ASIA TURBOMACHINERY & PUMP SYMPOSIUM
MARCH 2018 | SUNTEC SINGAPORE

Failure, Repair and Overhaul of 5 MW Right Angle Reduction Gear Box

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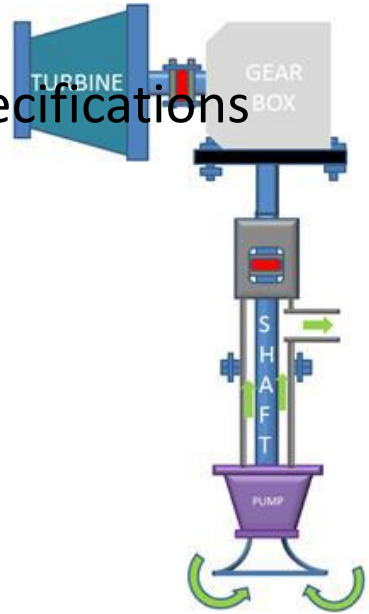
Abstract

L-1403A &B are 5 MW Right Angle –Double reductions gearboxes installed between Turbine (TP-1403) and Cooling water Pump (P-1403). Both gearboxes reported high vibration after 15 months of continuous operation one after the other. Vibration had a continuous increasing trend. CSI® was used to check the gearboxes that both showed looseness spectrum.

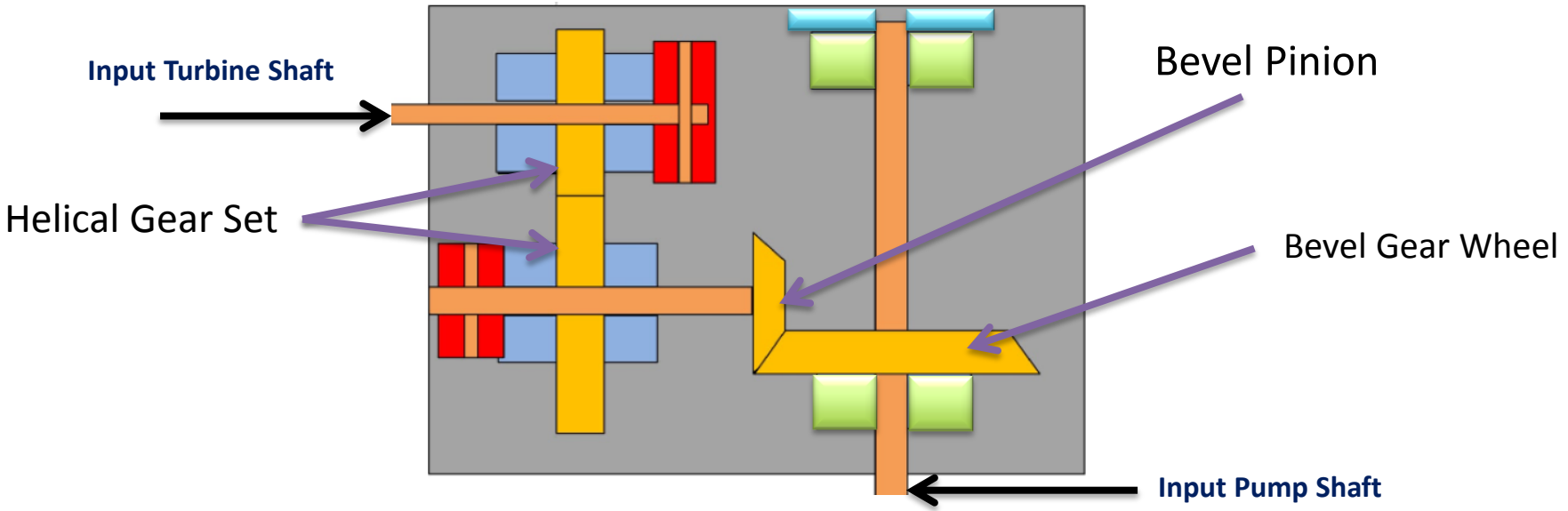
During inspection of L-1403 B Gear Box, broken tooth of LS Bevel Gear was observed. While L-1403 A inspection revealed pitting on HS gears. Gearboxes were repaired in house by increasing interference of bevel pinion with shaft.

Cooling Water Pump Schematic

- There are **four** Cooling water (CW) pumps
  - ✓ **P-1403 A/B** are Steam driven machine through Gearbox Reduction
  - ✓ **P-1403 C/D** are Motor driven. No issue/ abnormality with motor driven pumps
- **Operating philosophy:** Two steam driven and one motor driven pumps in service. Remaining one motor driven as standby
- L-1403A/B are cooling water gearboxes, bearing following specifications
  - **Power –** 5 MW
  - **Gear Types -** Bevel & Helical Gears (Reduction)
  - Gearbox Ratio – 1:8.9
  - **Bearings –** Tilting Pad & Ball Bearings
  - **Accelerometer on Casing**



Gearbox Construction



Thrust Bearing

Sleeve Bearing

Roller Bearings

Anti-Rotation Device

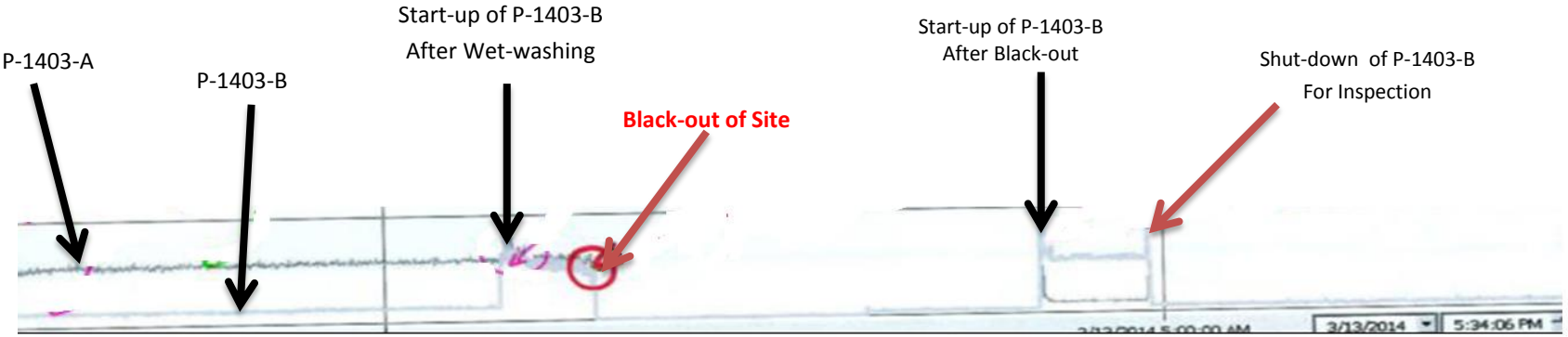
Observations and Anomalies

- On Jan,14 Abnormal noise from **L-1403A** gearbox and increased gear backlash was observed during window inspection
- Similar abnormal noise with lower extent observed from **L-1403B *(damaged one)*** Gearbox. Hence its inspection was planned for latter
- Surveillance Frequency was increased on Both pumps post this incident
- Accelerometer probes Vibrations reading on both increased but remained under Alarm limits

Observations and Anomalies

- On March 12th, during startup , L-1403 B was reported to have very high vibration Data was collected using CSI®
- Data showed high vibration and failure of Gears. It was then immediately shutdown and inspected.

Chronology of incident

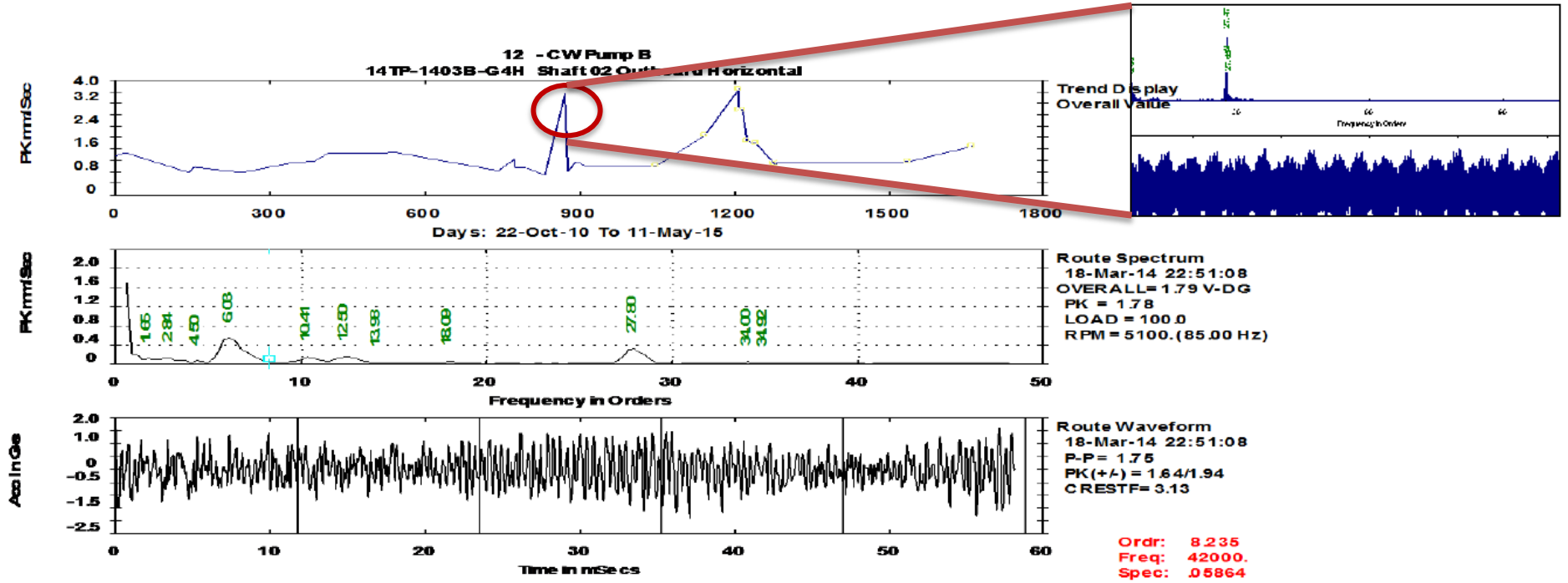


On Mar 12th, 2014 after Power failure, both turbine driven pumps remained in operation & were tripped manually due to low steam pressure

Chronology of incident

- **Post blackout**, on restart of CW pumps
  - ✓ L-1403A gearbox noise & vibrations remained same as they were prior to Blackout
  - ✓ L-1403B ***(broken tooth)*** gearbox noise & vibrations increased & machine was decided to be inspect on 14th March
- L-1403-A was kept in service – for Business continuity – and inspected every 03 months

CSI Trends

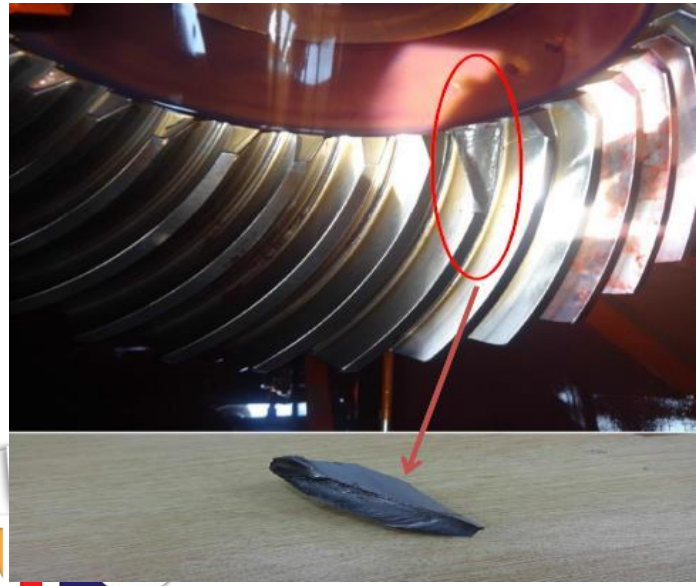


Typical trend of Broken tooth-Fish Tail wave forms

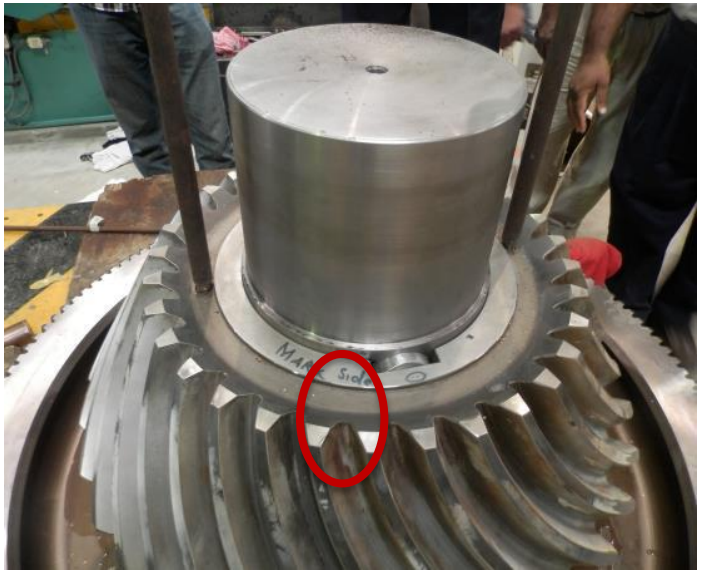
Observation and Wear Pattern

Bevel Pinion & Gear

L-1403-B, Broken LS Bevel Gear tooth



L-1403-B worn HS Bevel Pinion Teeth



Key and Keyways

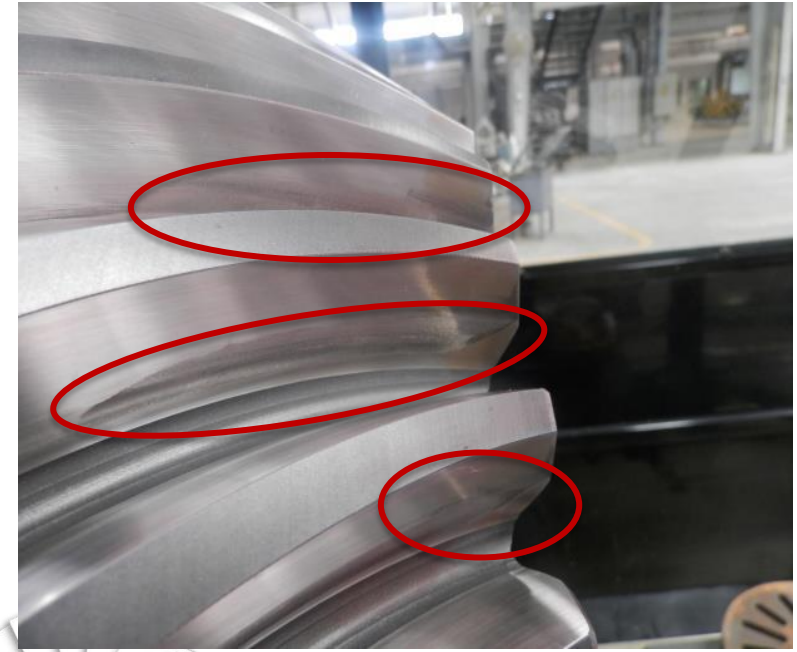
Bevel Pinion sitting Collar

Extruded Keys – High Torque

Loose Bevel Pinion

Bevel Pinion (which meshes with LSS gear) was found **0.018”** loose on shaft (which ideally should be interface fit with the shaft)

Bevel Pinions Wear



L-1403-A

L-1403-B

Shaft Condition underneath Bevel Pinion

Fretting Corrosion

L-1403-A

L-1403-B

Other Observations

- All Bearings – Normal
- Clearances in Bearings – Within Range
- Anti-Rotation Device – Normal
- Roller Bearings - Normal
- Casing Internals - Normal

Root Cause Analysis

RCA-Fretting Corrosion

- One of the critical observation taken during the removal of HS Bevel Pinion was the evidence of fretting in the Hub of Bevel gear and Shaft.
- "Fretting is a special wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force." *ASM Handbook*

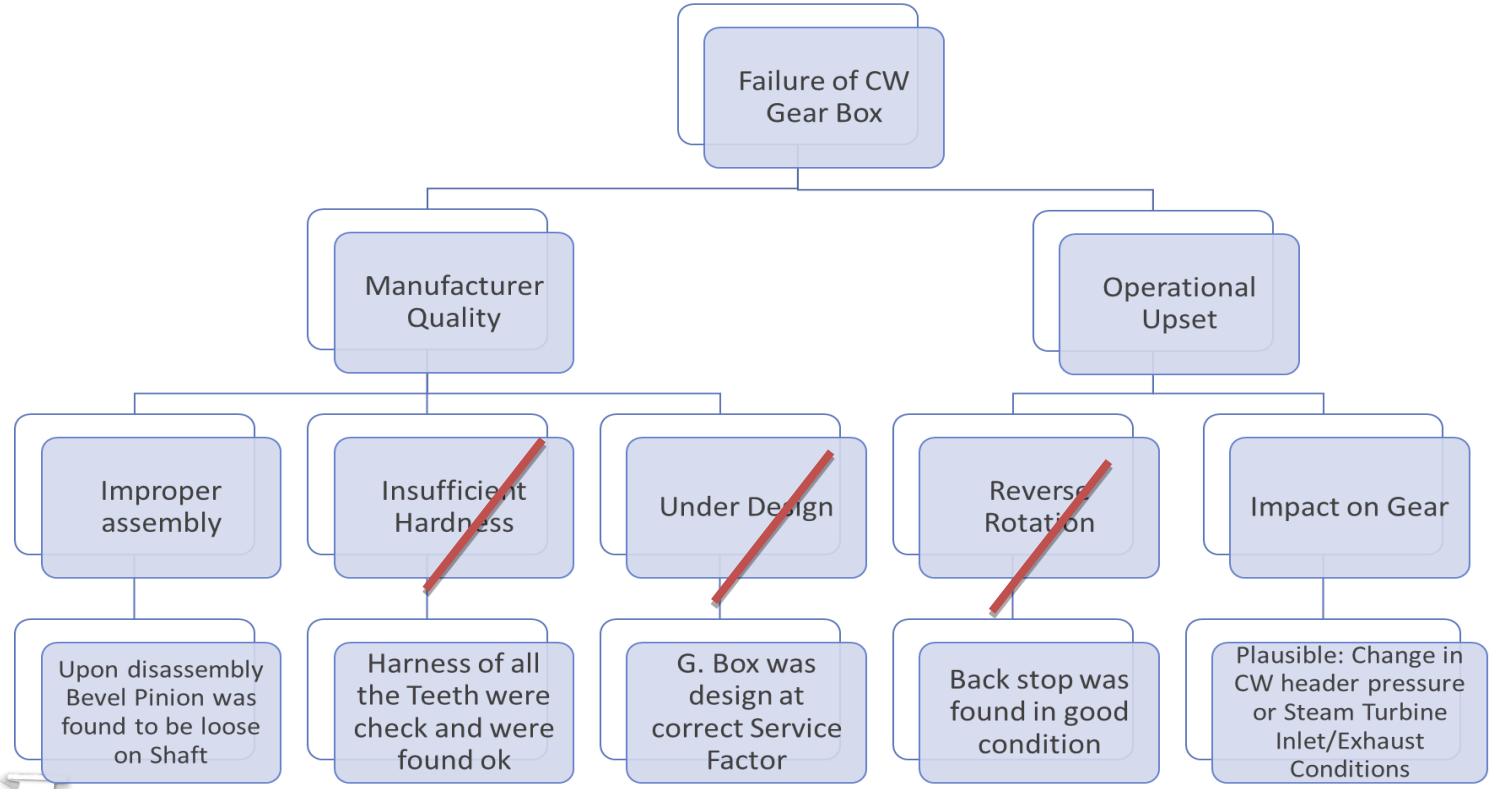
RCA-Fretting Corrosion

- Fretting Corrosion aggravates in
  - Presence of lubrication
  - Cyclic loading
  - High Torque
- All of the above was present in this case.
- Case was then taken up with OEM for his review and in parallel in house repairs were done.
- Immediate solution to address this was to increase the Fit.

In-house Repair Methodology

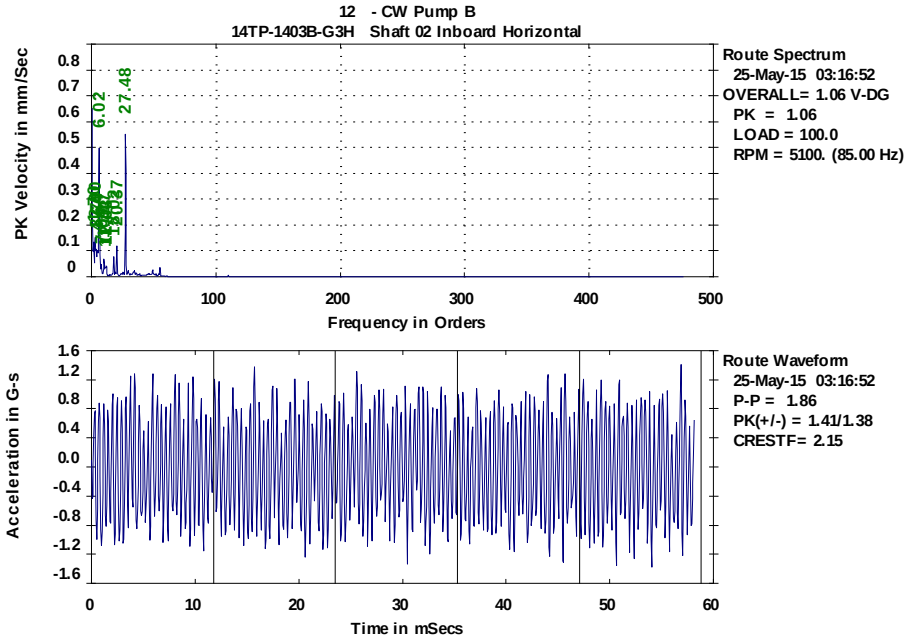
- Machining of Internal Diameter of Bevel Pinion to ensure uniform Diameter
- Build-up of Shaft using Electrode E-6010 followed by PWHT
- New Keys and Keyway Machining. Keys to be Snug fit
- DPT & MPI of all parts
- Increased interference to 0.003” between shaft and pinion
- Smoothening of broken tooth area on Bevel Gear. Removing material thru pencil grinder and reuse Bevel Gear.

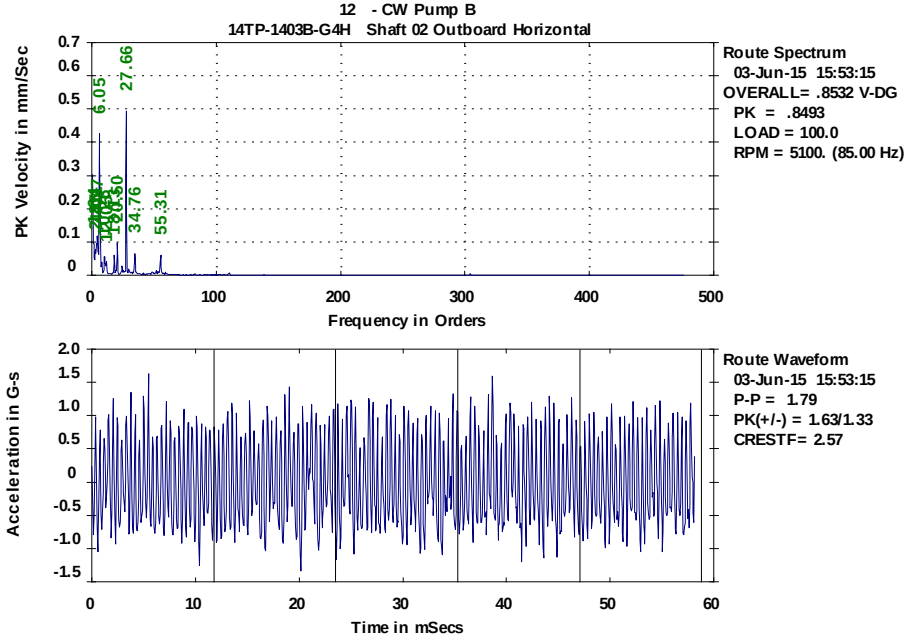
RCA


Failure of CW Gear Box
Manufacturer Quality
Operational Upset
Improper assembly
Insufficient Hardness
Under Design
Reverse Rotation
Impact on Gear
Upon disassembly Bevel Pinion was found to be loose on Shaft
Harness of all the Teeth were check and were found ok
G. Box was design at correct Service Factor
Back stop was found in good condition
Plausible: Change in CW header pressure or Steam Turbine Inlet/Exhaust Conditions

K.F

Pot Repair startup





Analysis:

- The maximum vibration recorded post startup was less than 1 mm/sec RMS value. With PK-PK value of about 1.8 mm/sec.
- No impacting in waveforms

Conclusion and Lesson Learnt

Conclusion

- Loose pinion on shaft had resulted in repeated cyclic loading on the LS gear which eventually generated the high stress points on gear teeth
- During Startups, the initial torque on gears are normally high, therefore post black out, upon TP-1403B startup the high stressed portion on a LS gear teeth had given away, resulting in high noise & vibration
- Bevel gear pinion interference with the shaft was not adequate (which is a design Work-man ship related flaw). That further aggravates during the course of time & eventually resulted in failure.

Conclusion

- OEM latter accepted the fault and increased tolerance from 270 H7/n5(transition fit) to 270 H7 270 r6 shaft leads to a min interference of 0.0018” and a max of 0.005”. It was hence a design error.

- The gear set has been running from 03 years with no increase in vibration level and within acceptable noise levels

Lessons Learnt

- Fit Type to be given due consideration during design phase
- FAT to be carried out to asses design considerations
- No reliance on Accelerometer
- Proper Vibration Monitoring Regime Development
- Use of Sound meter for Noise Monitoring
- Oil analysis for metallic particle through a Gear Box Return Oil drain to be made part of routine monitoring