44TH TURBOMACHINERY & 31ST PUMP SYMPOSIA
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GEORGE R. BROWN CONVENTION CENTER

FCCU PRT Compressor Blade Failure Case Study

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AUTHOR BIOGRAPHIES

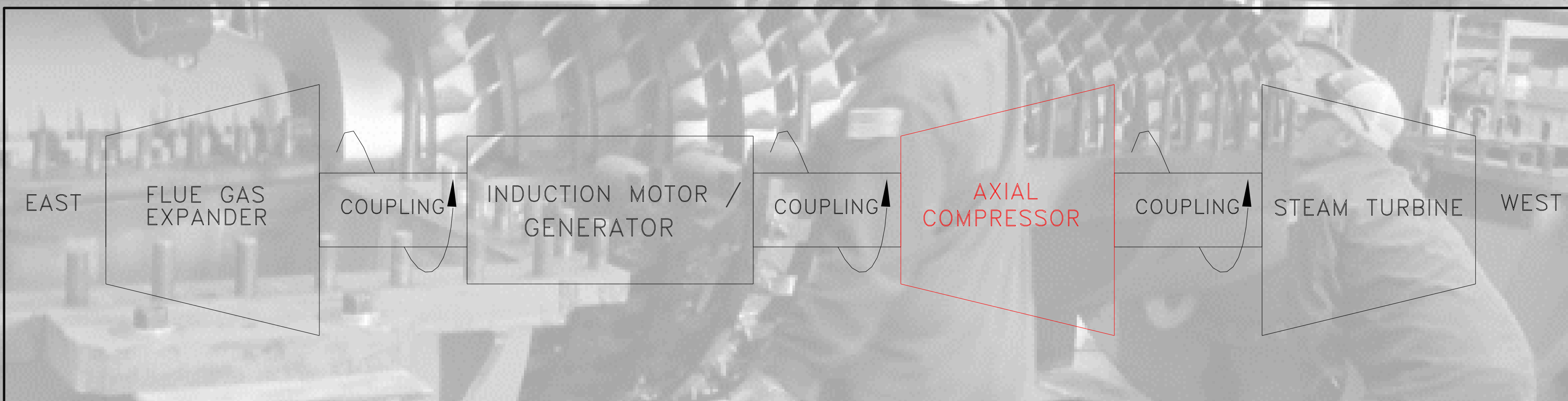
- **Austin Anderson**, Rotating Equipment Reliability Engineer, 8 years maintenance/reliability of rotating and fixed equipment; Sherwin Alumina, CITGO Petroleum.

- **Chris Sykora**, Sr. Structural Analyst, 8 years design & structural analysis of rotating turbomachinery & afterburner/exhaust systems; GE Aviation & Rotating Machinery Services, Inc.

- **Tony Rubino**, Director of Compressor & Expander Engineering, 32 years design, manufacturing & troubleshooting turbomachinery; Pratt & Whitney, GE, CONMEC, Rotating Machinery Services, Inc.

HISTORY

- Axial compressor in Fluid Catalytic Cracking Unit service; constant speed operation w/ variable stator vanes for flow control.



- Entire flow path replaced at turnaround; utilized all available spare parts.

HISTORY (cont'd)

- 2 months after turnaround, unexplained 2% step reduction in flow capacity with negligible increase in rotor vibration; small increase in inlet pressure and discharge temperature
- Closing and reopening variable vanes did not restore flow.
- Blockage from filter house in inlet of compressor estimated to be cause of flow loss.

HISTORY (cont'd)

- 25 months after turnaround, 6X increase (to 8+ mils) in peak rotor vibration (70% of bearing clearance).
- Vibration primarily 1X running speed.
- Step reduction of flow 3%.
- Blade failure estimated as cause of elevated vibration.

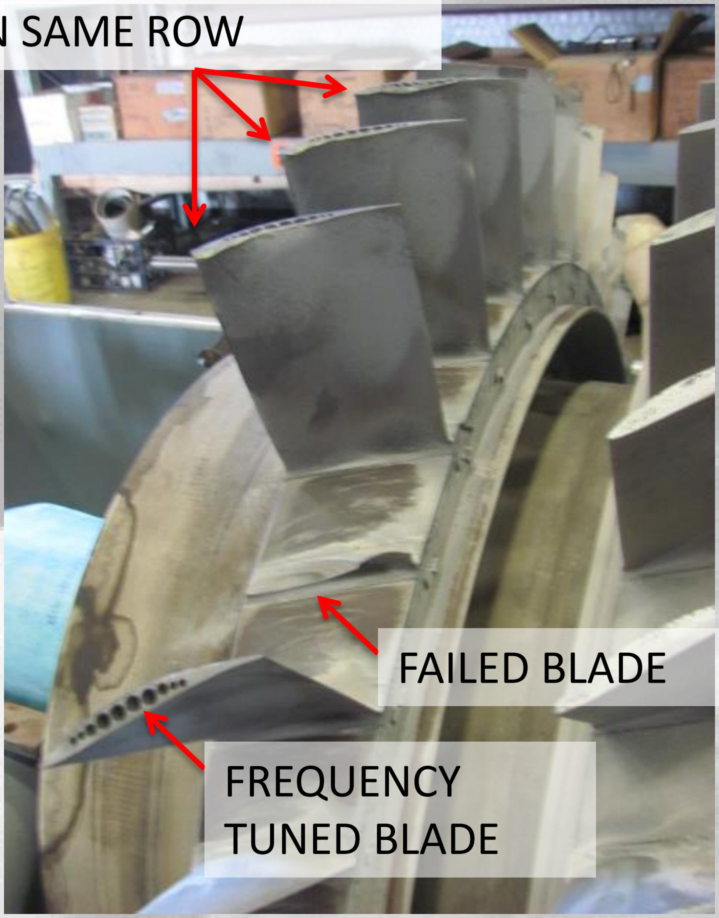
HISTORY (cont'd)

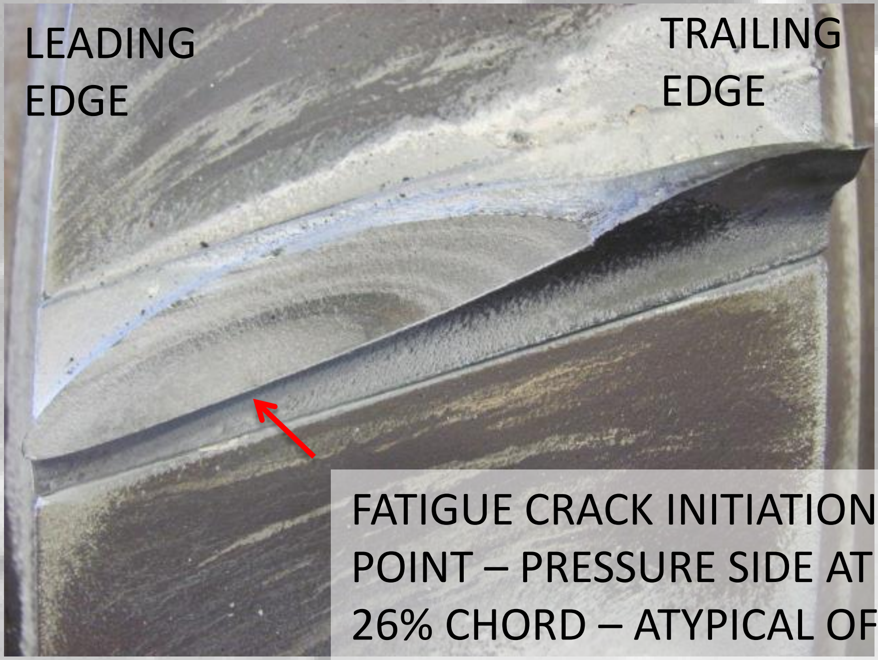
- Recommendation made to shutdown compressor to minimize consequential damage
  - Refurbished rotor was only flow path component available as a spare.
- Compressor was shutdown for inspection and repair.

OBSERVATIONS - Disassembly

- One first stage blade separated near blade attachment at fillet runout onto airfoil.
- Only the failed blade had a fatigue indication.
- Trailing edges of all Inlet Guide Vanes (upstream of 1^{st} stage blade) severely damaged.
- Other downstream airfoils had minor, sporadic impact damage from contact with failed blade.
- Foreign material found in compressor.
- Tip rub noted on casing above first stage blade.

OBSERVATIONS (cont'd)





OBSERVATIONS (cont'd)

REMOVED IGV's WITH BENT TRAILING EDGES FROM CONTACT WITH "BATTED" FAILED BLADE

SEPARATED BLADE COATING REDEPOSITED ON CASING SURFACE

SMEARED MATERIAL FROM TIP RUB

RUB HEAVIEST DEPOSIT SAMPLE LOCATION

IGV'S REMOVED

OBSERVATIONS (cont'd)

EXPANDED METAL AND SCREENS FOUND MISSING - INGESTED BY COMPRESSOR

DEBRIS ON FLOOR OF FILTER HOUSE

INVESTIGATION APPROACH

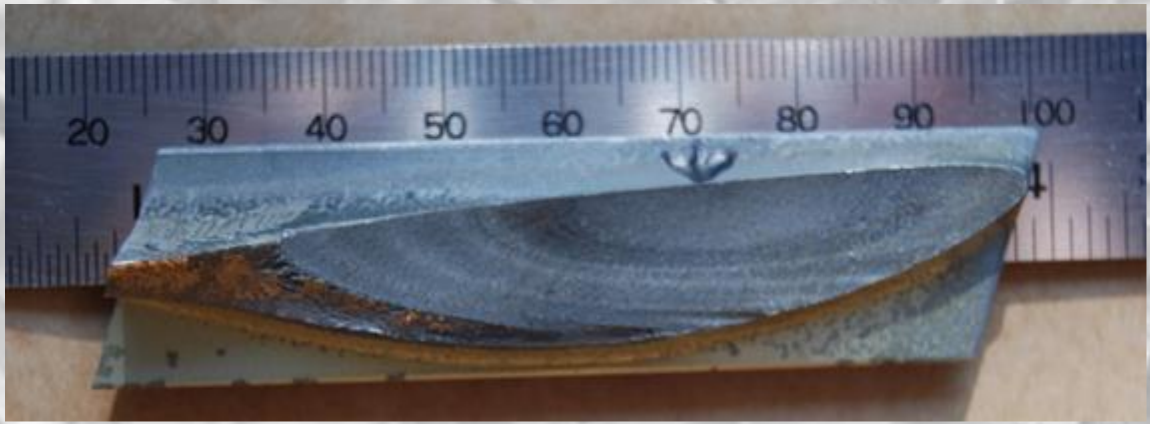
- Verify blade design suitable for application.
- Verify blade manufacturing executed per design intent.
- Identify operational anomalies that may have contributed to blade failure.

ANALYSIS RESULTS - Design

- Blade design suitable for purpose based on structural analysis and operating history
  - previous blades operated for 13 years
  - previous blades retired at overhaul.
- Blade design has adequate frequency margin.
  - satisfactory Campbell Diagram
  - frequency response verified by impact testing
  - all remaining 1st stage blades frequency tested to verify consistency of manufacturing.

ANALYSIS RESULTS - Metallurgy

- Blade failure initiated due to high cycle fatigue.



- Blade microstructure and mechanical properties within typical values; no manufacturing anomalies.

ANALYSIS RESULTS - Metallurgy

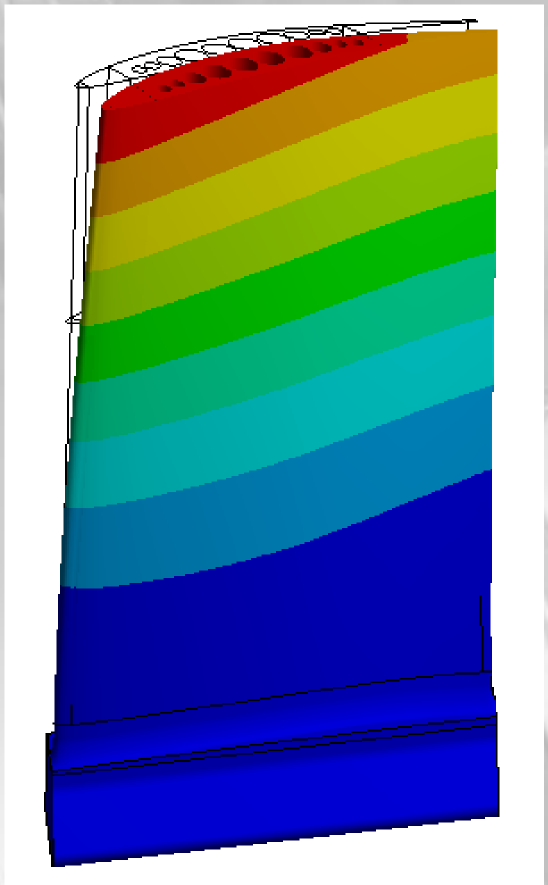
- Material found adhered to adjacent blade tips consistent with galvanized steel screen.
- Tip deposit removed from casing:
  - One sample was 0.03” (0.8mm) thick consisting of approximately 42 unique layers
  - 87% Fe, 12% Cr, & 1% Si
  - Other samples contained also Al & Zn
- Rub material deposited on casing matched chemistry of inlet filter housing components.

ANALYSIS RESULTS - Operation

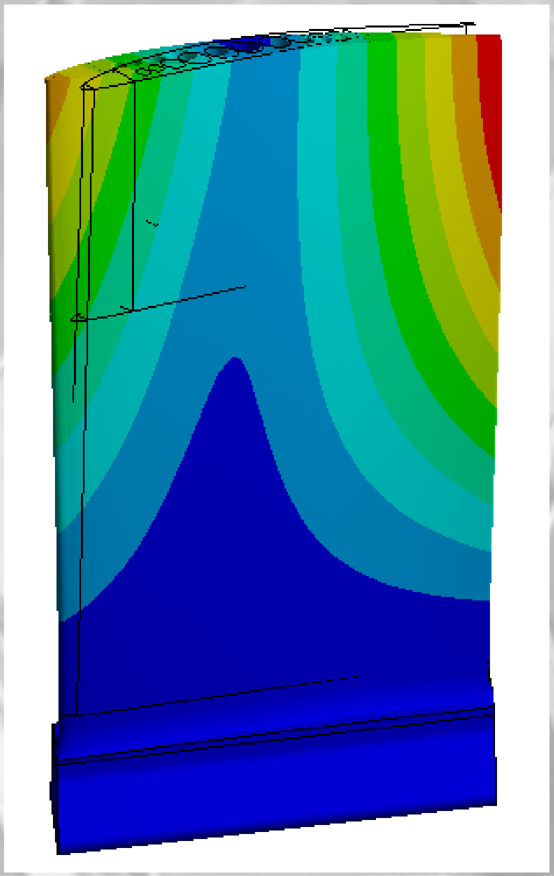
- Train operates at constant speed well away from stall or choke regions.
- Location of fatigue initiation site **<u>inconsistent</u>** with peak stress areas of first three vibration modes.
- Location of fatigue initiation site **<u>consistent</u>** with observed tip rub loading and forced excitation of first mode deflection.

ANALYSIS RESULTS - Operation

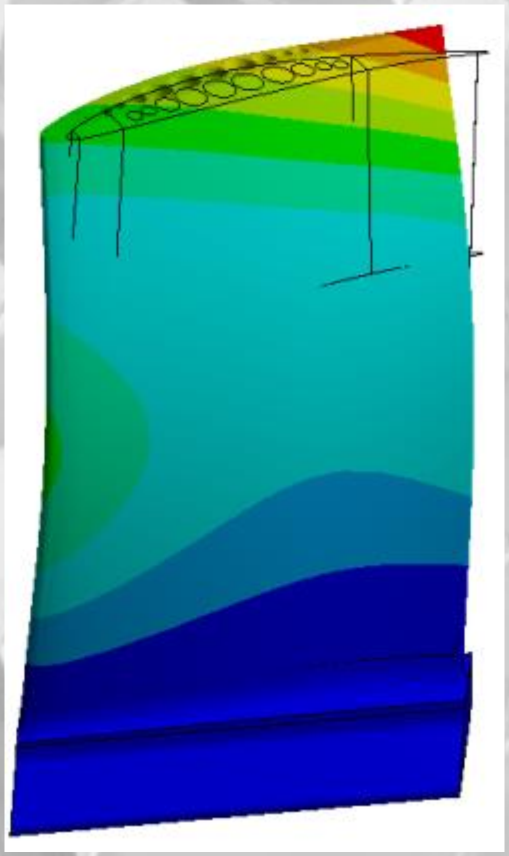
- Stage 1 Blade Mode Shapes



Mode 1 – 1st Flex Bending



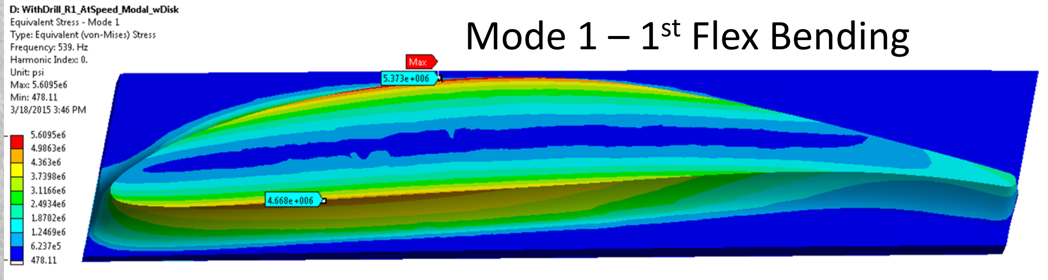
Mode 2 – 1st Torsional

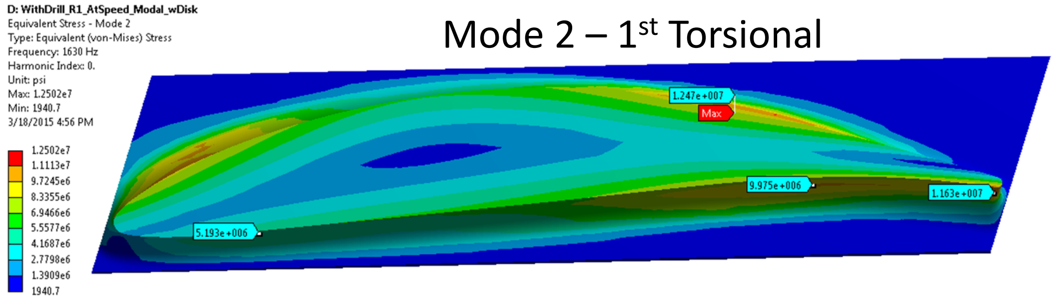


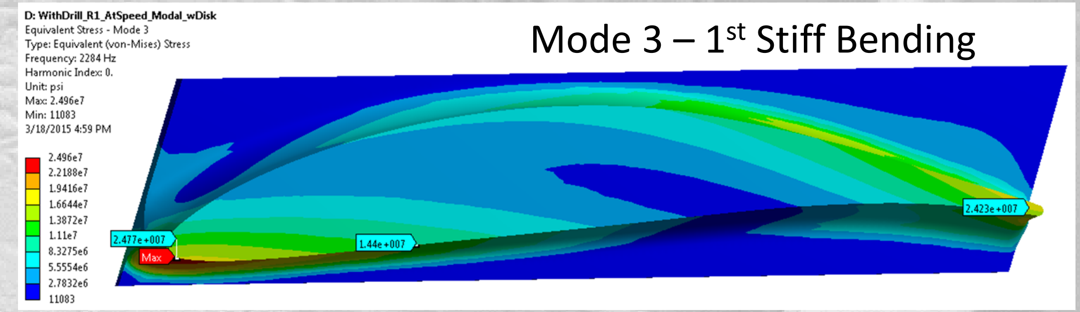
Mode 3 – 1st Stiff Bending

ANALYSIS RESULTS - Operation

- Stage 1 Blade Modal Peak Stresses

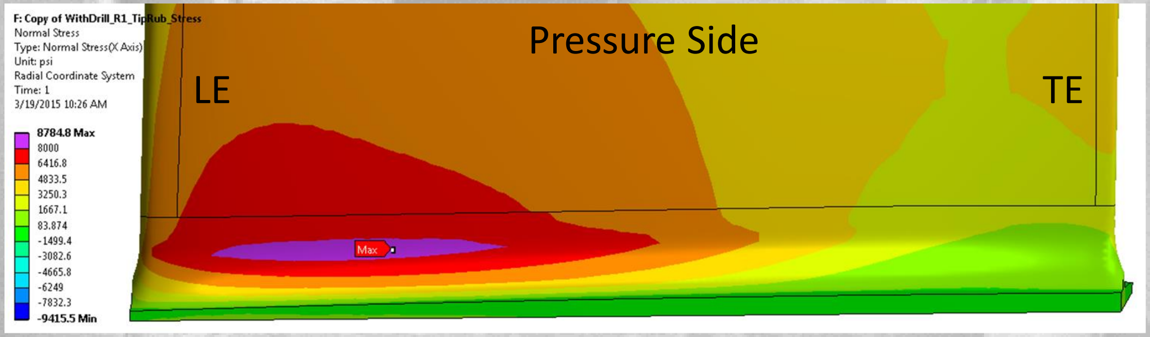


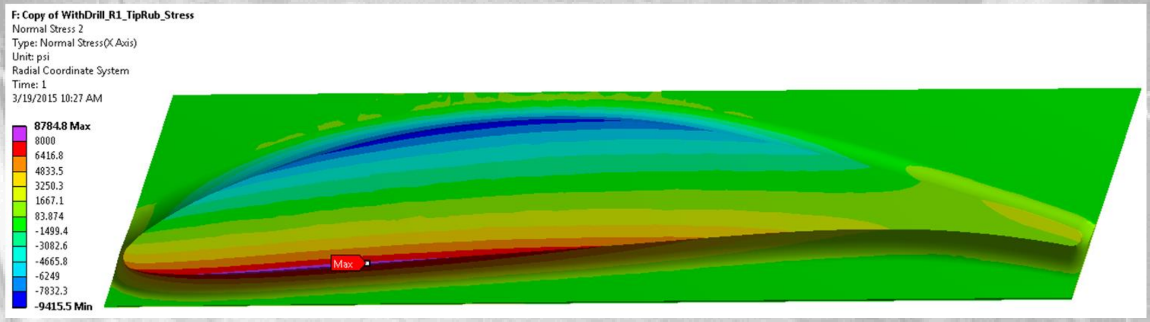


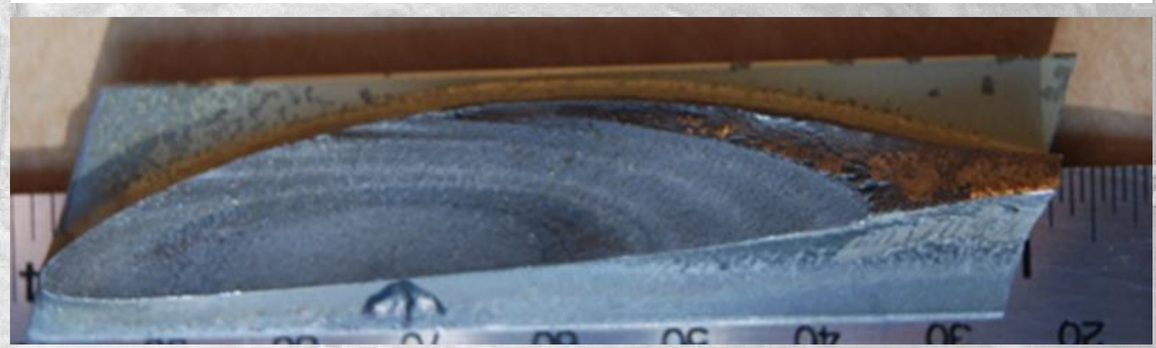


ANALYSIS RESULTS - Operation

- Stage 1 Blade Tip Rub Peak Stress







CONCLUSIONS

- Root cause was fatigue crack initiation due to cyclic loading from a tip rub.
- Material from the inlet screen became trapped between the casing and “longest” blade causing tip forcing function
- Shutdown & inspection decision was the “right decision” avoiding additional consequential flow path damage, and train structural damage from elevated vibration.

LESSONS LEARNED

- Inlet system inspection and maintenance should be a planned, high priority activity during turnarounds.
- Maintain adequate flow path spare components.
- Sudden, sustained, unexplainable flow capacity changes should be investigated at earliest opportunity.
- Include inlet system instrumentation to for ΔP changes
- Provide provisions for manway & borescope access
- Include visual inspection for both the inlet system and the front end of the compressor. Also to perform preventive maintenance on the inlet housing implosion door trip monitors during shutdowns

THANK YOU

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BACKUP SLIDES

ANALYSIS RESULTS - Frequency