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Steam Turbine Reoccurring Rubs, Troubleshooting and Corrective Action

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AIR PRODUCTS

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Biographies

- **Patrick J. Smith** is a Principle Engineering Associate - Machinery in the Operational Excellence Technical Team at Air Products & Chemicals. He is based in Allentown, PA. He has over 35 years of rotating machinery experience.
- **Brent M. Ziegler** is an Engineering Associate – Machinery in the Integrated Gases Americas Engineering Team. He is based in Allentown, PA. He has over 15 years of rotating machinery experience.

Abstract

Rubs in steam turbines can be especially difficult to diagnose because the vibration signature can manifest differently depending on the location, severity, rotordynamics, machine design and bear similarities to other common causes of elevated vibration. This case study presents the information gathering, engineering analyses and site testing performed to diagnose a 22 stage condensing steam turbine with an intermittent rub. On-stream troubleshooting allowed the vibration to be largely mitigated until the next maintenance opportunity and proper scope development to address stuck pedestal sliding surfaces distorting the casing and causing the rub.

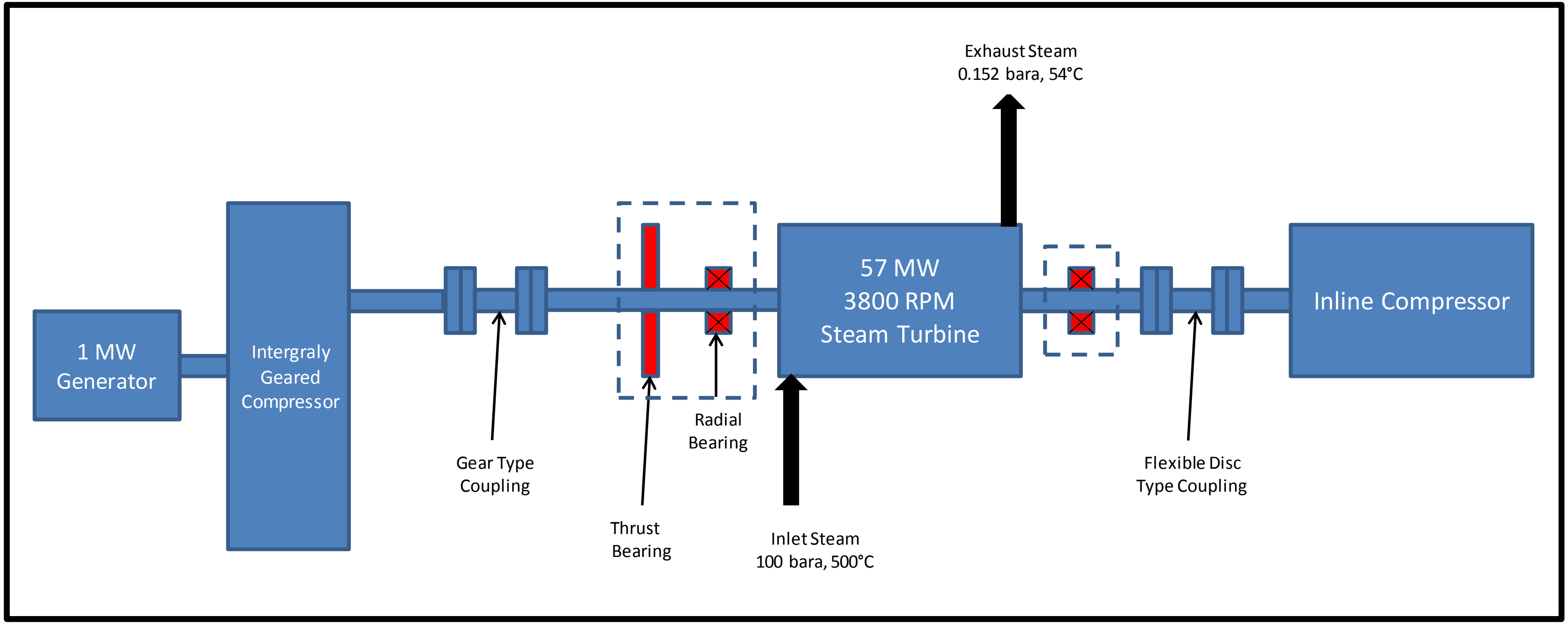
Plant / Machinery Train Overview

- 2800mTPD Air Separation Unit (ASU)
- 60 MW, 22 Stage Condensing Steam Turbine

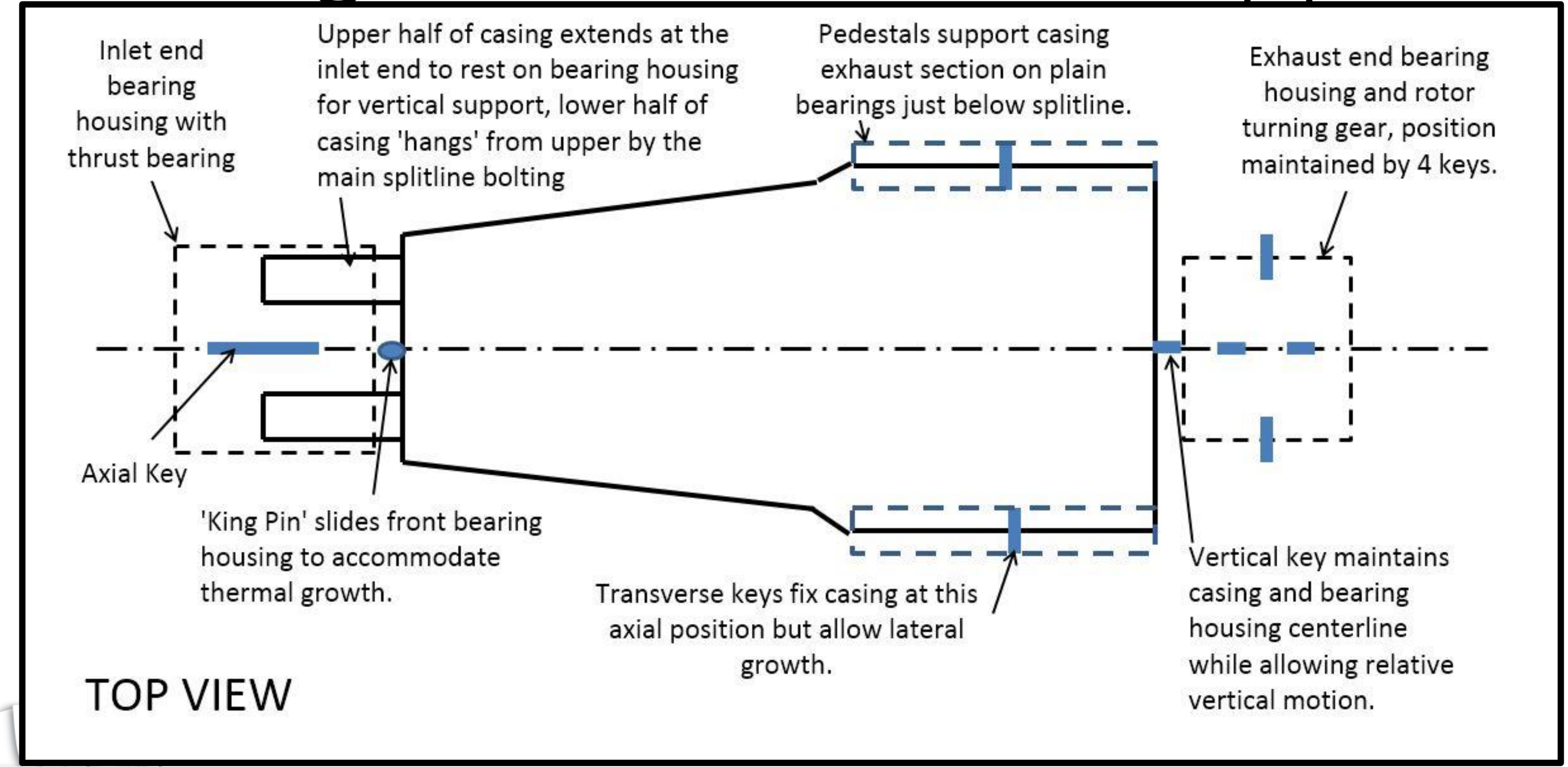
  Drives:

  - Main Air Compressor
  - Booster Air Compressor
  - Synchronous Generator
- Dedicated Pipeline Oxygen Customer

Train Arrangement



Arrangement of Turbine Supports



Inlet Bearing Housing

Exhaust End Bearing Housing

History

- Commissioned in 2003.
- Early 2009, emergency utilities lost after plant trip.
- Thermal bow temporarily locks up ST Rotor.
- Operations forcibly rotates the rotor rather than waiting for it to cool and straighten.

- *The bow was worked out, and normal operation resumed. There was a hit on the efficiency and gland steam, but stable vibration on the turbine.*

History – Initial Event

- Several months later, plant rates are increased.
- Turbine vibration intermittently increases by 2-300%
- Turbine/Plant load and speed changes unsuccessful in mitigating the vibrations.
- Turbine shutdown to inspect inlet and exhaust end bearings. Bearings acceptable, but reduction in rotor *total* axial float (w/ thrust bearings removed).
- Rotor repositioned slightly to provide some additional active side thrust clearance.

Key Observations

- Vibration increase is subysynchronous, 1x is stable.
- Significant exhaust end bearing pedestal response.
- Vibration excursions typical in the heat of the afternoon (>33C) and last several hours.
- Vibration excursions subside during infrequent rain.
- Sprinklers were rigged around the machine to create artificial rainstorms.
- Various sun shade configurations were tried.

Rotor Change

- In Summer 2010, the customer experienced an unrelated major equipment failure.
- The turbine scope was limited to a hastily planned rotor change during the available downtime.
- Considerable internal seal damage was discovered in the balance piston area and at both gland seals.
- All seals were reworked back to factory clearances.

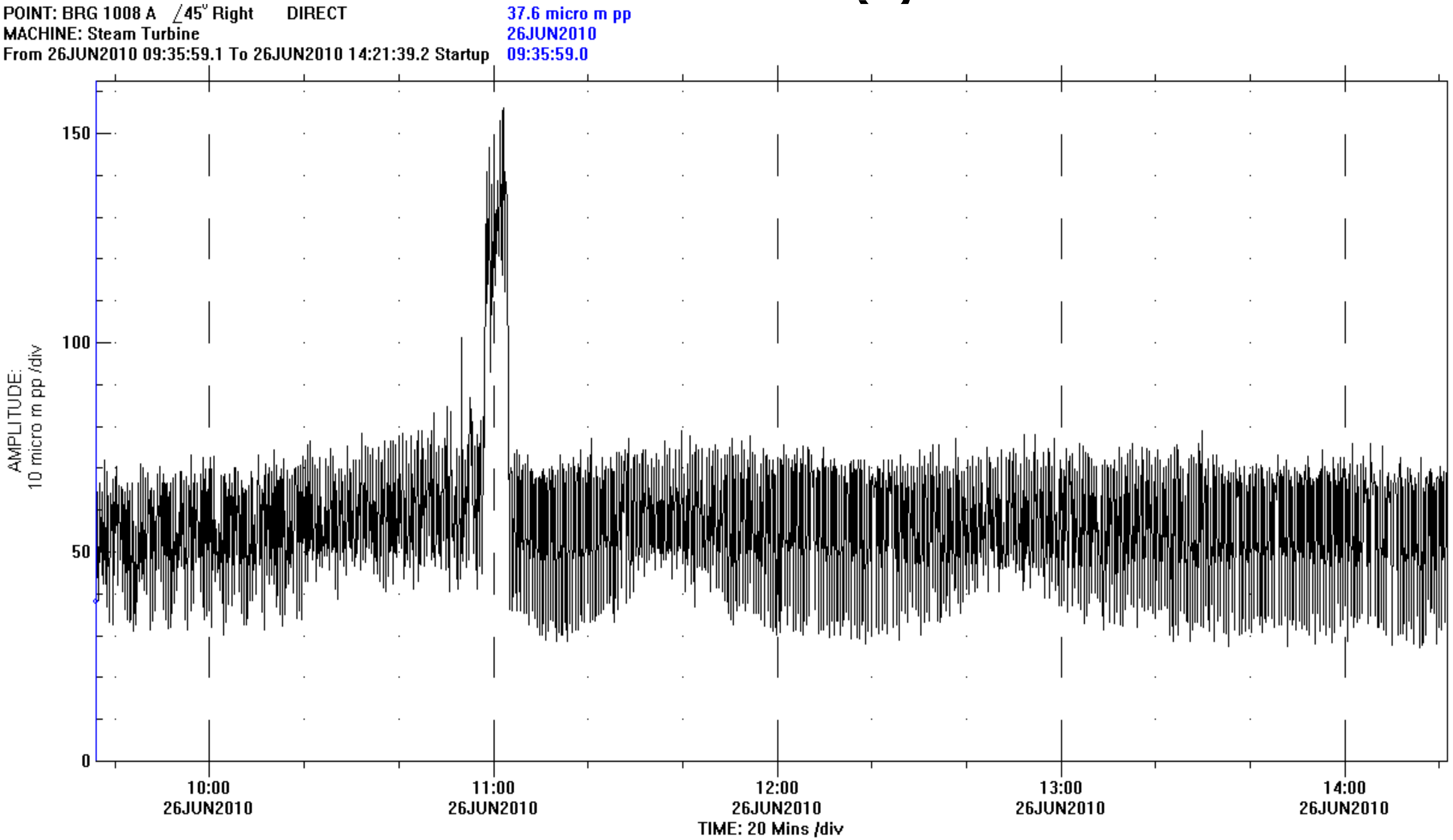
- *After plant restart, there was no change in the nature or frequency of vibration excursions.*

TPS

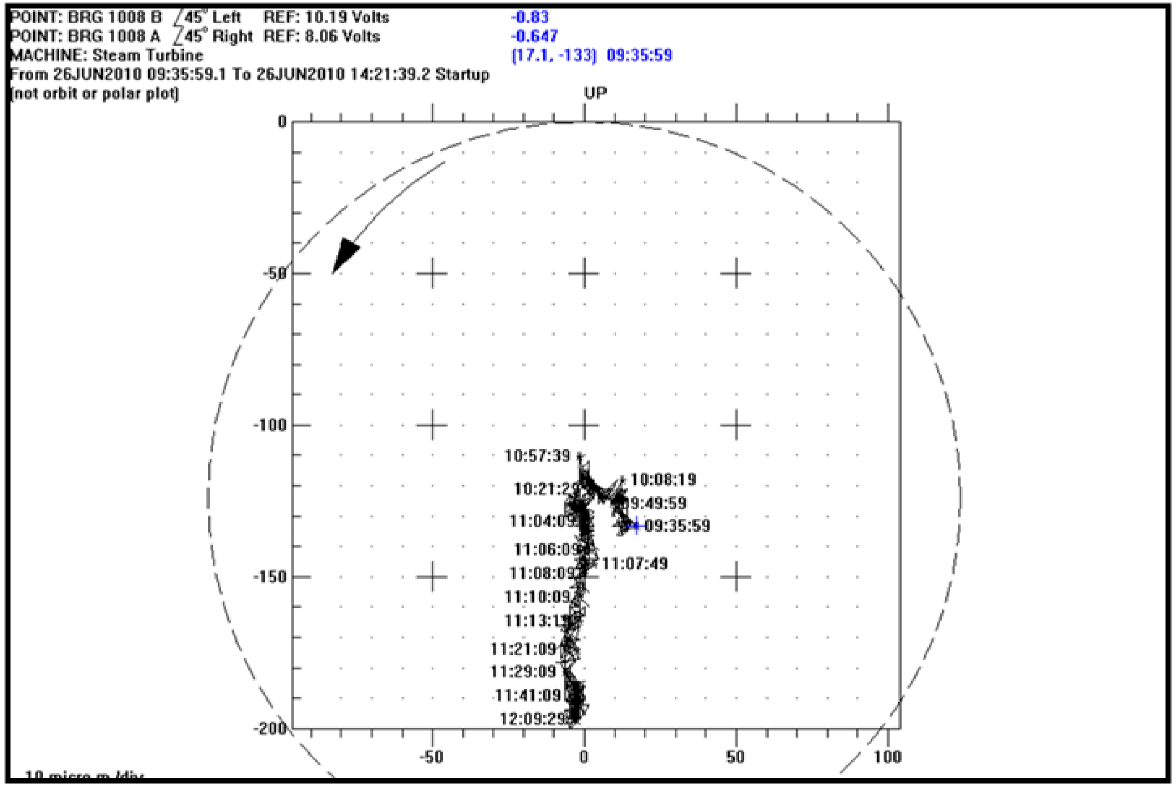
Investigation Post-Rotor Change

- How was the water spray mitigating the vibration?
- Focused evaporative cooling of only exhaust end casing support pedestals was proven effective to virtually eliminate the subsynchronous vibrations.
- Heat deflectors were added to shield the supports from the heat of the exhaust duct to the condenser.
- The exact excitation causing the subsynchronous vibrations remained elusive.

Trend from Water Mitigated Event



Shaft Centerline Plot for Mitigated Event

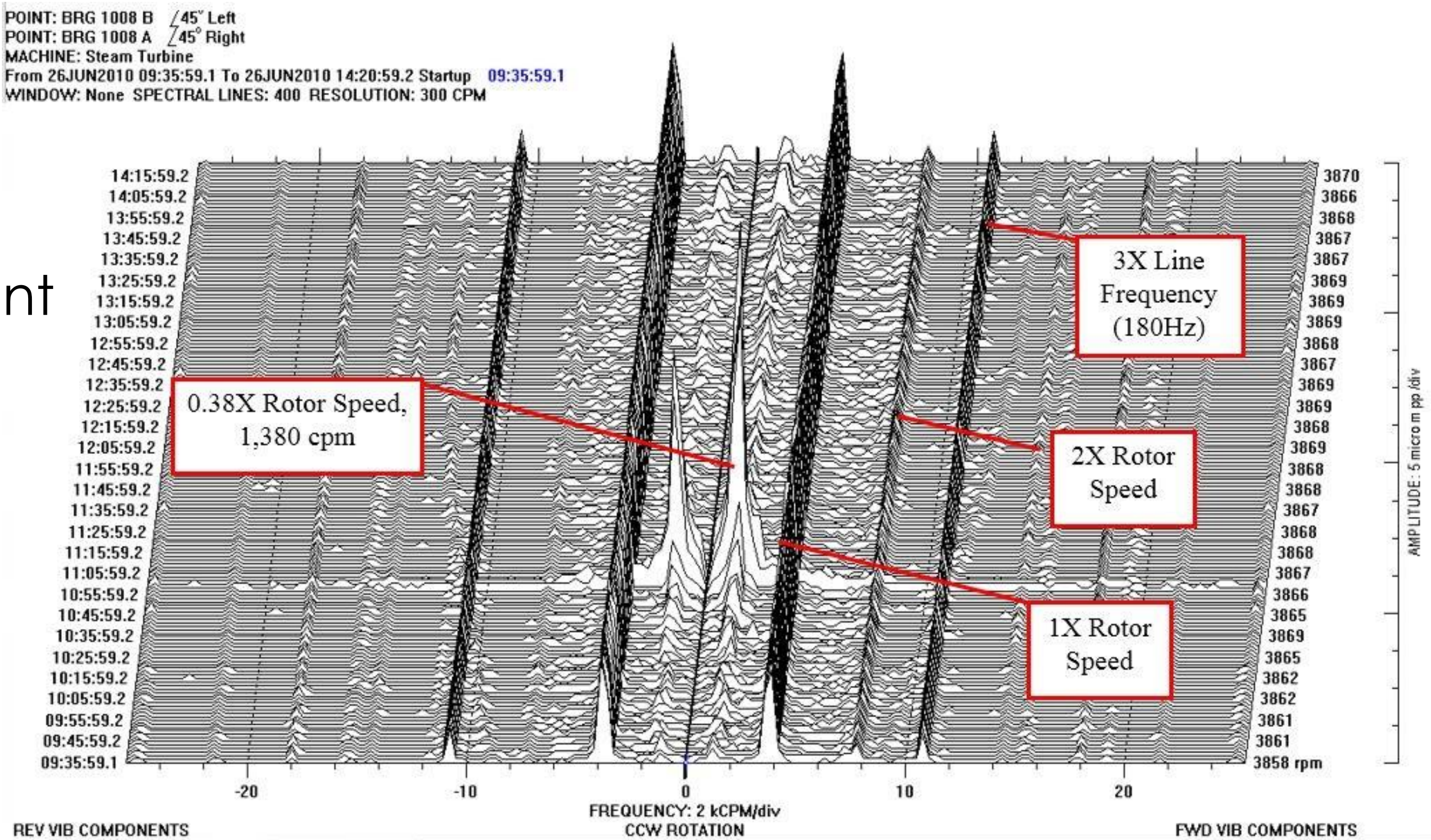


Full Spectrum Waterfall - Exhaust End

-Steady 1x Magnitude and Phase

- >2 mil displacement on bearing housing

-Mitigated with water cooling



VIBRATION SIGNATURE

- Quick onset and disappearance of the subyschronous vibration indicative of instability.
- Shaft centerline changes and Orbit flattens.
- .38x run speed, near rotor critical.
- Customer hired consultants deem the vibration behavior atypical of a rub, point to fluid instabilities in the seals or bearings.
- ***If it were a rub, how could the components not 'wear in' with so many hours in operation at elevated vibration levels?***

Collaboration with OEM

- OEM Rotordynamic analysis showed a very stable rotor bearing system.
- Ambient induced phenomenon with no correlation to load or steam conditions also puzzled vendor.
- OEM had experience cross tying the static bearing pockets of the jacking oil system on compressors with lemon bore bearings.
- Also tested running Jacking oil with Train at speed.
  - *Cross-tie enhanced stability but still required active cooling of pedestals and heat deflectors*

Jacking Oil Static Pocket Cross Tie

Rotordynamics

- Commissioned independent lateral analysis.
- Good agreement between field data, OEM and independent analysis.
- Further investigated sensitivities around oil temperature and viscosity, bearing clearances, preload (Lemon Bore), and pedestal stiffness.
- Investigated seal coefficients – deemed insignificant effect at design or elevated pressures.
- Studied feasibility of change to tilt pad bearings.

Data Gathering on Movement

- Casing was clearly binding or experiencing an external force, but where exactly?
- Attempts to further characterize this movement:
  - Faro Arm temporarily mounted for measurements
  - Lasers Position monitoring
  - Manual temperature logging and IR Camera Survey
  - Manual measurements with Dial indicators
  - Optical Survey
  - Breaking vacuum to test vertical deflection

Investigation Photos

Benchmarks in Casing

Portable CMM

Laser Measurement Equipment

Results of Investigation of motion

What Worked, What Did Not;

- Manual measurements effected by heat, require multiple indicators and personnel to monitor
- CMM was a bust, ambient temperatures too high.
- Lasers, showed real motion, but only at limited points, confirmed it was a complex 3D motion
- Temperature surveys did not pinpoint any localized excessive temperatures.

Planned Mitigation During 2012 TAR

- Full standard overhaul scope plus:
  - Clean and lubricate all keys and plain bearings
  - Significant concerns of potential ‘spring’ and not being able to reinstall if removed.
  - Kingpin in bind and damaged during removal, casing jumped.
    - *Was residual strain normal due to friction under front bearing housing, or was that in a bind?*

Mitigation During TAR, Continued

- Re-shimmed casing improving on factory internal alignment and weight distribution on supports.
- Repositioned inner casing and blade carriers within casing to improve concentricity.
- Opened up Exhaust end gland clearance, custom machined offset geometry.
- Lubricated and moved without removal some inaccessible keys.

Other Corrective Actions

- Inspections of condenser supports, baffles, internal components – no major findings
- Installed Roof over machine train
- Installed Gland Probes on exhaust end of casing
- Installed BN3500 and full time spectrum analyzer
- Installed traps on casing drains to prevent water spray on inner casing during trips
- Major rework of turbine insulation

Exhaust End Gland Rub

Conclusions

- Exhaust end gland rub caused subsynchronous vibrations
- Multiple support surfaces and keys stuck.
  - No means to re-lubricate plain bearing areas. (history says this is not necessary indoors)
  - Turbine should not have been installed on standard support frame outside/uncovered.
- Casing was found distorted, there was not even weight distribution on supports. Difficult to assign cause between shop build, field install, and or some distortion in operation.
- Casing still moves slightly unevenly to one side during warmup. All external forces or support binding has not been fully resolved, but has had a 'clean run' since 2012.