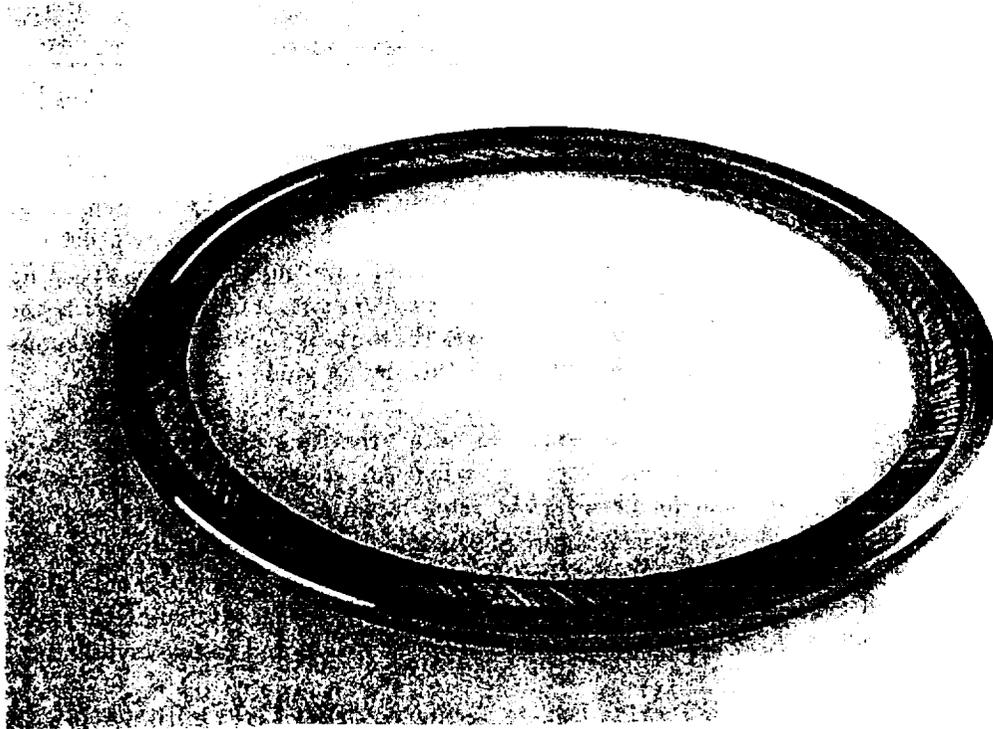


CURRENT DEVELOPMENTS IN BRUSH SEALS

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Cranston, Rhode Island

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Photograph of an Annular Brush Seal

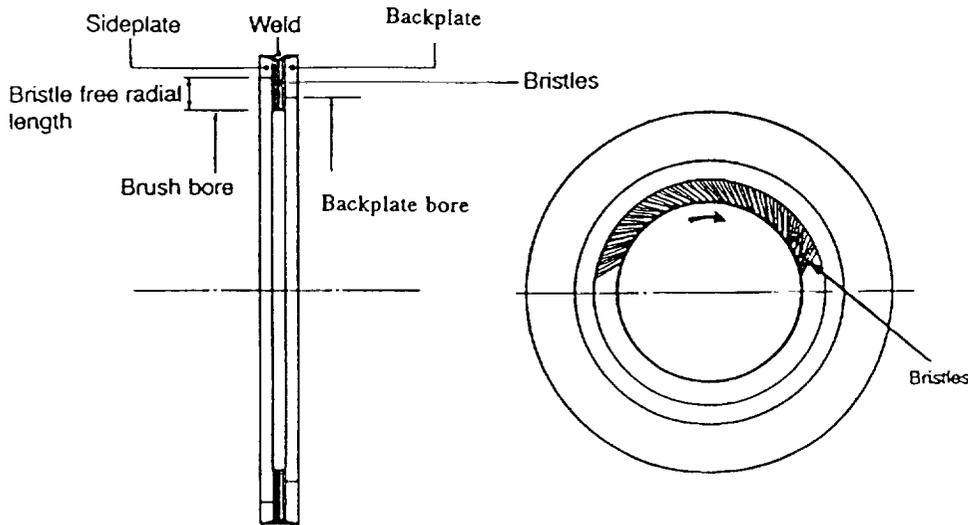


Illustration and Nomenclature of a Typical Brush Seal

Brush Seal Development Program

U. S. Air Force - Sponsored Integrated High Performance
Turbine Engine Technology (IHPTET) - PRDA-II

- OBJECTIVE: DEVELOP A COMPREHENSIVE DESIGN METHODOLOGY FOR BRUSH SEALS USING:
 - APPLICATION REQUIREMENTS FROM ENGINE MANUFACTURER
 - EXPERIMENTAL CHARACTERIZATION OF SEAL DESIGN AND TRIBOLOGICAL PAIRS
- GOALS:
 - SUBSTANTIALLY LOWER LEAKAGE THAN LABYRINTH SEALS
 - SEAL LIFE CONSISTENT WITH MAN-RATED MISSION REQUIREMENTS
 - INVESTIGATE SINGLE AND MULTIPLE STAGED BRUSH SEALS
 - TEMPERATURE - up to 1200F
 - SURFACE SPEED - up to 900 FPS
 - PRESSURE - ΔP ACROSS THE SEAL, 50 PSID
- PROVIDE:
 - COMPREHENSIVE SEAL DESIGN GUIDE
 - BRUSH SEAL FOR TEST IN A DEMONSTRATOR ENGINE

Brush Seal Development Program

U. S. Air Force - Sponsored Integrated High Performance
Turbine Engine Technology (IHPTET) - PRDA-III

Started: October 1992

Will complete: 1995

- OBJECTIVE: DEVELOP DESIGN METHODOLOGY FOR ADVANCED BRUSH SEALS
 - SIMILAR METHODOLOGY TO PRDA-II EXCEPT:
MORE EXTENSIVE CFD-BASED MODEL BEING DEVELOPED AT TEXAS A&M UNIVERSITY
- TECHNICAL GOALS
 - 1400 FEET PER SECOND - SURFACE SPEED
 - 1400° F
 - 150 PSID PER STAGE
- PROVIDE:
 - COMPREHENSIVE DESIGN GUIDE
 - BRUSH SEAL FOR TEST IN AN IHPTET DEMONSTRATOR ENGINE

Brush Seal Testing at EG&G Fluid Components Technology Group Research and Development

PRDA-II 1990-1993

- | | | |
|----------------------------|--|-----------|
| - Baseline Testing | 12 seals | 184 hours |
| - Tribological Evaluation | Ring-on-ring samples
and 9 small (2") brush seals | |
| - Characterization Testing | 17 seals | 484 hours |
| - Design Selection Testing | 8 seals | 280 hours |
| - Performance Testing | 3 seals | 101 hours |

PRDA-III 1992-1995

Characterization Testing to date

4 seals - 76 hours

Projected - 20 seals for characterization and performance

» 350 hours more testing

Other Brush Seal Programs

- | | |
|-----------------|-----------|
| - Various seals | 120 hours |
|-----------------|-----------|

Brush Seal Testing at EG&G Fluid Components Technology Group Research and Development

1990 to 1993

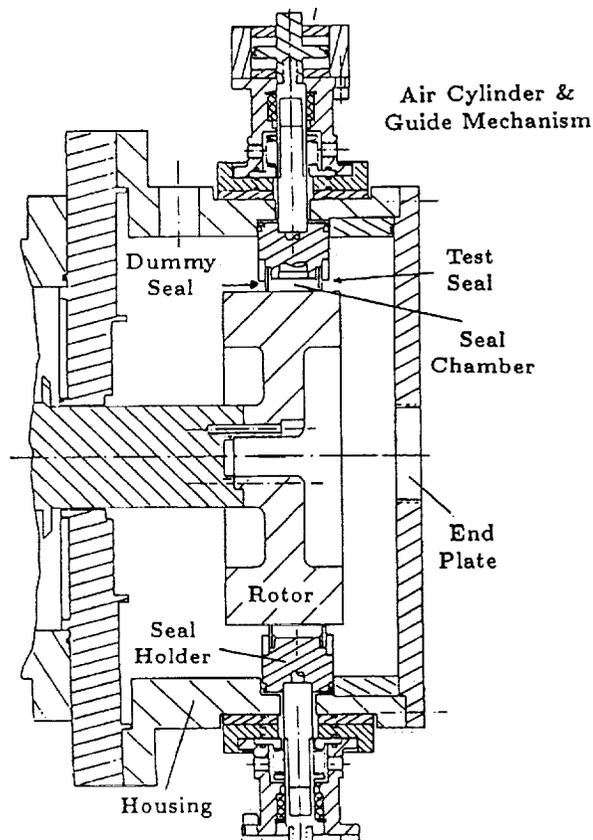
Maximum Conditions of Testing - to date

- Tested 9 inch diameter seal with 4.5 mil of runout and applied radial excursions of up to 19 mil for 765 cycles, Leakage acceptable for the application
- Highest temperature - 1200°F
- Highest surface speed -14 inch I.D. seal - 1,080 FPS
- Highest ΔP across seal 60 psid

Brush Seal Testing at EG&G Fluid Components Technology Group Research and Development

- Test Rigs used for brush seal programs
 - High Speed - High Temperature Tribology Test Rig
 - » 60,000 rpm, small samples, 1200°F
 - Gas Seal Test Rig
 - » 16,000 rpm, 2000 psi, 600°F, up to 4 inch diameter runners
 - Aerospace Test Rig
 - » 24,000 rpm, 200 psi, 1000°F, up to 20 inch diameter runners
 - » Can set in desired continuous runout and can induce excursions of up to .030 inches (radial) during dynamic testing. Excursions done by moving the seal housing.

Experimental Procedure



Radial Excursion
Dynamic Test

30 mils

Brush Seal Development Program

IHPTET - PRDA-II

- **Major Results**

- Developed new design to alleviate “bristle hysteresis” effect
- Developed tribological pair, bristle material and coating combination, that performs well at required speed and temperature goals
- Delivered brush seal acceptable to engine manufacturer for test on demonstrator, anticipated to test December 1993
- Design Guide has been published, U.S. Air Force publication

Note: Copies of AIAA Propulsion Conference papers:

“Hysteresis and Bristle Stiffening Effects of Conventional Brush Seals”

and

“Tribological Evaluation of Brush Seal Applications”

are available in the back of the room.

Brush Seal Development Program

IHPTET - PRDA-III

- **Where we are**

- Completed initial series of “wear pattern tests”
- Have new designs for higher pressures being fabricated
- Have started tribopair work

- **What next**

- Test higher pressure designs
- Investigate ceramic brush seal bristle possibilities, as we go to higher temperatures

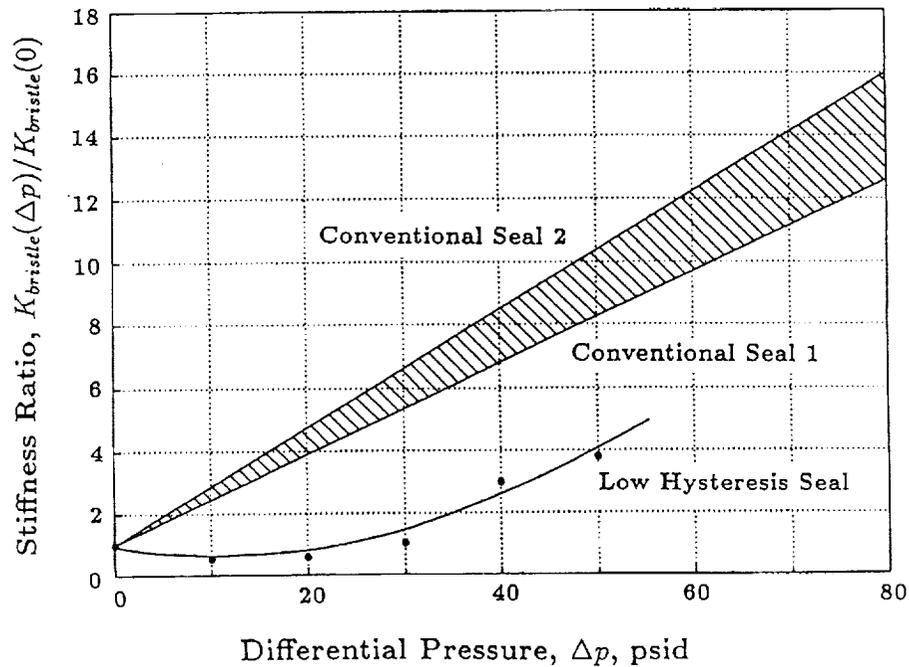
Test Results

- * Bristle Stiffness versus Pressure
- * Dynamic Test Leakage Data
 - Concentric Rotor
 - Eccentric Rotor
 - Radial Excursion

Flow Parameter, $\Phi = \frac{\dot{m} \sqrt{T}}{p_u D_i}$

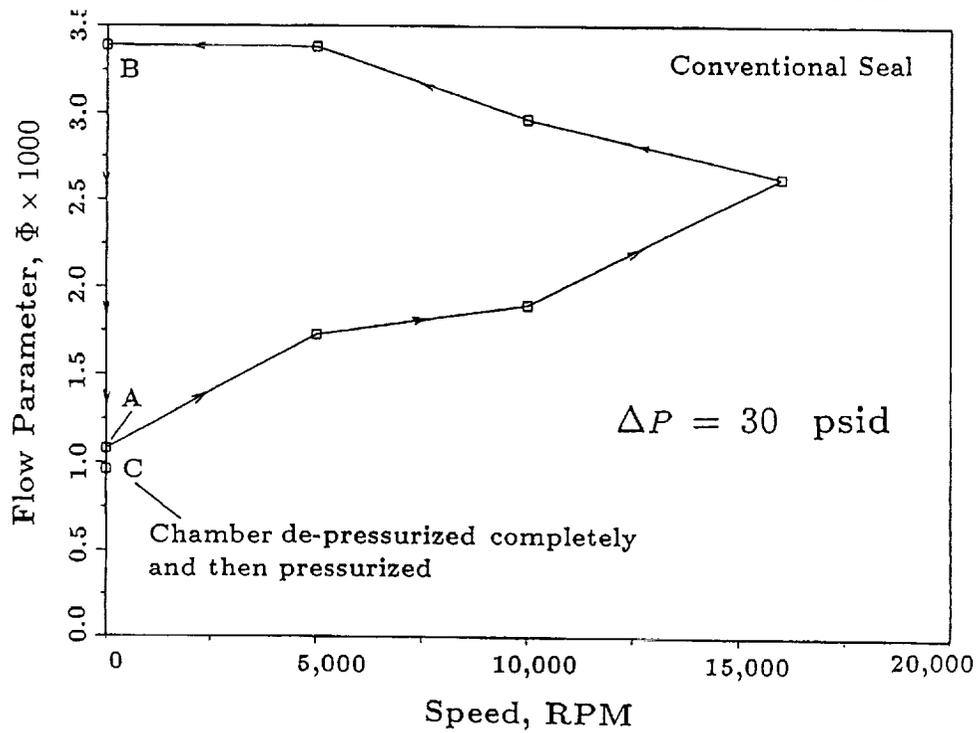
Test Results

Bristle Stiffness versus Pressure



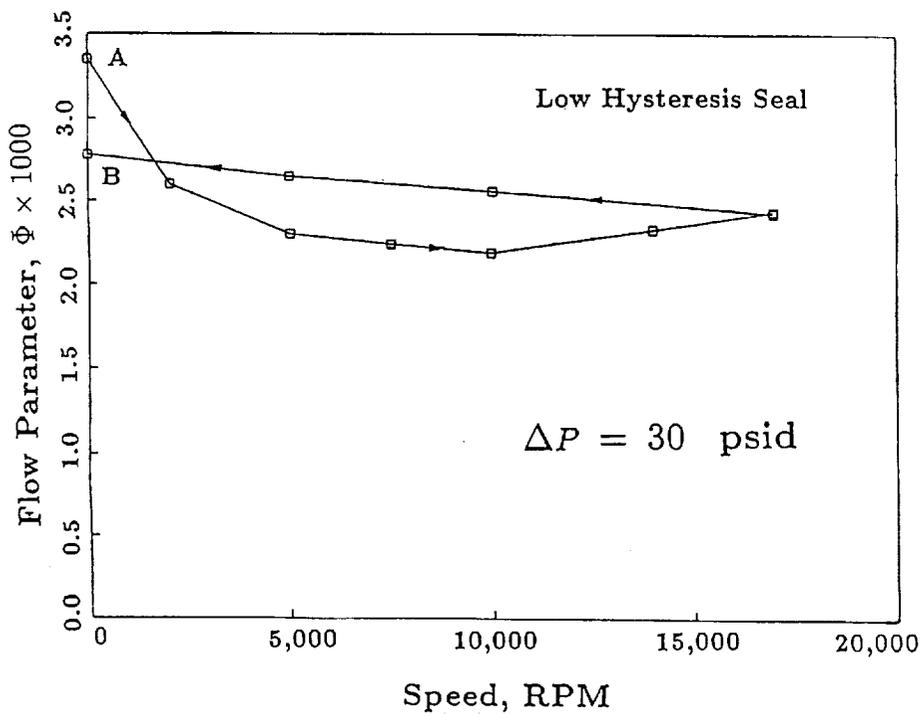
Test Results

Dynamic Test with Concentric Rotor



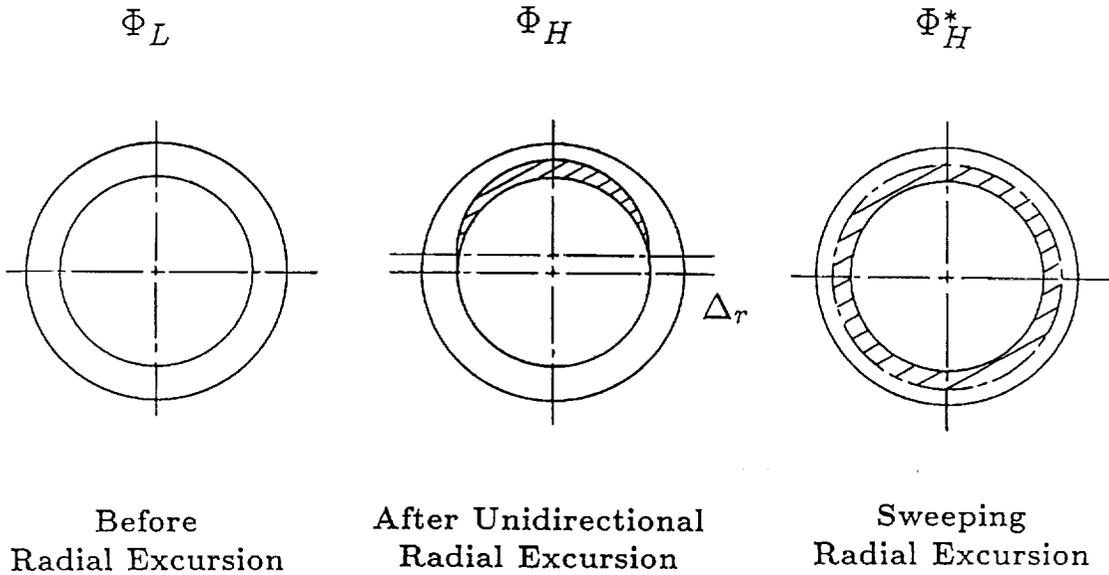
Test Results

Dynamic Test with Concentric Rotor



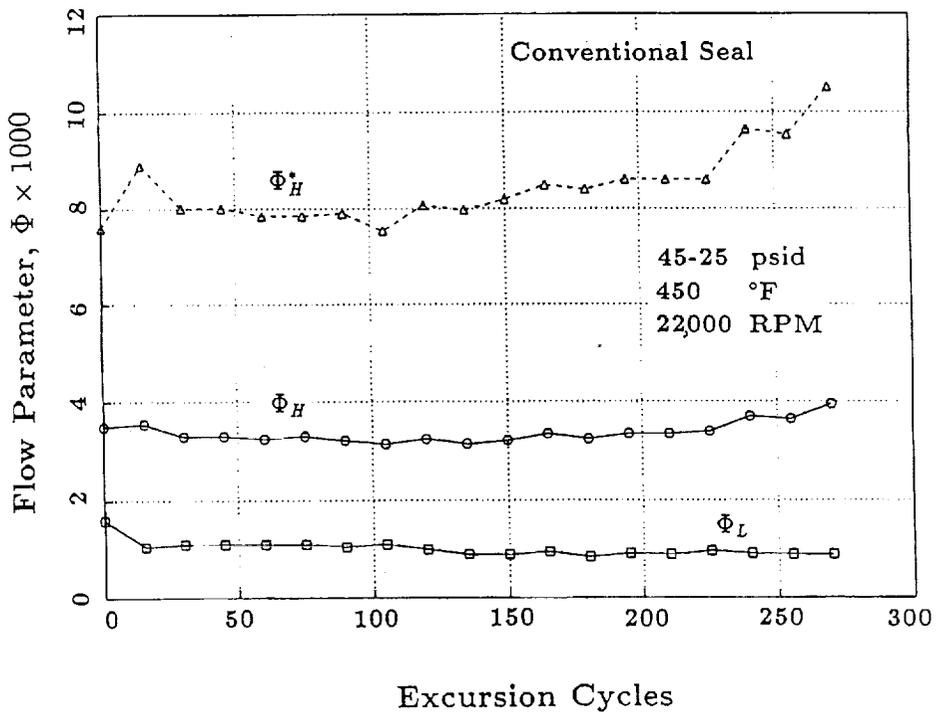
Dynamic Test with Radial Excursion

Flow Factor



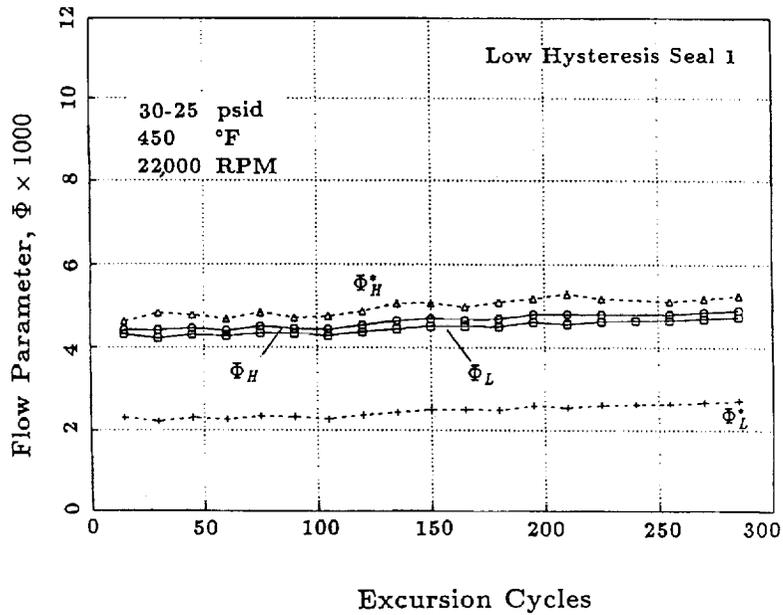
Test Results

Dynamic Test with Radial Excursion



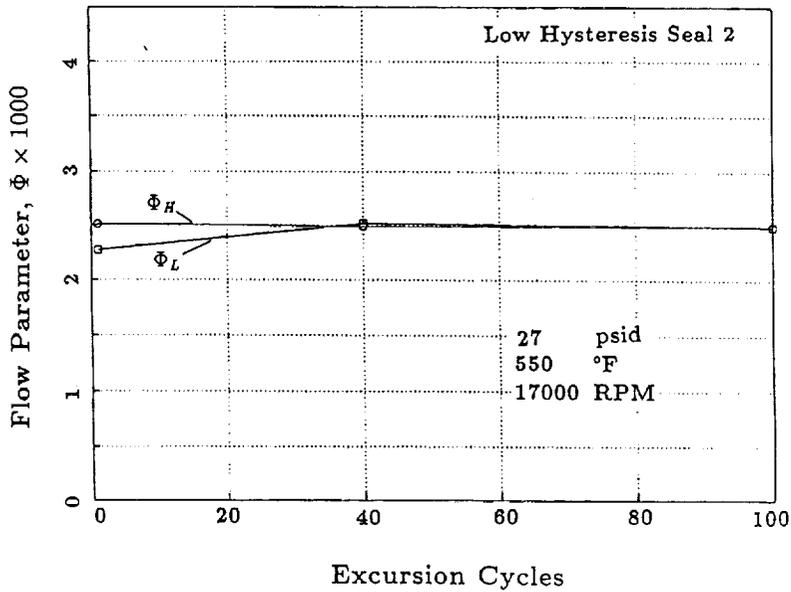
Test Results

Dynamic Test with Radial Excursion



Test Results

Dynamic Test with Radial Excursion



Conclusions

*** Conventional Brush Seals**

- Hysteresis : Leakage
- Bristle Stiffening : Life

*** “Low Hysteresis” Brush Seal**

- Above Effects Considerably Reduced
- Low Leakage over Operating Cycles
- Potential for Longer Life