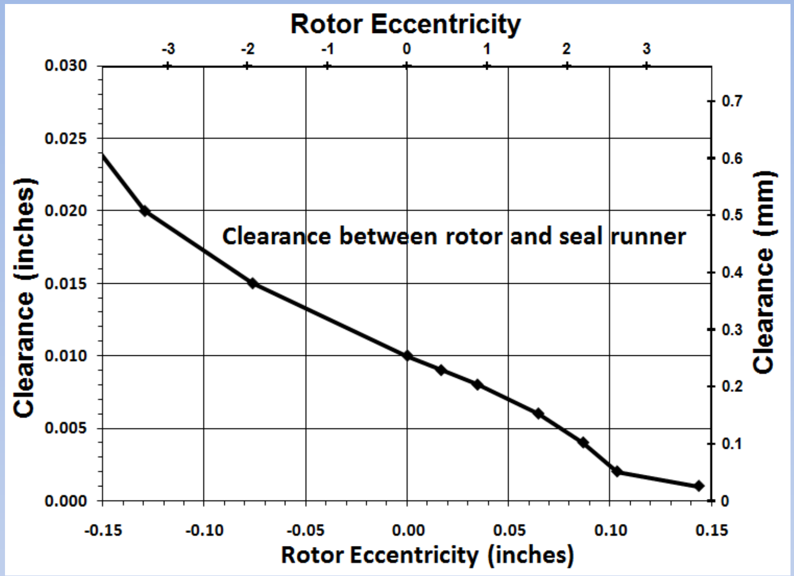
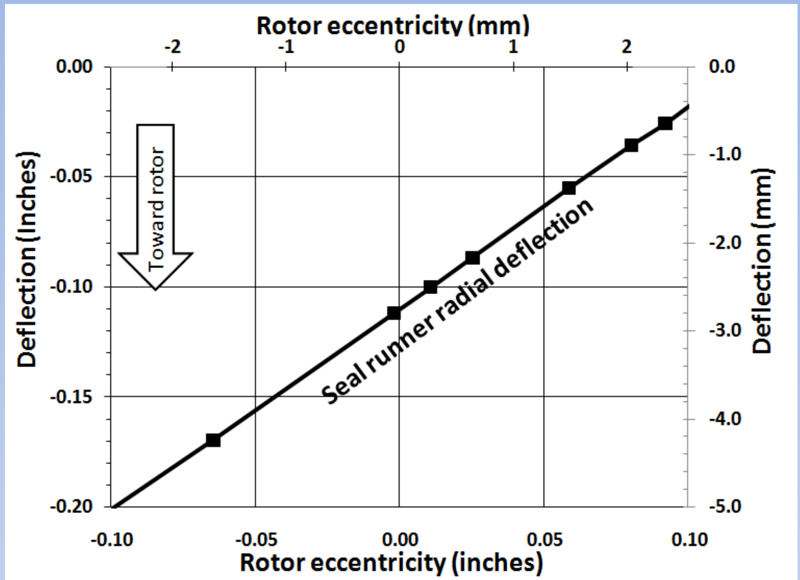
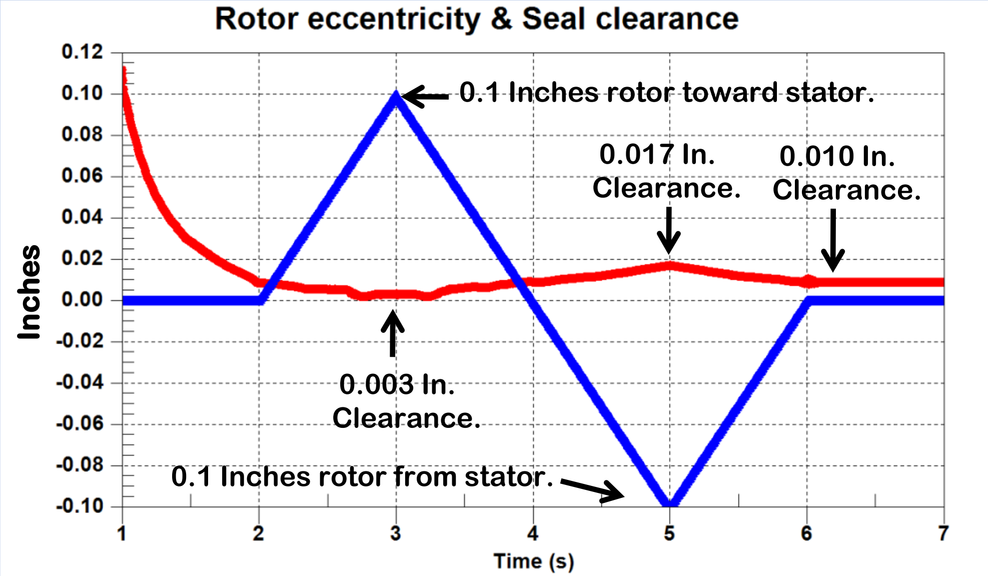
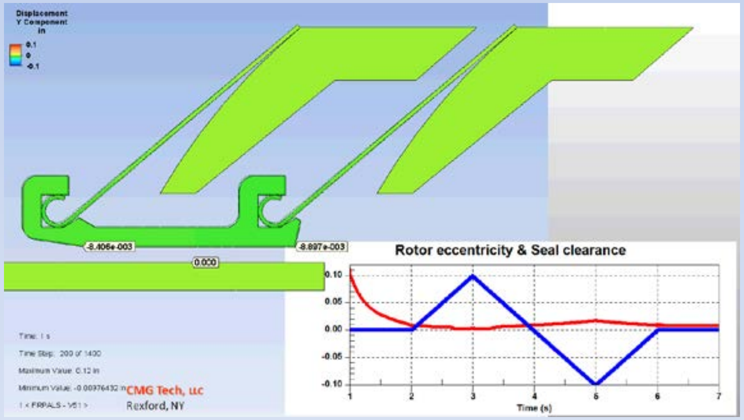
FILM RIDING PRESSURE ACTUATED LEAF SEALS : Clearance vs Eccentricity.









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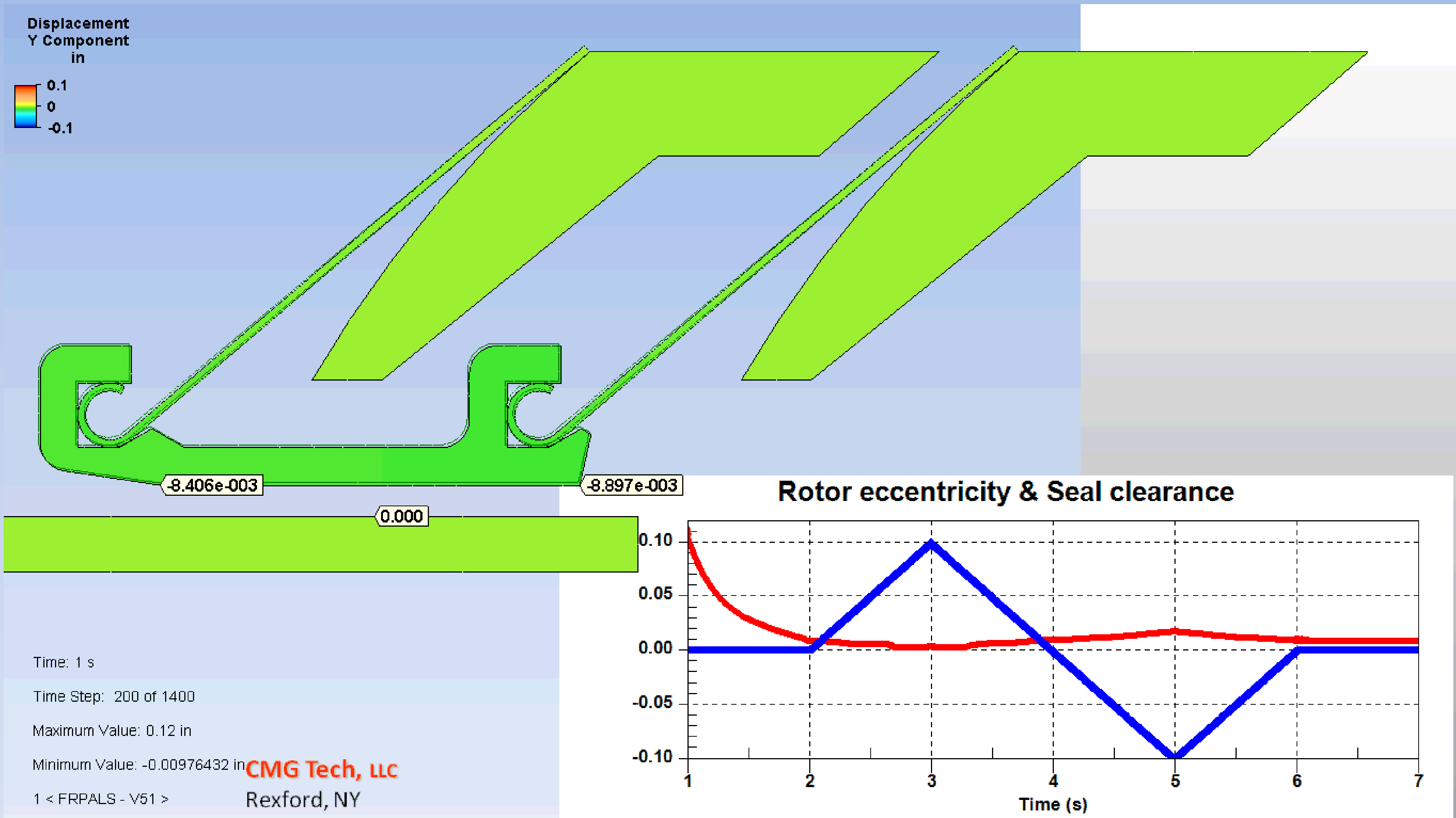
FILM RIDING PRESSURE ACTUATED LEAF SEALS : Clearance vs Eccentricity.



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Design analysis results:

1. Practical seal runner geometry: adequate hydrostatic load capacity.
2. Static seal leaf and hydrostatic film force analysis:
   - Reduced seal leakage at 0.010 inch nominal clearance.
   - Non-contacting at rotor eccentricity of 0.100 inches.
   - Compliant seal clearance vs. rotor eccentricity:

Eccentricity, inches	- 0.100	0.000	+0.100
Seal clearance, inches	0.017	0.010	0.003

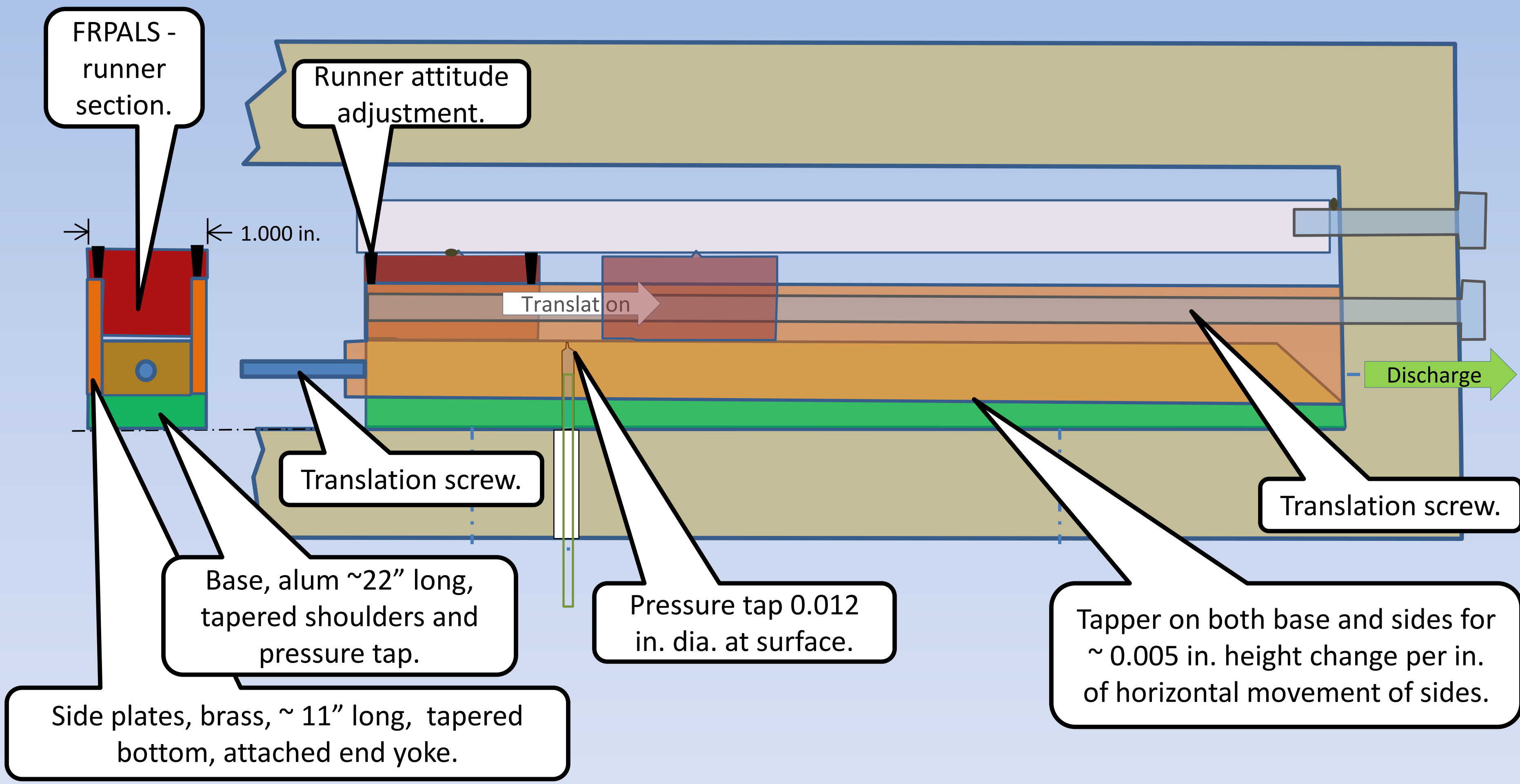
Seal Development Plans:

1. Full-scale 2-D static test:
    - Confirm 2-D seal leaf actuation and runner translation with pressure.
    - Measure clearance over range of ‘eccentricities’.
    - Measure runner film pressure vs. axial position.
    - Measure seal leakage.
    - Acoustic monitoring for dynamic activity.
    - **Validate predictive seal design tools & methodology.**

2. Full-scale 3-D segment static test:
    - Confirm 3-D seal actuation and runner translation with pressure.
    - Measure clearance over range of ‘eccentricities’.
    - Measure seal leakage.
    - Measure dynamic activity
    - **Demonstrate 3-D seal operability and reduced leakage.**

3. Sub-scale rotating rig seal testing:
    - Measure multi-segment leakage.
    - **Evaluate dynamic performance.**

2-D Test Rig Sketch to Measure FRPALS Runner Pressure Distribution.



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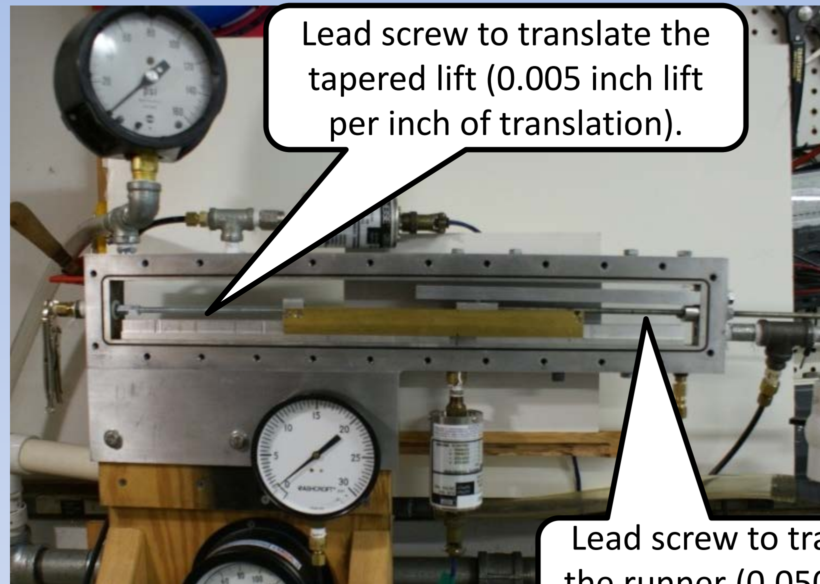
2-D Test Rig For Film Riding PALS Runner Pressure Distribution Measurement.

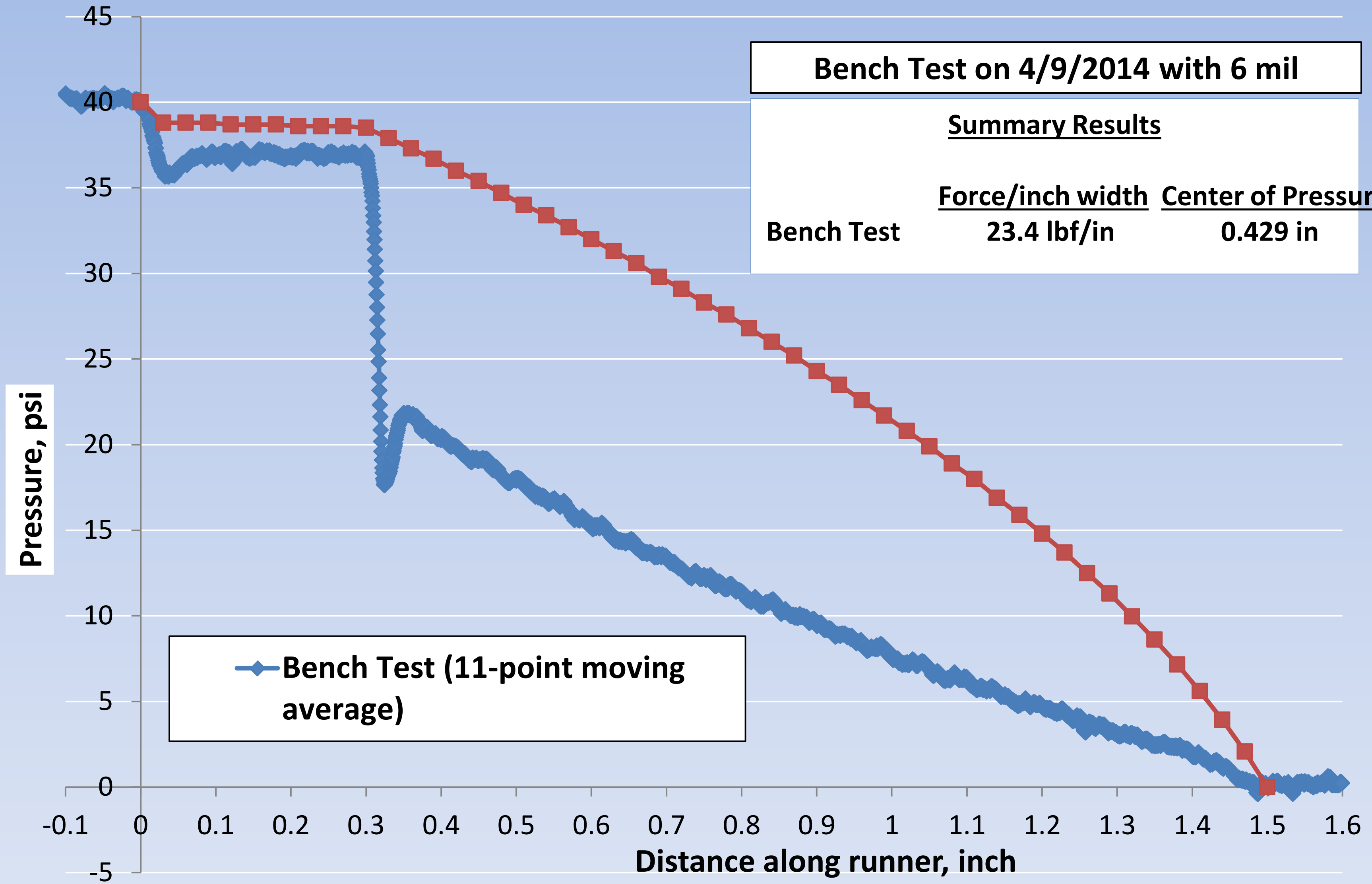
Bench test – arrangement of 2-D FRPALS modification, pressure transducers, flow meter (background) and NI USB data acquisition with NI Signal Express software.



A closer look at 2-D FRPALS tapered slide to lift the runner, translation screws and pressure transducers.

FILM RIDING PRESSURE ACTUATED LEAF SEALS

Bench Test Comparison with GCYLT



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Design evaluation conclusions:

- Feasibility established.
- Continue development.

Reduced leakage	→	***superior performance.***
Rub avoidance	→	***sustained performance.***
Compliant seal	→	***design for performance.***