DEVELOPMENT OF ADVANCED SEALS FOR INDUSTRIAL GAS TURBINES—ABRADABLE SEALS

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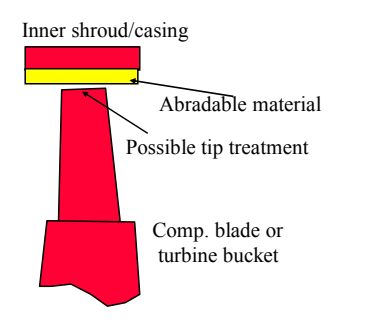
Improved sealing has been under development for several years for GE industrial turbine applications. The work summarized in this presentation is being carried out at GE's Global Research and Center in cooperation with GE Power Systems. A team of over a dozen individuals at GE-GRC focus on developing advanced seals for several turbine locations.

The focus of this presentation is the development for abradable blade tip sealing for industrial gas turbines. The presentation includes: description of how abradable seals work, where they are located in a gas turbine, types of abradable materials, method of application, and detailed information for turbine locations.

Details of the abradable seal development are given in AIAA-2002-3795 paper.

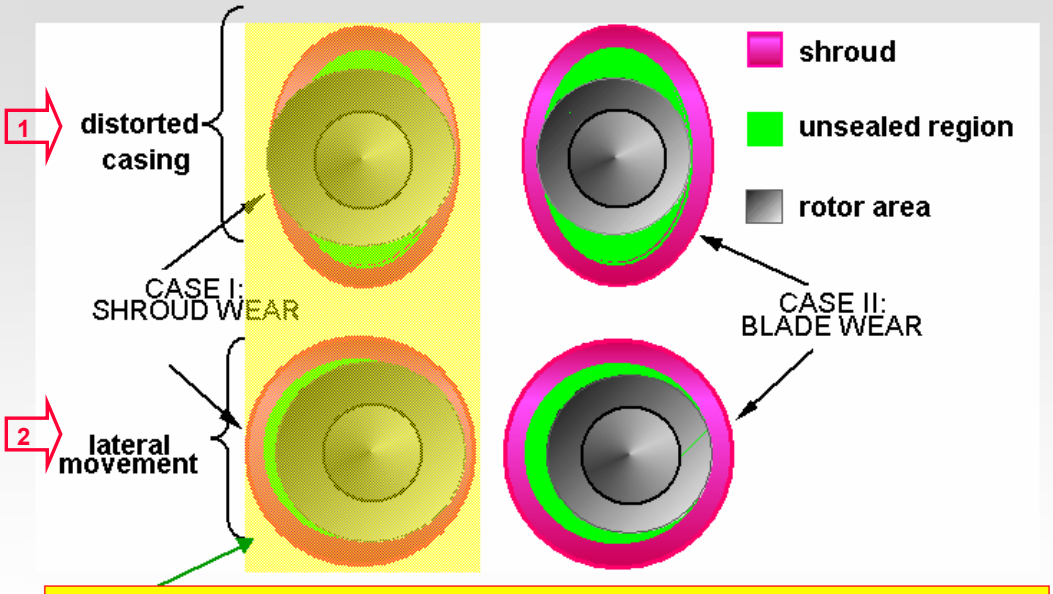
Abradable seals:

- Used in aviation gas turbines since late 1960's/early 1970's
- Gaining popularity in power generation turbomachinery components
- Applied to casings and shrouds to decrease clearances otherwise difficult to achieve
- Relative simple approach with low cost and design implications
- Without abradables, cold clearances are large enough to prevent rubbing due to tolerances, out-of-round casings, and offset rotors.
- Abradable is sacrificial; worn away without damaging rotating blade tips→ lower cl's



Further reasons for using abradable seals

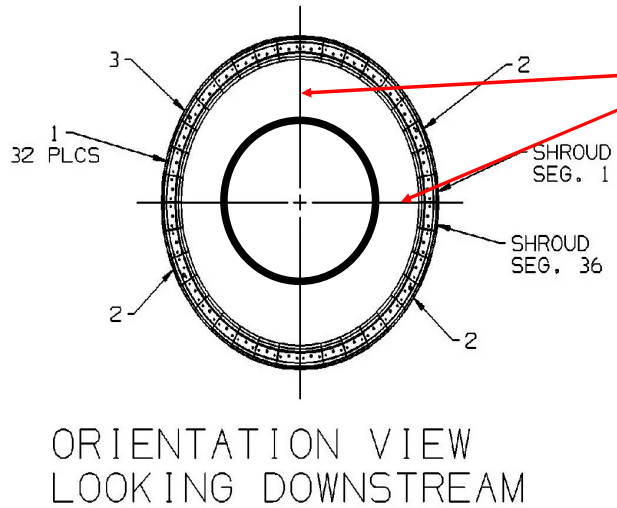
Abradable sealing also reduces clearances for …



Abradable shroud case → Local removal of a sacrificial shroud coating reduces leakage compared to bucket wearing

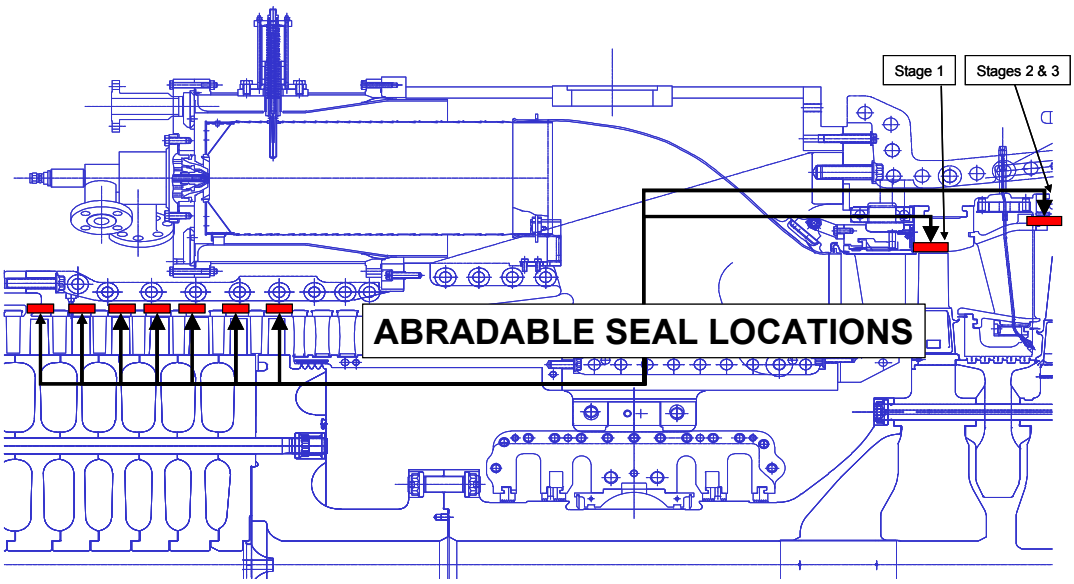
Example of a Casing Out of Roundness

Sketch of turbine shell out of roundness



~ 0.050+ in out of roundness Is not uncommon

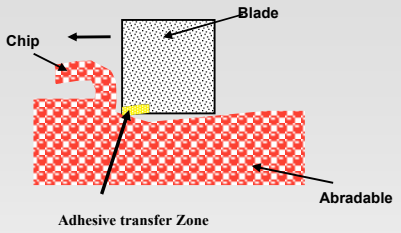
ADVANCED SEALS -- Gas Turbine Focus Locations



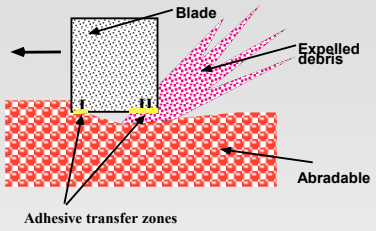
ABRADABLE SEALS

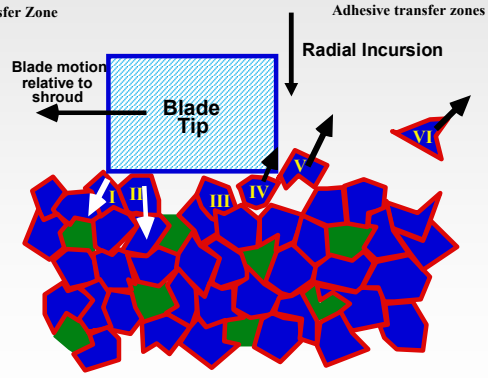
Rub Mechanisms

Below ~ 100 m/s (330 ft/sec)



Above ~100 m/s (330 ft/sec)*



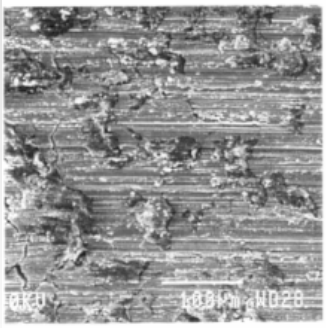
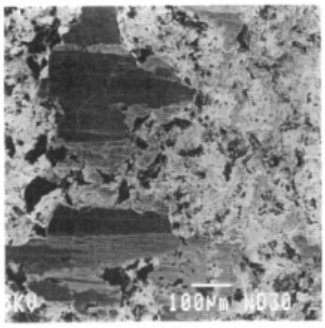
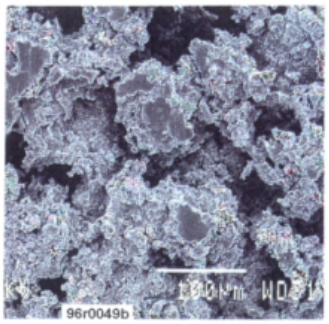


Material removal mechanism is different at high speeds in gas turbines compared to machining operations.

*Assuming blade tip thickness range of 0.7 - 2.0 mm (20 - 80 mils)

Matrix | Fugitive Phase / Porosity | Release Agent

Predominant Wear Mechanisms

Melting Wear	Densification	Particle Breakout
		
AlSi-polymer	Nickel-Graphite	CoNiCrAlY-hBN-Polymer

Differing mechanisms with various classes of thermally sprayed abradables

ABRADABLE SEALS

Design Considerations

Abradables have:

- Low strength → susceptible to gas and particle erosion
- Inherent porosity → Prone to oxidation at higher temperatures
- Conflicting requirements → treat as a complete tribological system, i.e.,
  - Relative motions and depth of cut - blade tip speed and incursion rate
  - Environment - temperature, fluid medium and contaminants
  - Cutting element geometry and material - blade tip thickness, shrouded or unshrouded blades
  - Counter element - abradable seal material and structure

Seals must be designed to suit the particular application based on the tribo-system

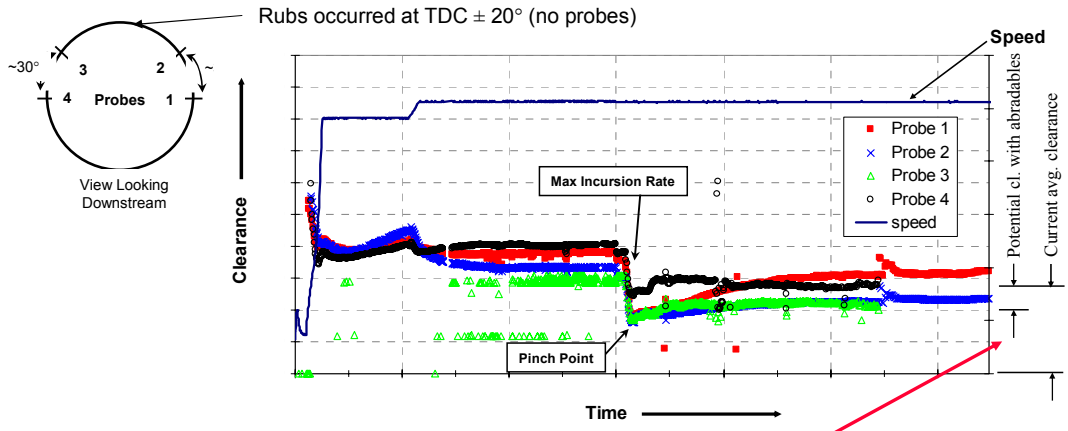
CTQ's for Abradable Development

CTQs:
- Increase power output 0.4 to 0.8%
- Reduce heat rate 0.4 to 0.7%
- Target life vs. application
- Minimum blade tip wear without any tipping
- No damage to other turbine parts if coating fails
- Etc.

Abradable (extrinsic) Requirements:
- Clearance reduction
  - coating thickness vs. application
- Abradable @ operating temperatures
- Long Service life
  - Oxidation life at operating temp's
- Erosion resistant
- Lab tests – rub rig, furnace, erosion rig
- Engine and rainbow tests

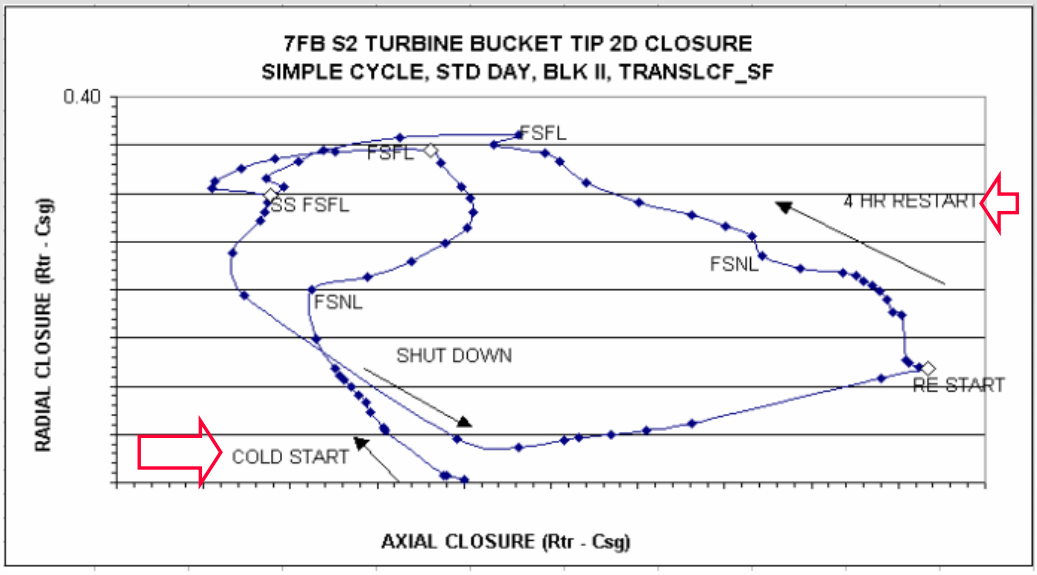
Abradable Seals Driven By Customer Requirements

Typical Transient Radial Closure Cycle

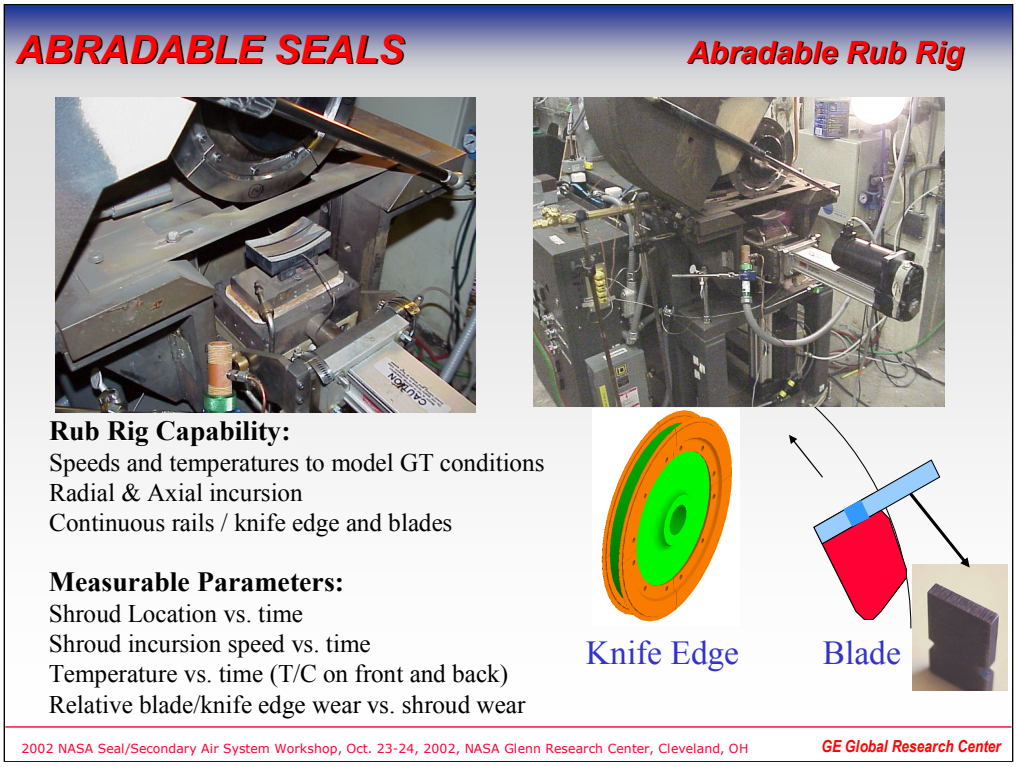


- Pinch point likely occurs during loading
- Desired coating thickness can be determined from radial closure data
- Significant clearance reduction possible

Typical Stage 2/3 Axial/Radial Transient Movement



Stages 2 and 3 encounter significant axial and radial movements during transients that must be accounted for in abradable material design.



Advanced seal testing capabilities at CRD

3 test rigs:

"Shoebox" (Static testing, Air only)

Used for static seal characterization and basic leakage testing of labyrinth, honeycomb, and brush seals.

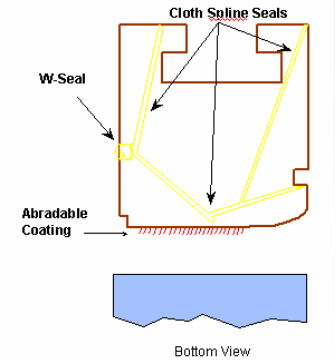
5.1" Rotary Rig (Dynamic testing, Air or Steam, up to 1200 psia)

Used for testing subscale seals at approximately full scale conditions (speed, pressure, temperature)

36" Rotary Rig (can be reconfigured to 50") (Dynamic testing, Air only)

Used for testing full scale seals at subscale conditions.

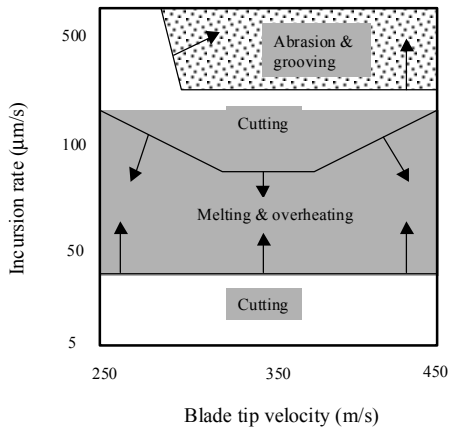
Stage 1 Turbine Shroud Abradable Seals



Uprate Shroud

ABRADABLE SEALS

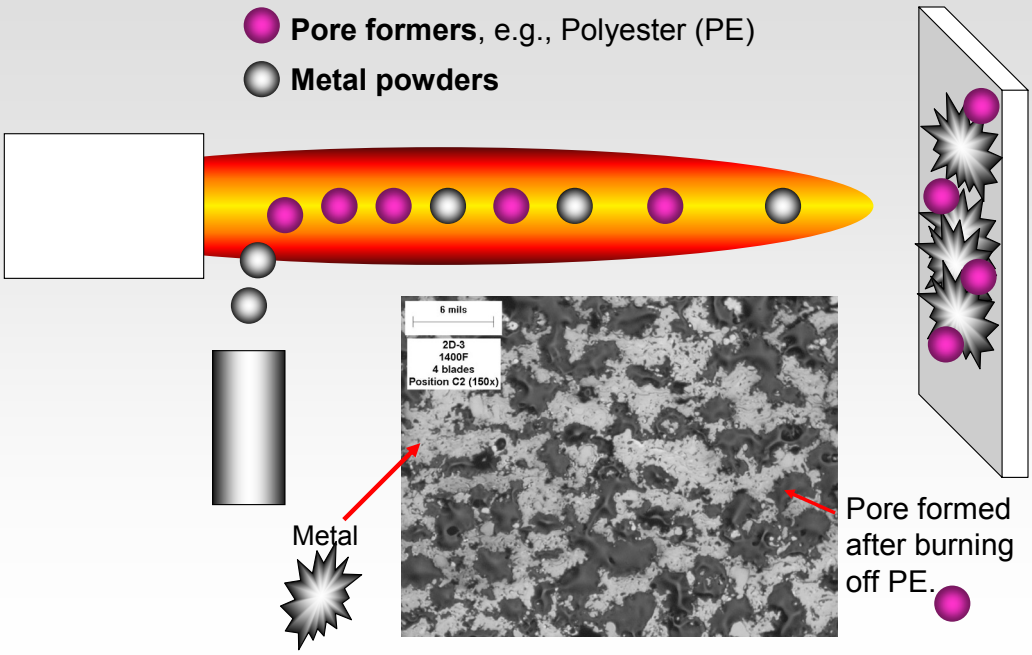
Wear Maps for MCrAlY based Abradable coatings Vs Ti blades



Porous CoNiCrAlY + hBN (500°C)

Abradability of MCrAlY based coatings against Ti blades is mainly affected by porosity and to some extent on the amount of release agent.

Porous Metallic Abradable Coatings by Plasma Spray



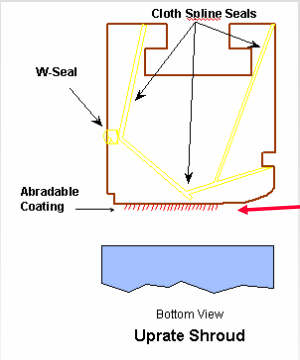
ABRADABLE SEALS

Rub Rig Test Results

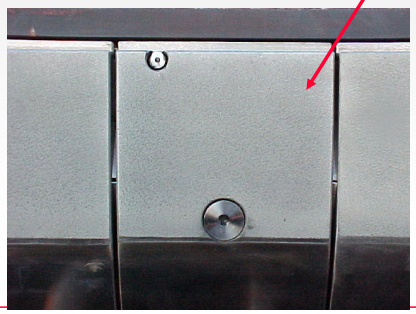
GT50 is a porous MCrAlY coating with optimized porosity to balance abradability with oxidation and erosion resistance at E-Class GT stage 1 shroud conditions

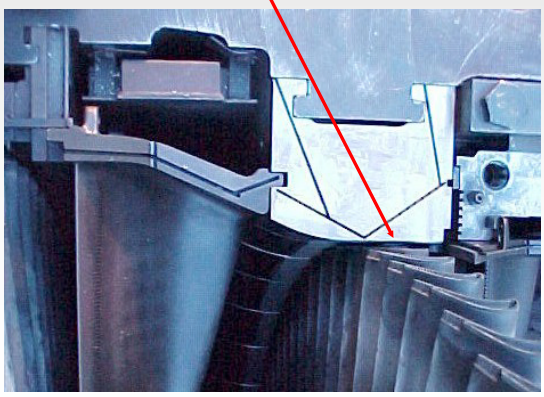
Good cut of GT 50 with little blade tip material removed

Stage 1 Shroud Abradable Seal Installation

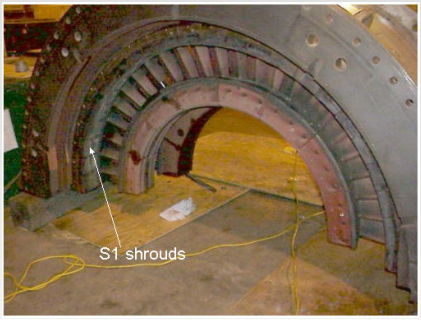


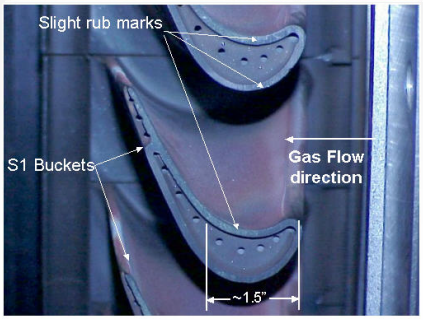
GT50 abradable coating applied to shroud inner surface





Stage 1 Turbine Shroud Abradable Application



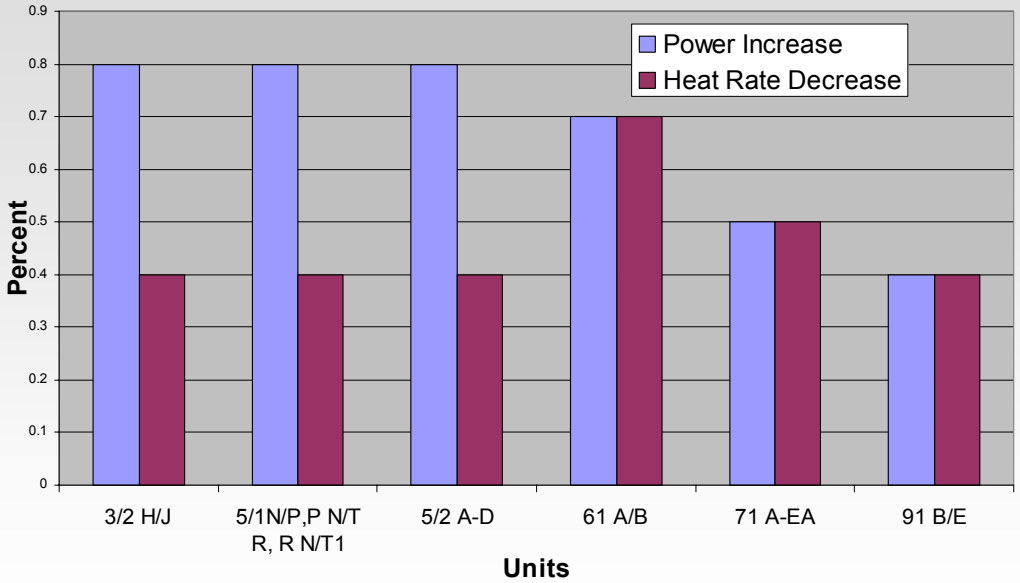


Inspection of GT50 coating after 12,410 hours, 229 starts:

- Little signs rubbing on blade tips or shroud.
- Shroud coating appearance similar to other inspections.

Performance Benefits

Turbine Stage 1



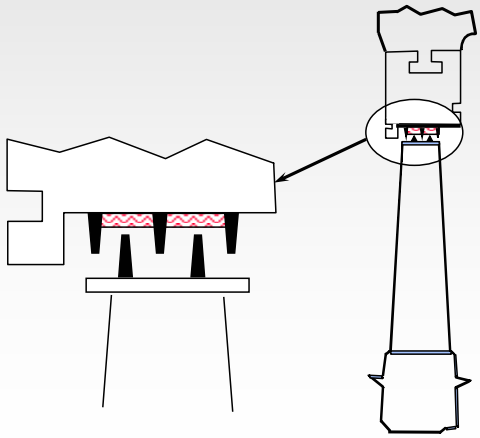
Performance gains from 0.4% to 0.8%

Units with GT50 Abradable Coating on Stage 1 Shrouds

Frame 3	1
Frame 5	27
Frame 6	85
Frame 7	69
Frame 9	17
Total	199

Good initial penetration into E-Class turbine fleet after 3 years

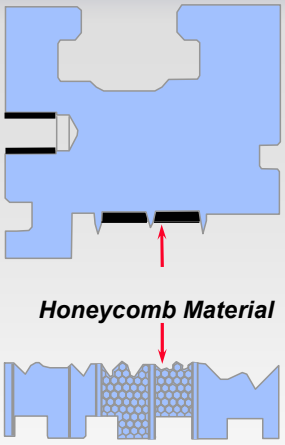
Stage 2 & 3 Turbine Shroud Abradable Seals

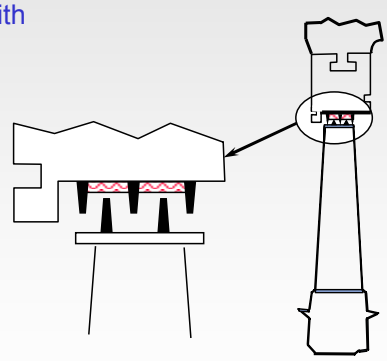


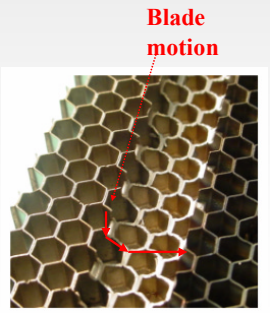
STAGE 2 & 3 ABRADABLE SEALING

Components, Feature & Benefits

- Honeycomb Material Brazed Between Casing Shroud Teeth
  - Tighter Clearance with Buckets
    - Improved performance
  - Reduced Bucket Damage Potential for Rubs
- Requires Buckets with Cutter Teeth

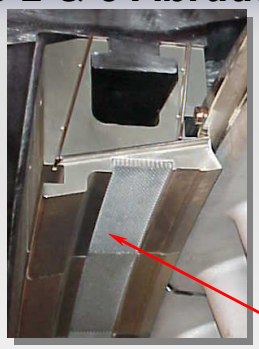


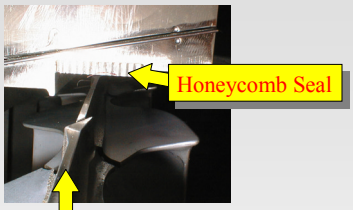


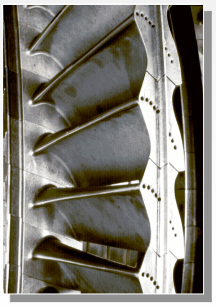


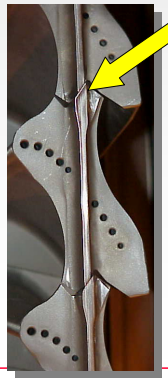
HC rub test sample showing radial/axial wear pattern from simulated rub testing

Stage 2 & 3 Abradable Sealing Application



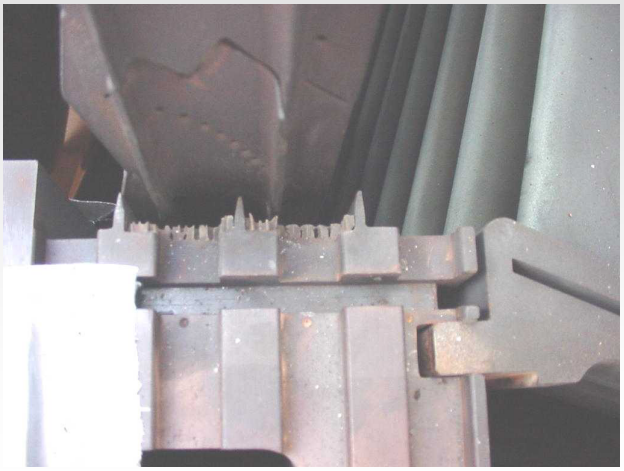






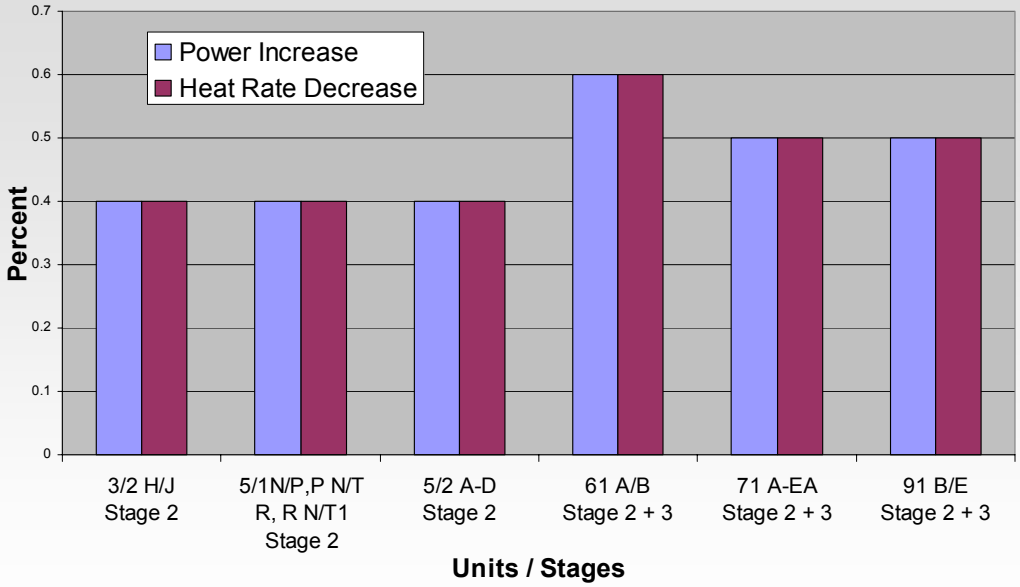
Stage 2/3 Turbine Abradable Application

Photos of installation after 24,000 hours



Performance Benefits

Turbine Stages 2 & 3



Combined performance gains from 0.4% to 0.6%

Units with Honeycomb Shrouds

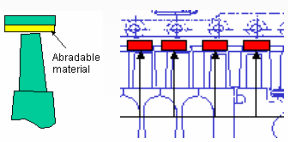
	Stage 2 HC Shrouds	Stage 3 HC Shrouds
Frame 5	17	N/A
Frame 6	341	306
Frame 7	444	423
Frame 9	65	63
Total	867	792

Significant penetration into E-Class turbine fleet

Summary

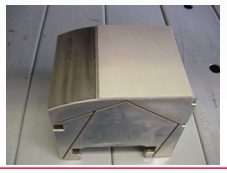
Status of Abradable Seal Application

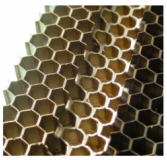
	Compressor	Stage 1 Turbine	Stage 2/3 Turbine
Benefits	TBD (~0.5 to 1%)	0.4 to 0.8%	0.4 to 0.6%
Materials	Material development complete Application processes selected	- GT50 for untipped E-Class GT temperatures - New coating (GT56) being introduced for longer life - For higher temperatures, coating developed for tipped blades. - New coating being developed for high temperature and untipped blades.	- Honeycomb (HC) in place - Longer life HC development in progress
Applica-tion Status	Cost/benefit being evaluated in the field	- GT50 – good initial penetration into E-Class GT fleet (~ 200 units) - Newer coatings being developed/ introduced into E- and F-Class GT fleet	Good penetration of HC into E-Class GT fleet (~ 900 units) and F-Class GT fleet



GT 50 Coated S1S One of ~ 200 sets

GT 56 Coated S1S—1st set being installed in late 2002





There is an organized, coordinated effort to develop and apply abradable seals to industrial gas turbines. E-Class turbines have been the primary focus of this presentation, but abradable seals are being considered for F-Class turbines as well. Compressor and turbine stage 2 & 3 applications are very similar for the two turbine classes. Considerable effort is being focused on the turbine stage 1 abradable tip sealing. Two generations of coatings have been introduced into E-Class turbines over the last three years. The F-Class stage 1 brings higher temperature challenges for the abradable sealing system being developed for that location.