Turbine Design for High Temperature Geothermal Steam

GEMS - November 2024

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Drilling Developments and Higher Temperatures

- Developments in drilling technology have led to potential of increased access to high temperature geothermal power generation
- Raised temperatures stretch the capabilities of organic fluids commonly applied today in binary cycle power plants
- This presentation is focused on the study of steam turbines for direct-use plant designs

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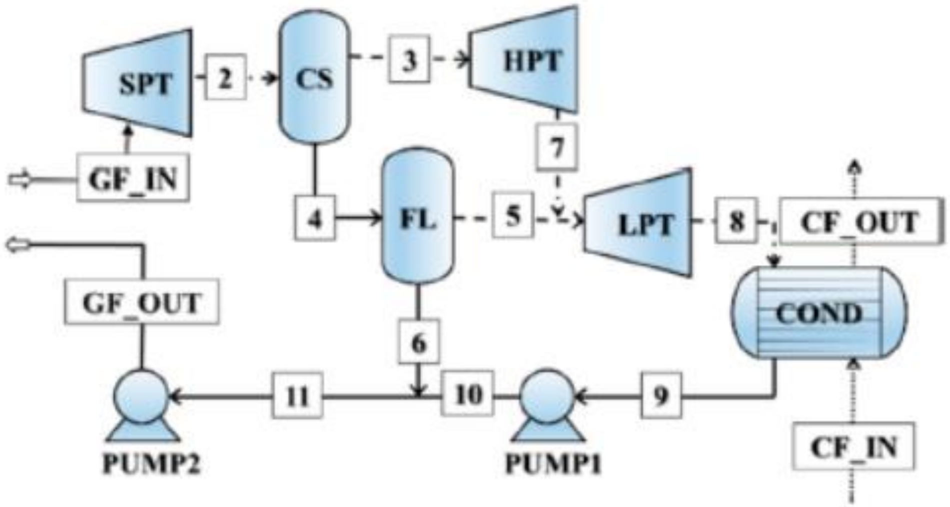
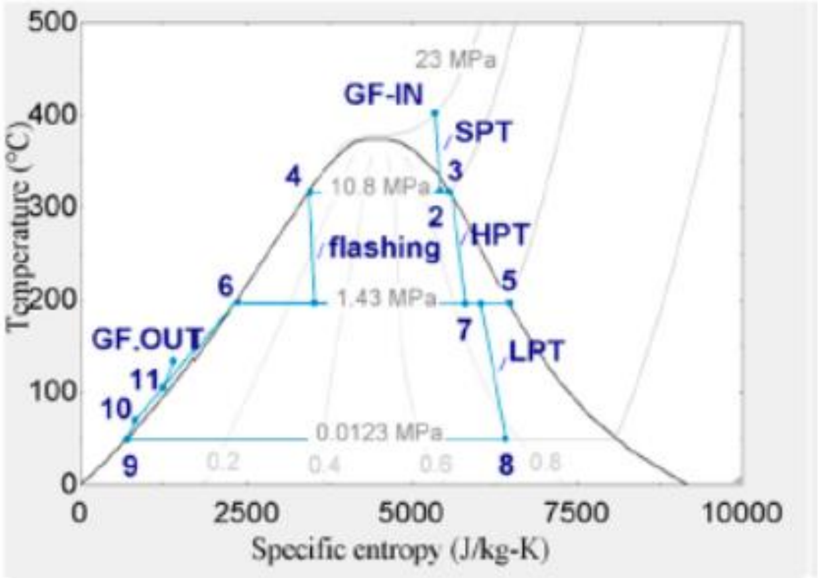
http://en.ennresearch.com/researchfield/deepgeothermal/scdrn/

Layout of Plant

Plant design will affect the turbine(s)

- Flow and steam characteristics from geothermal wells will inevitably fluctuate, but a reasonable range of capability is possible.
- Turbine stages are designed to maximize energy use for given available energy
- Review of steam constituents related to propagation at specific conditions is also of interest





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Design Targets

- Design of plant layout to maximize round trip efficiency
- Design of steam turbine flow path components for extended run time, minimized degradation
  - Bucket/Blade Erosion and Corrosion
  - Diaphragm Erosion and Corrosion
  - Sealing
  - Performance related design factors
    - Tip seals
    - Tight clearances

Bucket/Blade Erosion and Corrosion

- Areas of focus
  - Material and surface finish/coating
  - Interface between bucket/blade and disk
  - Bucket/blade's applied method of damping

Examples of Bucket Damping

Zigzag Pin

Damping Wire

(Continuous)

Rolled-in Wire

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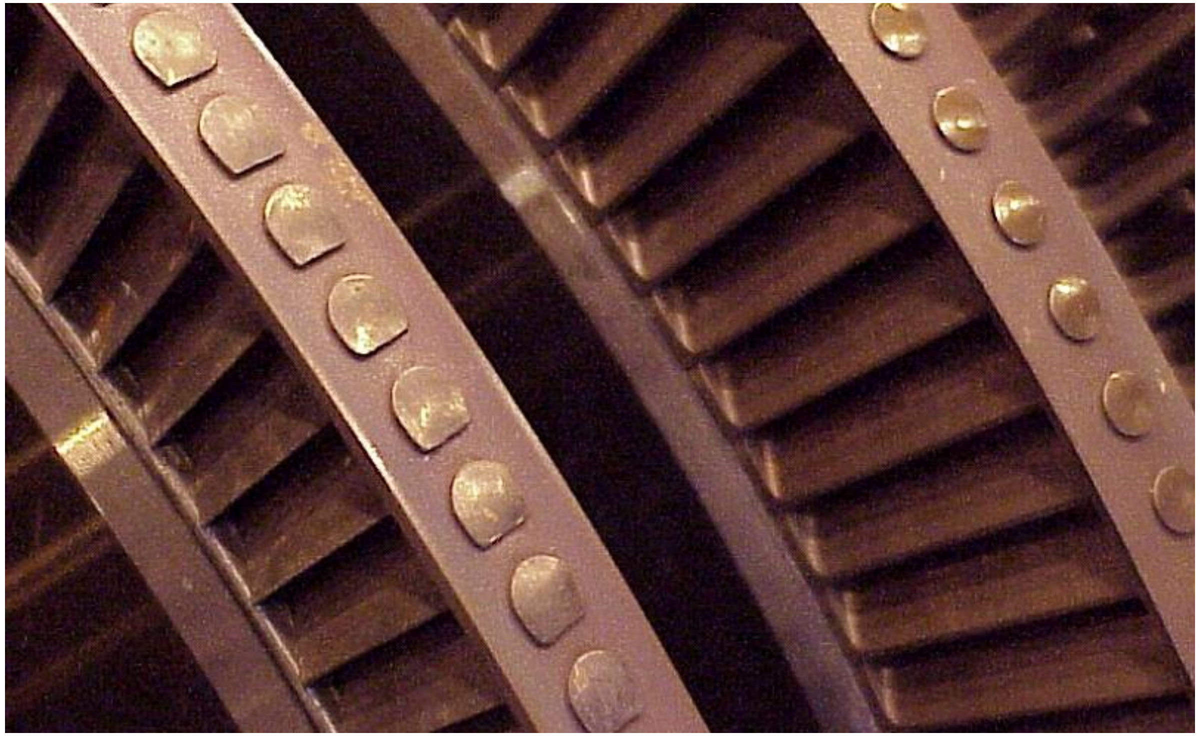
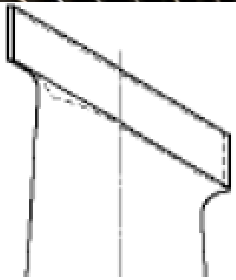
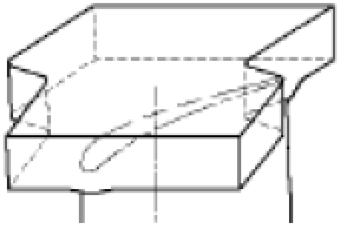
Examples of Bucket Damping

Peened Shroud



Z-Lock





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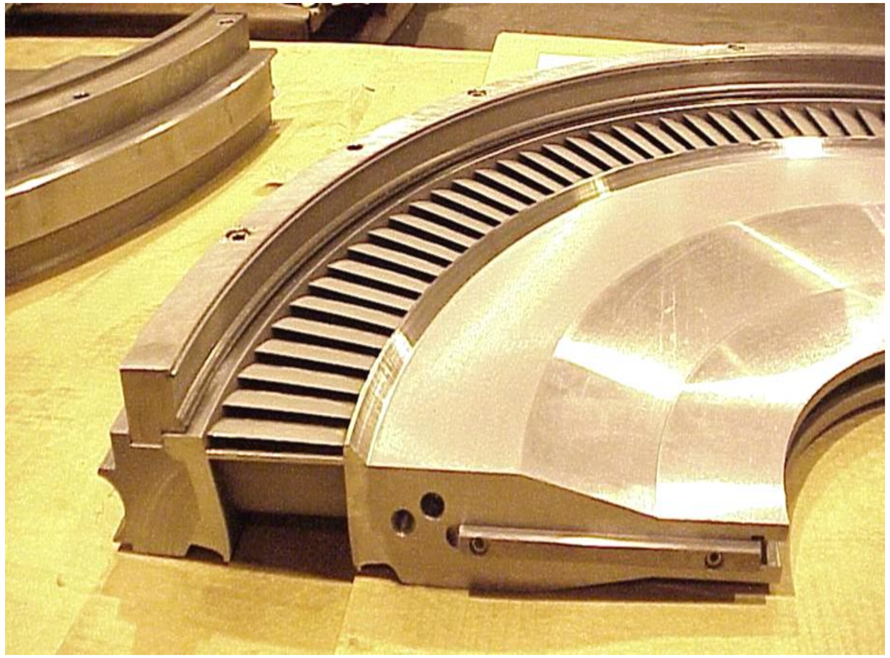
Diaphragm Erosion and Corrosion

- Stationary diaphragms also see erosion and corrosion effects
  - Similar in nature to rotating components
  - Diaphragm design impacts include moisture management (effective removal of moisture)



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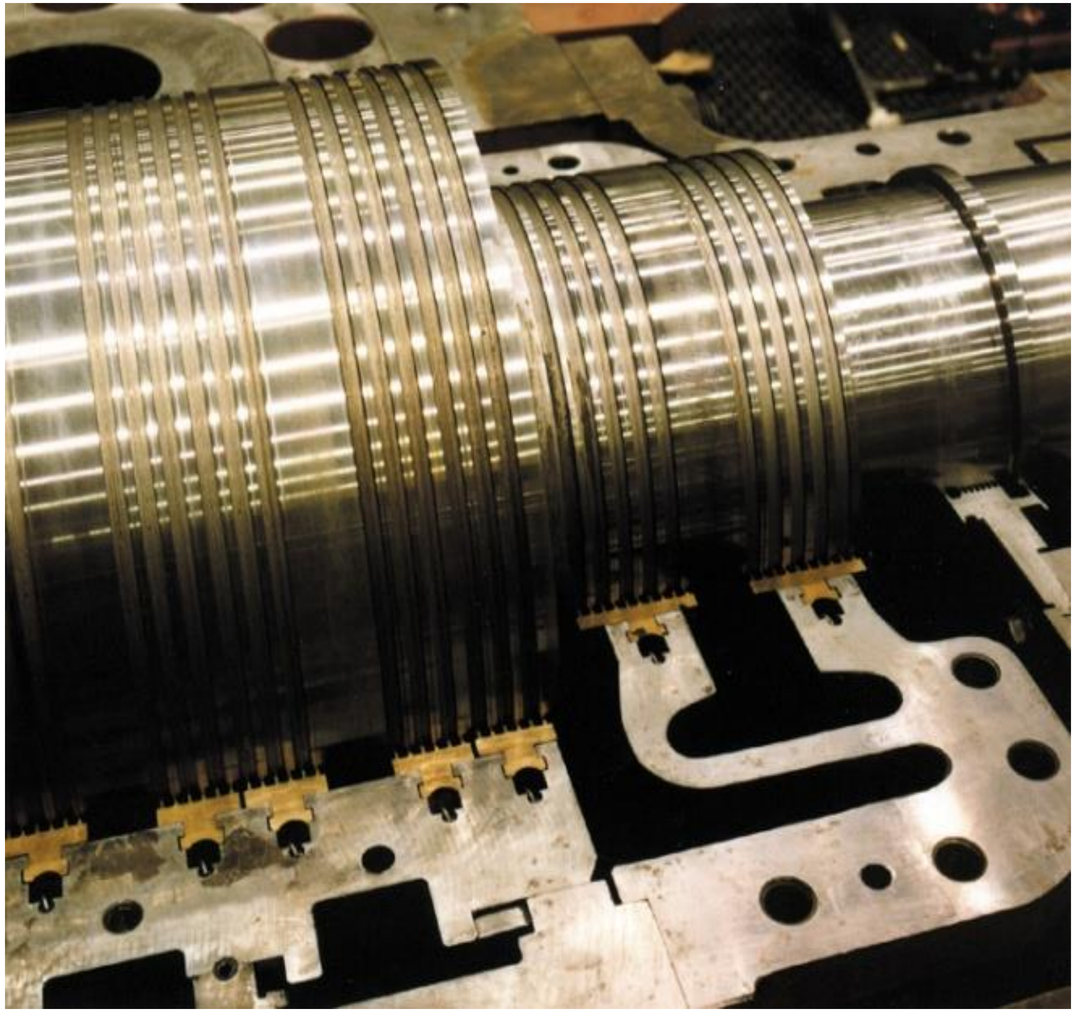
Sealing

- Areas of Focus
  - Clearances
    - Tighter Clearances means better performance, but possibly quicker failure when steam quality is poor
  - Seal Type
    - Some seal designs are more susceptible to corrosion or erosion related failure
    - Design preference toward continuous operation as reduced performance over plant shutdown



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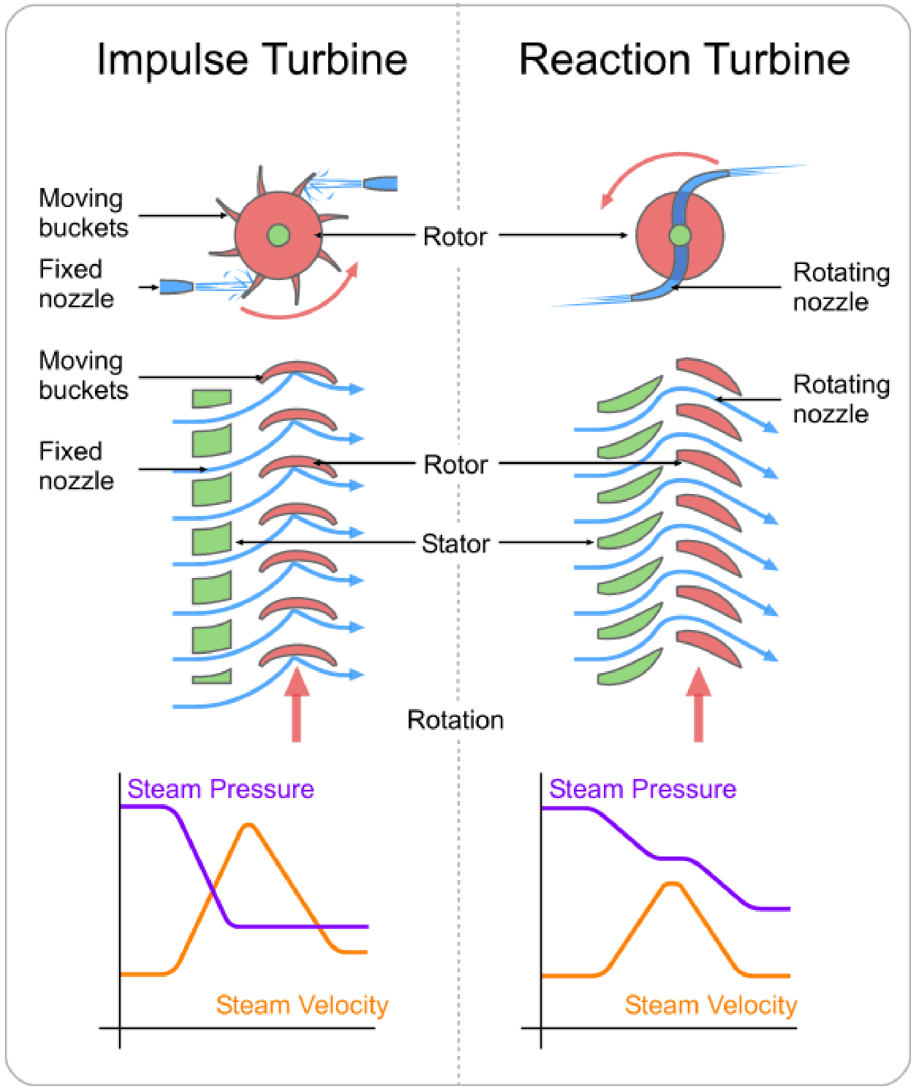
Impulse vs. Reaction Turbine Design

- Reaction stages rely on tight stage clearances
- Geothermal applications
- Balance of designing stages for reaction vs. impulse is a consideration



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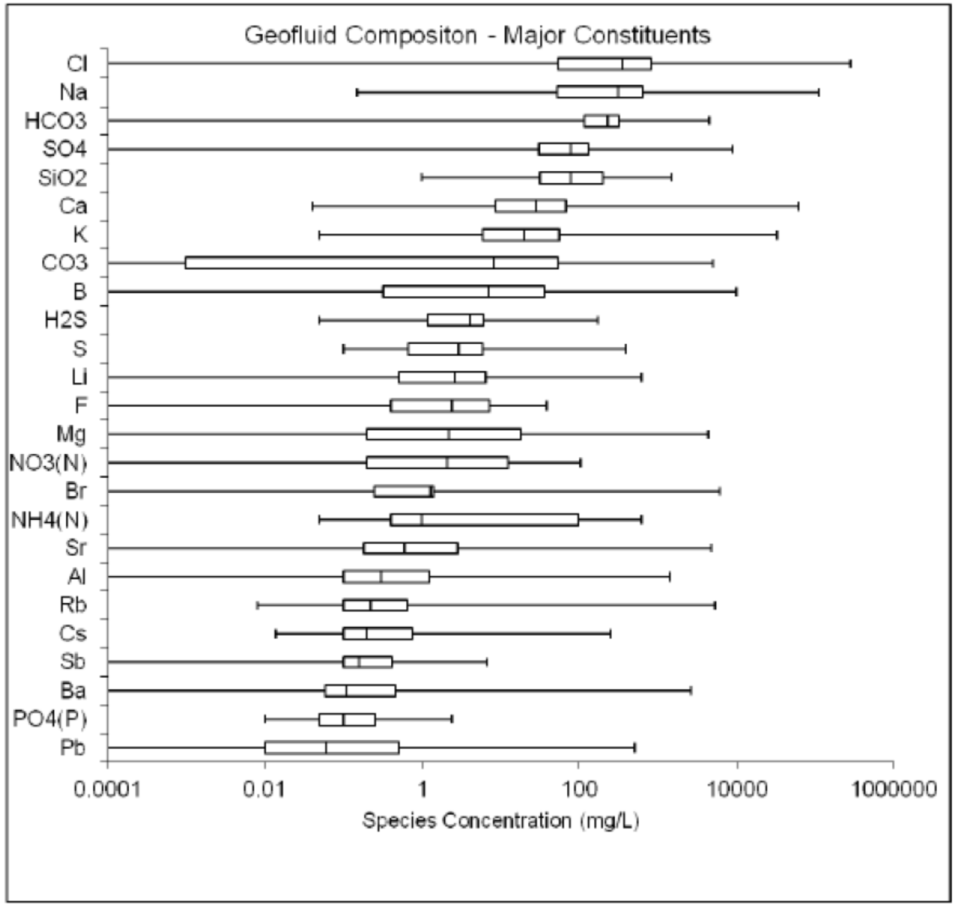
Methods of Mitigating Performance Loss

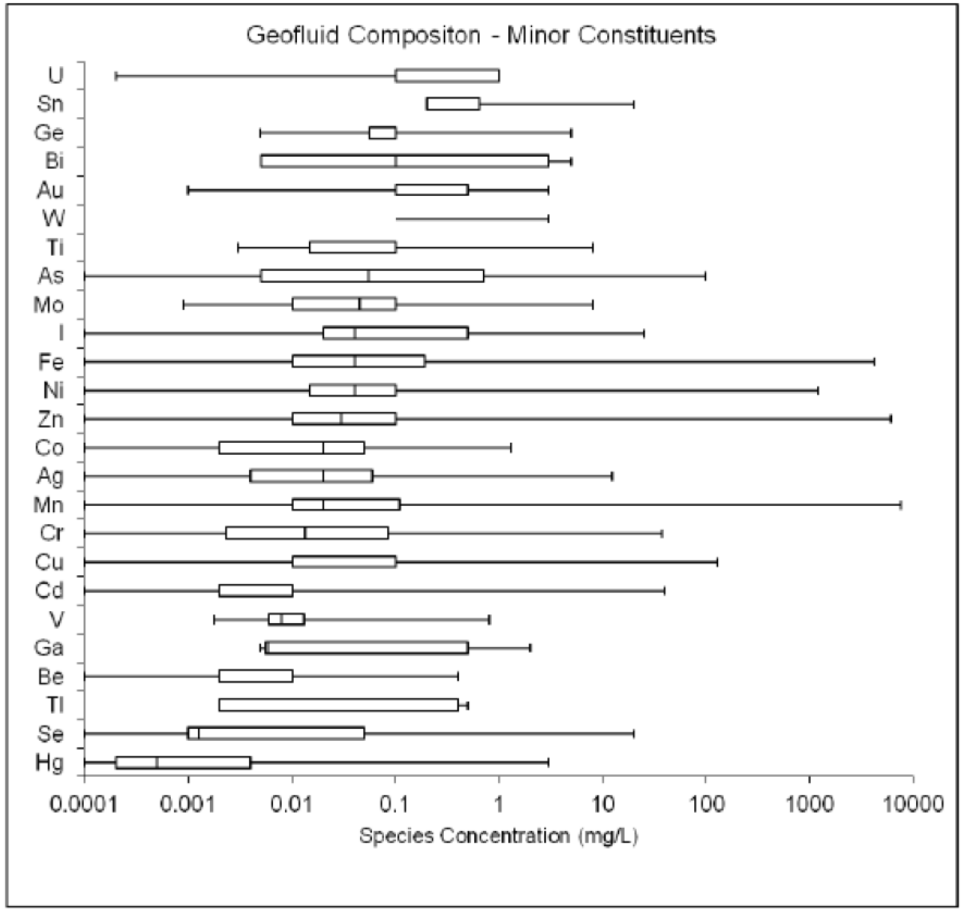
- Materials
  - Better strength
  - Lower bonding of corrosive elements
- Coatings
- Design out problems
  - Removal of spaces for deposit accumulation
  - Clearances in favor of mitigating particulates
- Routine maintenance with available flow path spares

Ti-N Coating

High Phosphorus Electroless Nickel Coating

Material Considerations for Geothermal Application





47 of 118 (40%) of the elements on the periodic table are listed as potential constituents with

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Steam Purity Requirements for Reliability

		CONTINUOUS	STARTUP
Conductivity - Micromhs/cm at 25°C			
	Drum	0.3	1.0
	Once through	0.2	0.5
SiO_2	(ppb, max.)	20	50
Fe	(ppb, max.)	20	50
Cu	(ppb, max.)	3	10
Na + K	(ppb, max.)		
	up to 800 psig	20	20
	801 to 1450 psig	10	10
	1451 to 2400 psig	5	5
	over 2400 psig	3	3
CL	(ppb, max.)	10	10-30

API 612 / NEMA SM-24

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DD IEC TS 61370:2002

Geothermal steam will not be come close to meeting these requirements

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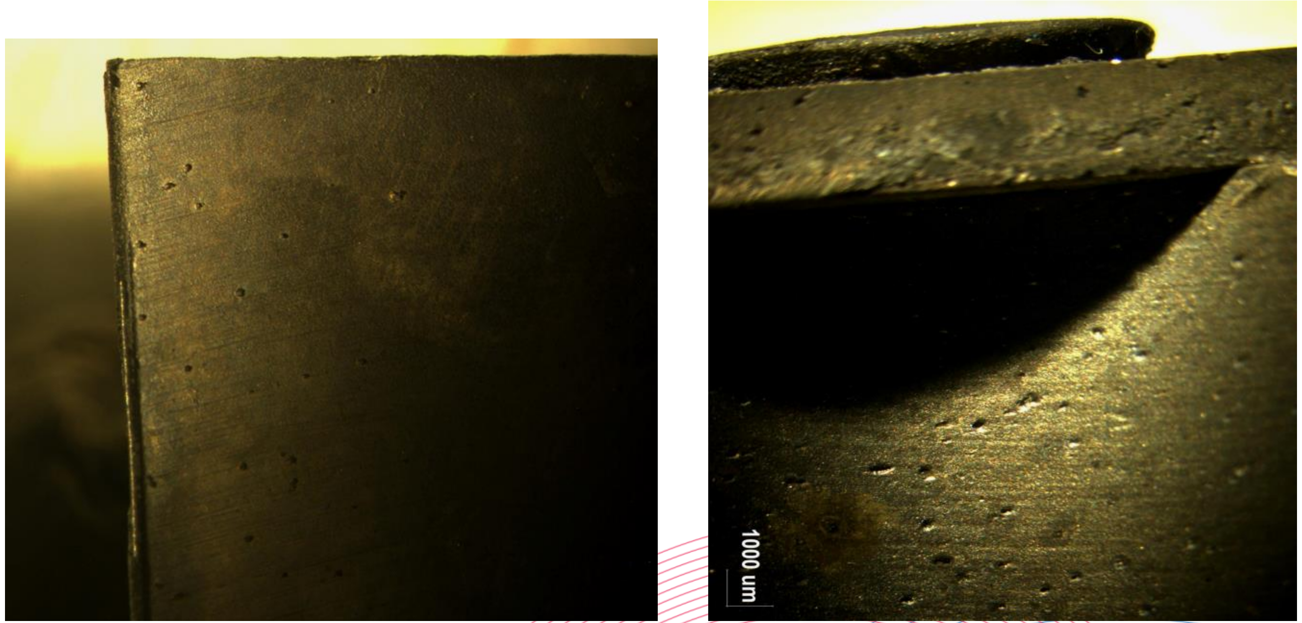
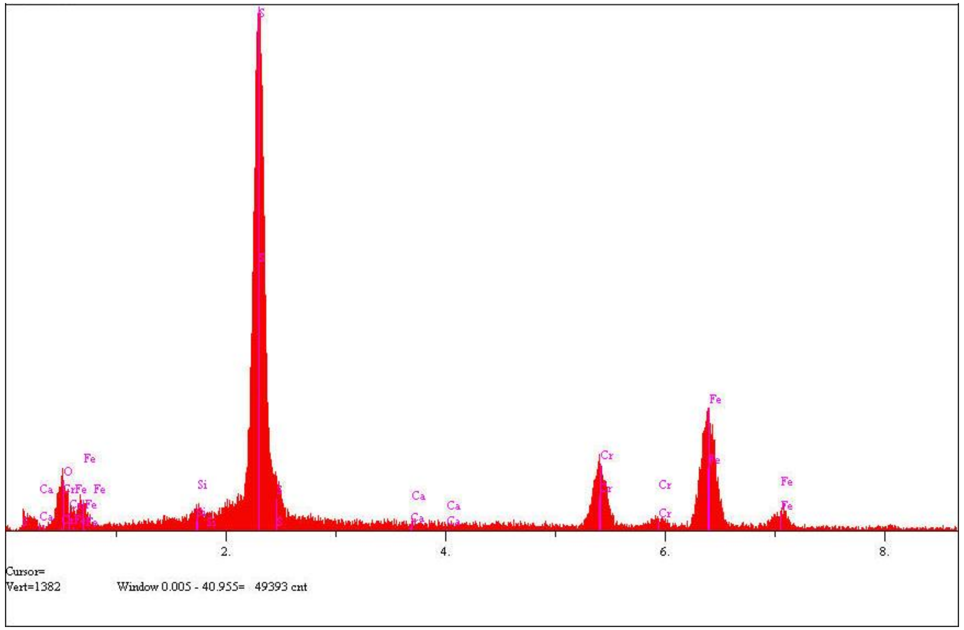
Blade Failures from Pitting Corrosion



Corrosion Pitting on surface of geothermal steam turbine blade

Blade failure from high cycle fatigue cracking



Extremely high levels of Sulfur found in corrosion pits through EDS analysis

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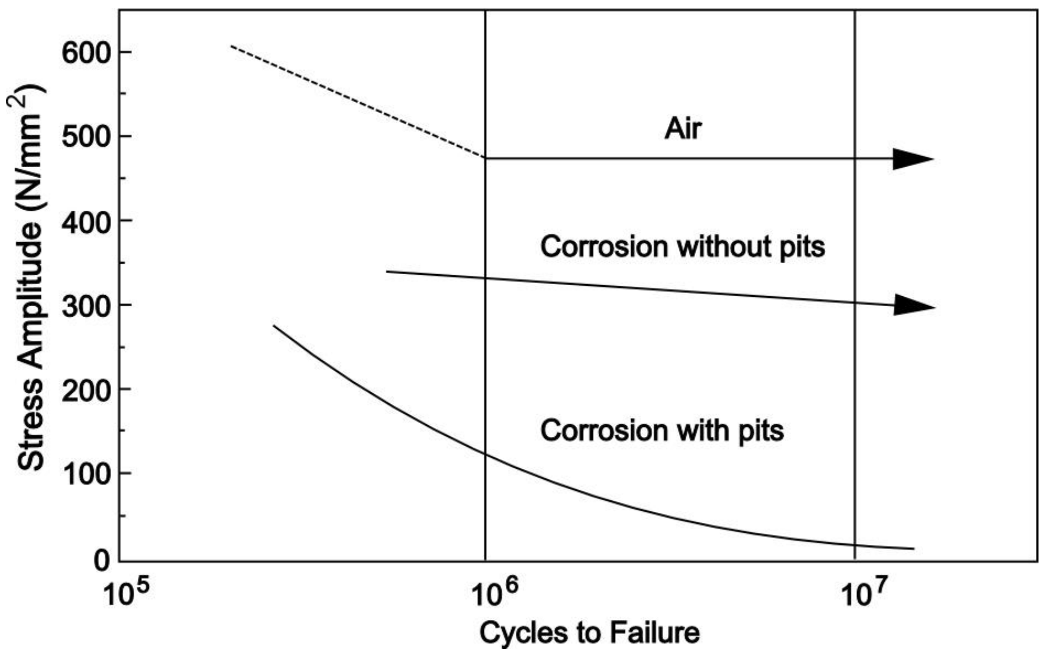
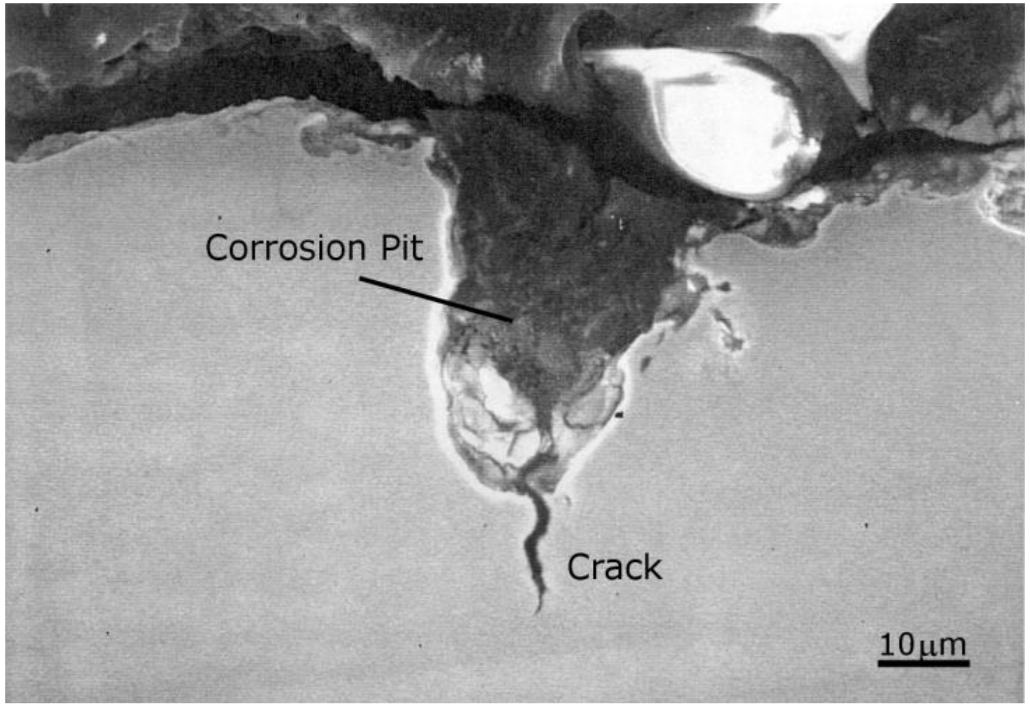
Pitting Corrosion and High Cycle Fatigue Cracking



Pitting corrosion can result in a 5x loss of fatigue endurance limit



Textbook image of a corrosion pit. Sharp cracking creates a localized stress riser that act as initation sites for fatigue cracks

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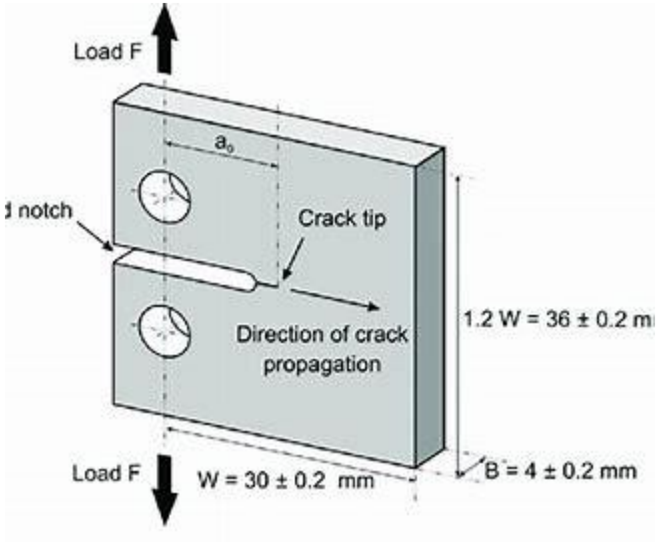
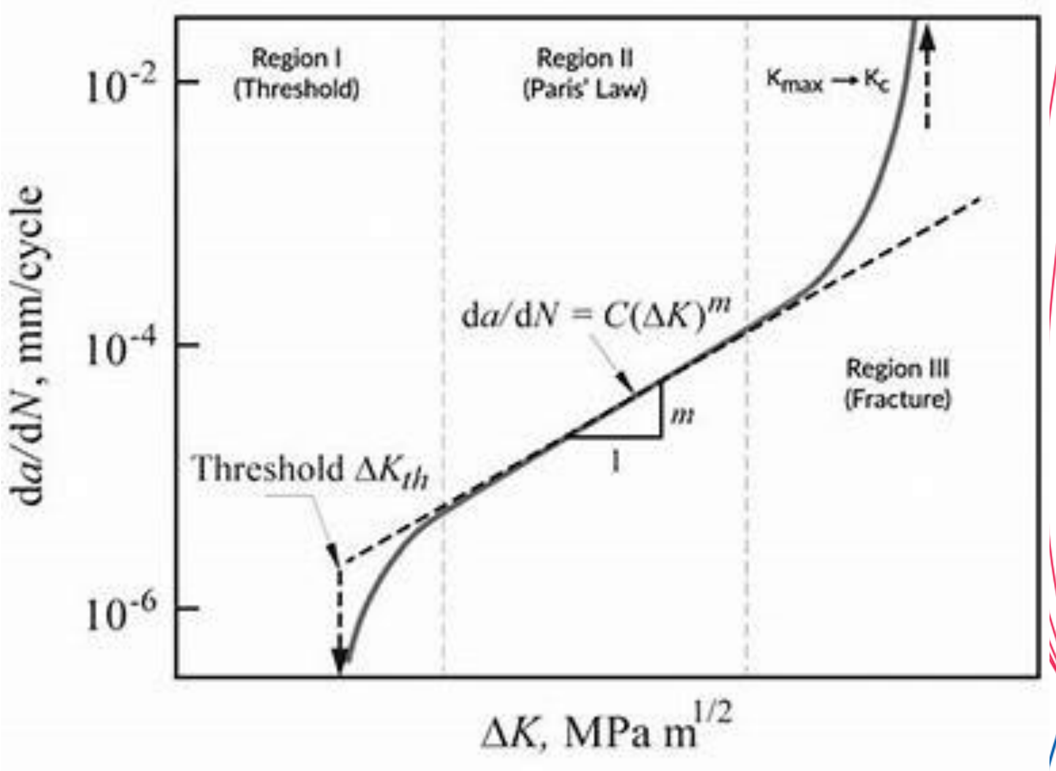
Fatigue Testing for Environmental Factors

ASTM E647 is Standard Method for Measurement of Fatigue Crack Growth Rates

- Used to determine crack growth rates, but also the threshold level for fatigue cracking





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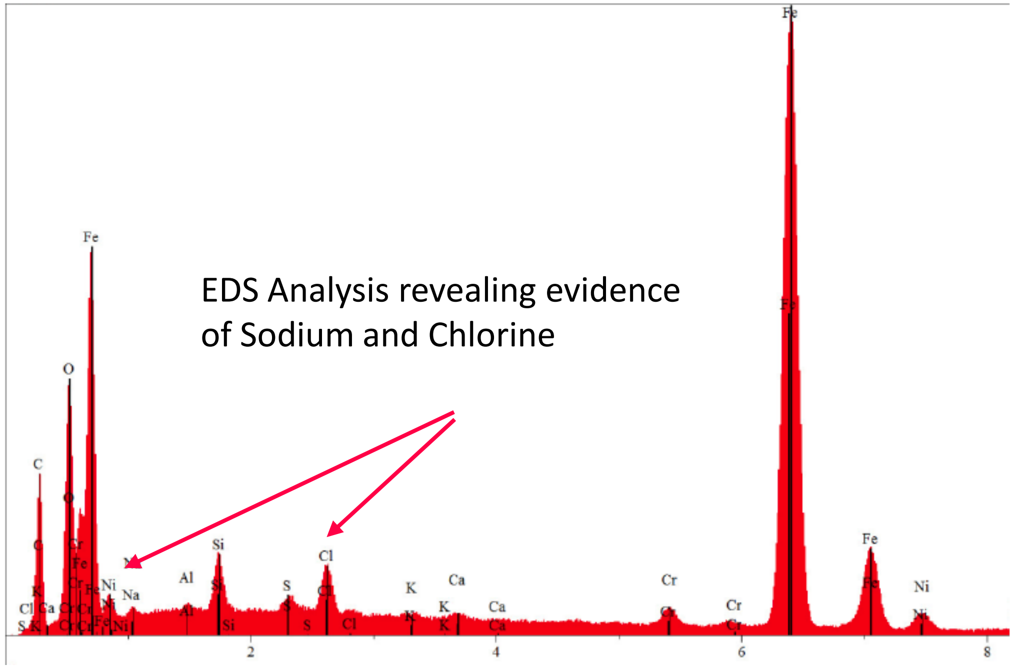
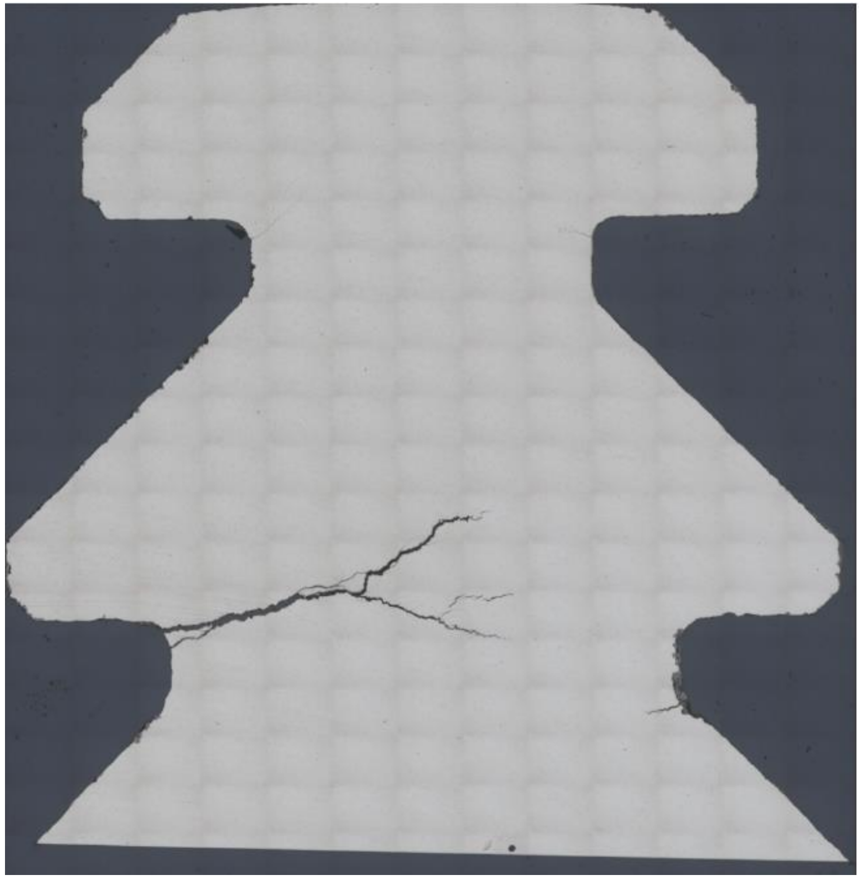
Stress Corrosion Cracking

Failed section of turbine disk root





Stress corrosion cracking on a steam turbine disk root

Stress Corrosion Cracking (K_{1SCC}) per ASTM F1624

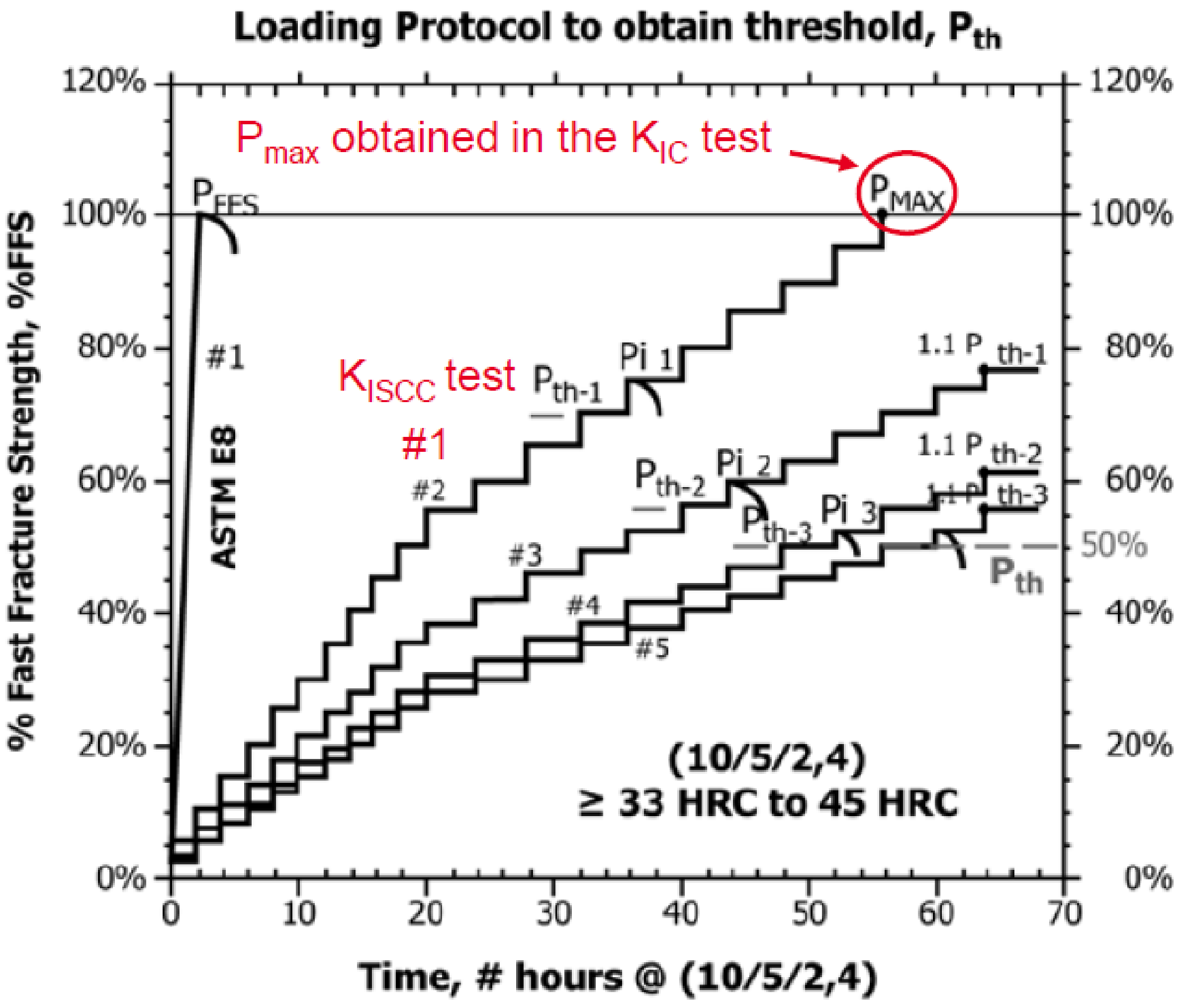
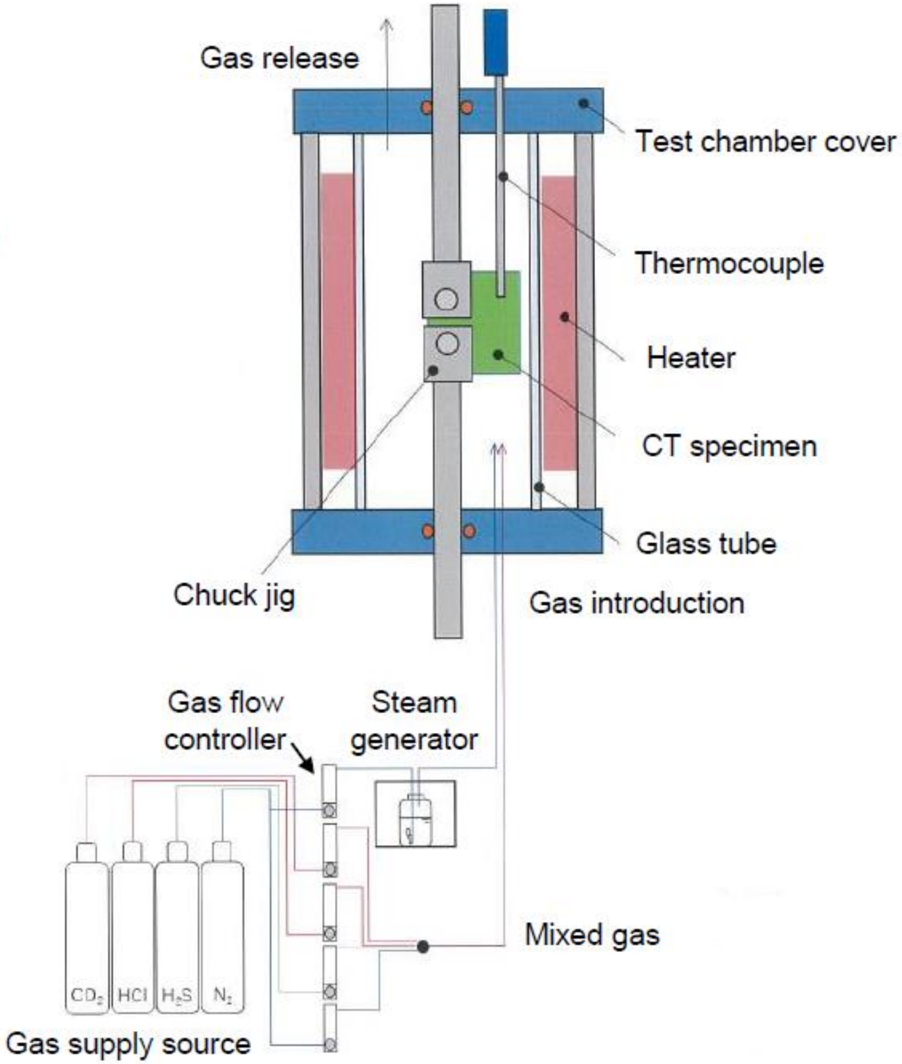


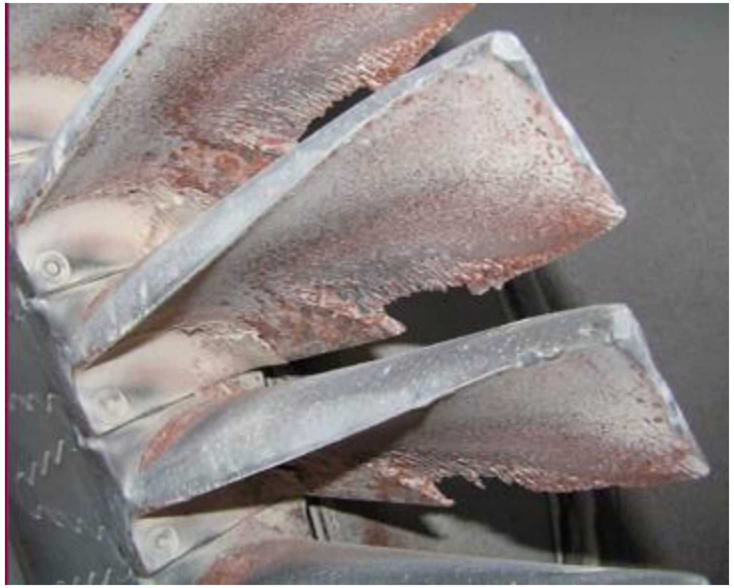
FIG. 3 Schematic of a (10/5/2,4) Step Loading Profile to Determine Threshold for the Hardness of Steel ≥ 33 HRC to 45 HRC

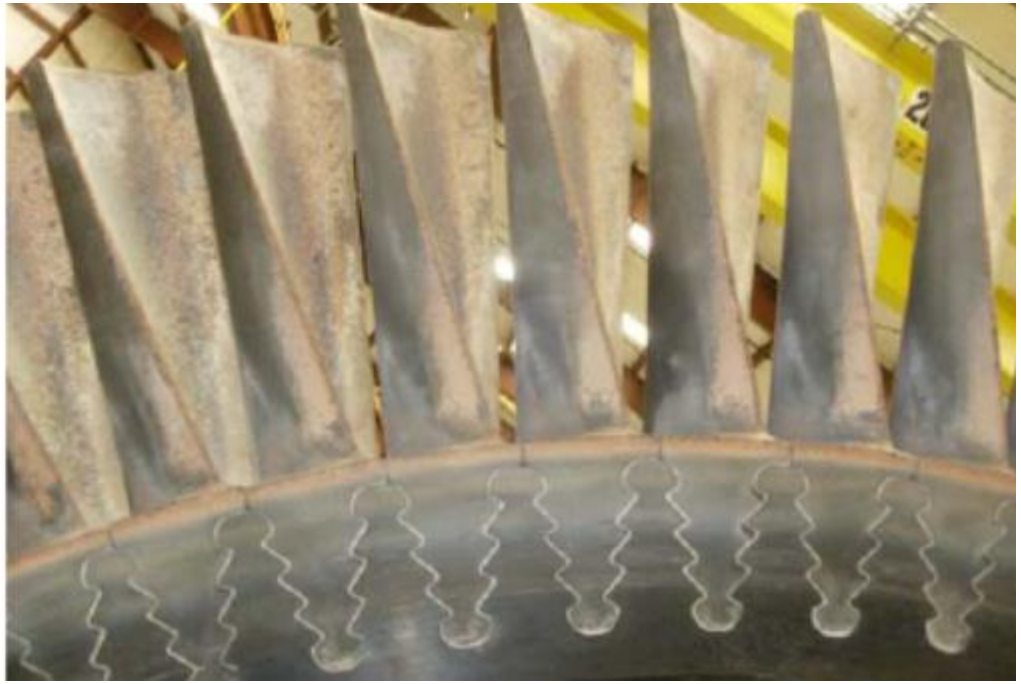


Schematic diagram of the K_{ISCC} test

Experience with Hot Gas Expanders

- Turbine operating in sulfidizing atomosphere, conditions are extremely corrosive
- Inlet temperatures up to 760°F
- Erosive particulate in gas stream (catalyst)
- Can still have high reliability with correct design features





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