ASIA TURBOMACHINERY & PUMP SYMPOSIUM
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Resolution of Steam Turbine High Vibration Due to Rotor Rub

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Abstract

This case study presents a high vibration trip incident experienced on a SP steam turbine after an overhaul. The machine tripped 4 times at a speed of about 4800rpm (just before 1st critical). The problem was identified quickly through the use of a vibration analysis system and issue resolved without needing to re-open the turbine.

During start up of the turbine following a full overhaul, the turbine tripped multiple times on 1x vibration. Vibration values were low during warm-up but rapidly picked up during acceleration as the speed increased towards the 1st critical. Vibration could be felt on the deck during acceleration.

Vibration analysis was done (Spectrum, orbits, shaft centerline, waterfall, bode and polar plots) and the problem was suspected to be caused by rubbing of the shaft and the labyrinth during acceleration which resulted in a thermal bow of the turbine shaft. The machine's rotor-dynamic behavior would go back to normal during every restart after several hours of trip.

During detailed troubleshooting, a hold-down bolt on the turbine Drive-end casing was found to be excessively tight. This restrained the normal thermal growth of the casing which caused a minor distortion as more steam was being introduced into the turbine. The distortion resulted in a rub which thermally bowed the shaft and resulted in the high 1X vibration

The issue was resolved by adding shims to the hold down bolts to allow clearance between the bolt and washer and hence allow casing to grow without restraints. The turbine was successfully restarted after the minor modification with very minimum vibration

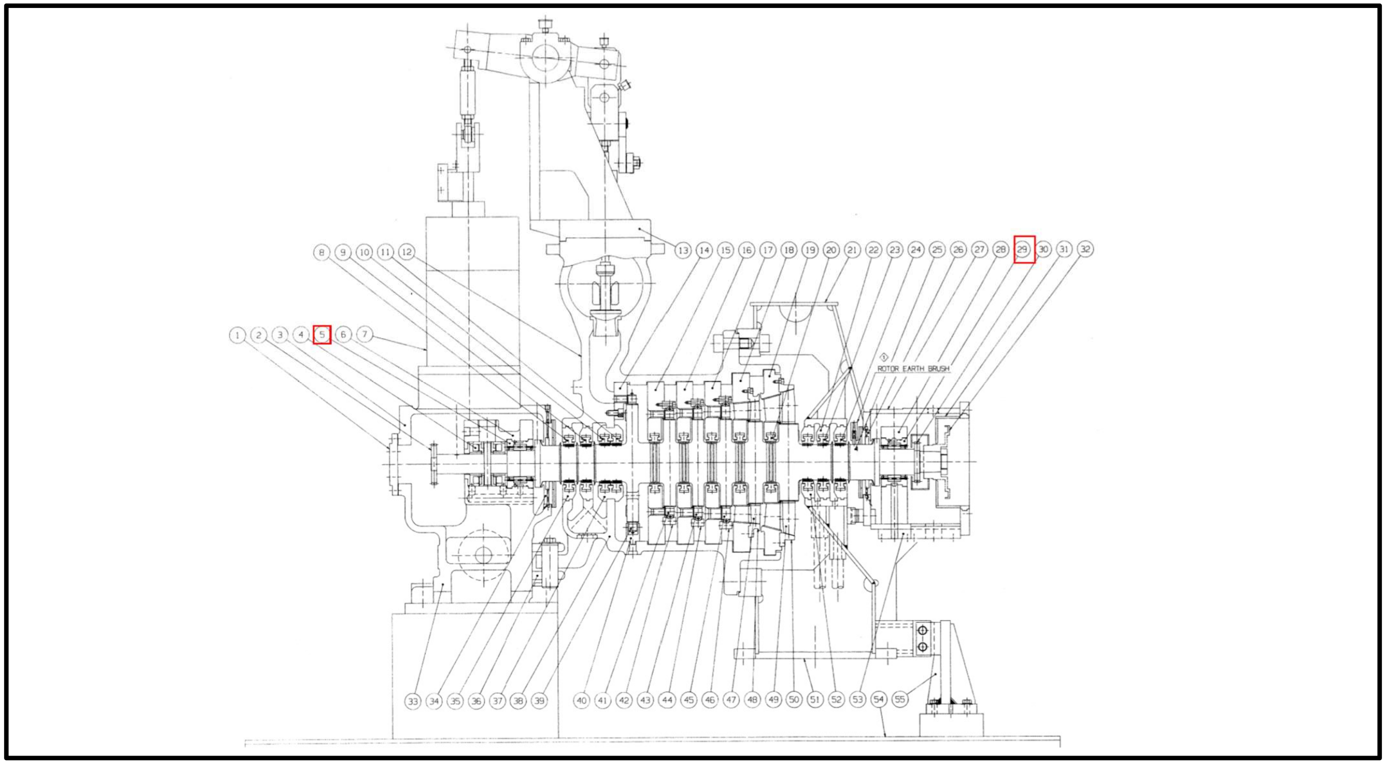
This case study will present the problem encountered, vibration analysis done and the resolution implemented

Agenda

1	Case Study Background
2	Problem Description
3	Vibration Analysis and Direct Cause Assessment
4	Mitigation Implemented and Results
5	Key Learning

Background

Steam Turbine Cross Section and Details



Condensing turbine
Turbine power: 1.66 MW
Rated Speed: 13,000 rpm
1^{st} Critical: 6,396 rpm
Steam flow: 2461 kJ/kg

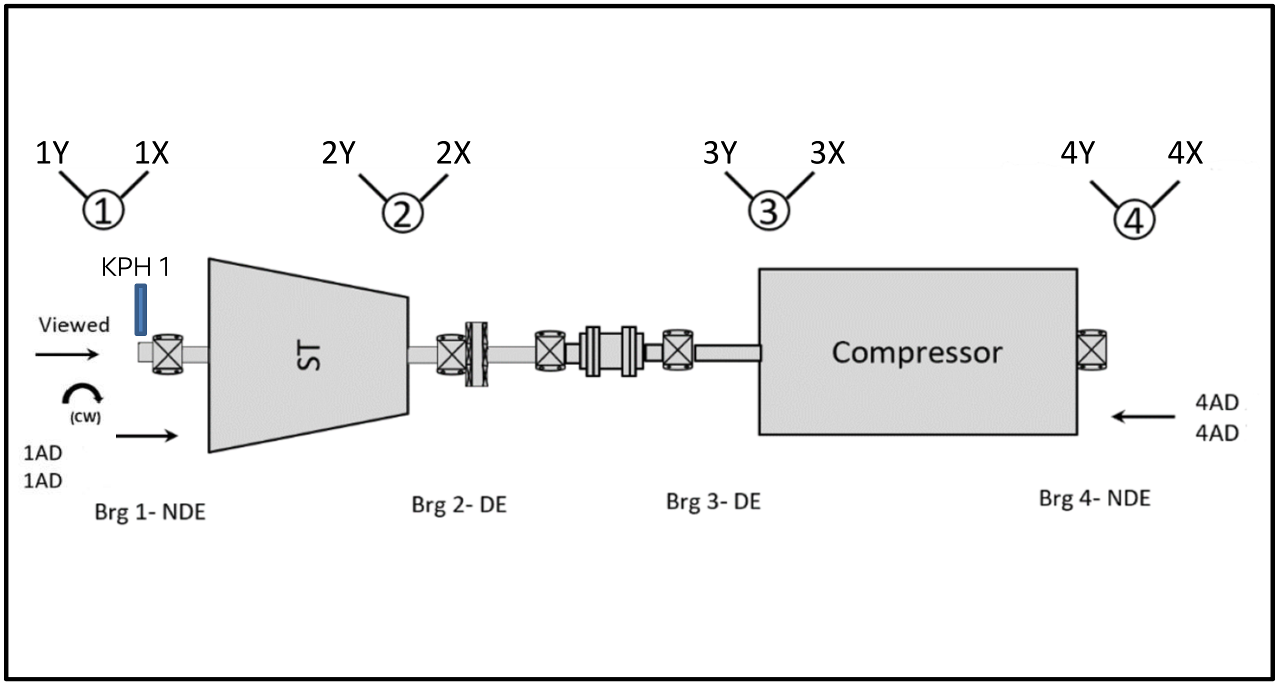
Details of work:

- Turbine undergone complete overhaul with rotor and internal interstage labyrinths replaced
- Internal clearances were set back to within new design limits

ATPS

Background

Steam Turbine Probe Orientation



Probe Orientation

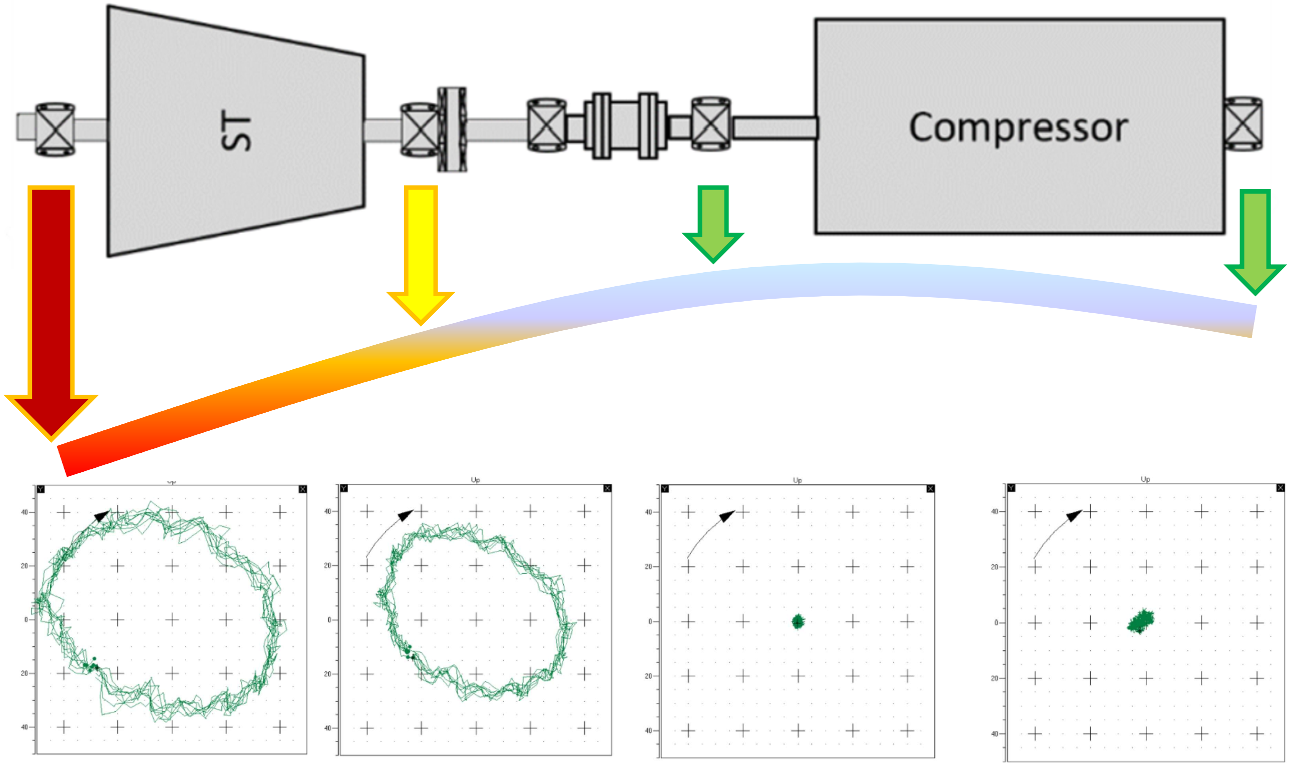
Tag#	Equipment	Bearing	X/Y	Key Phasor
1Y	Turbine NDE	1	45° Left	KPH 1 (45° Right)
1X	Turbine NDE	1	45° Right	
2Y	Turbine DE	2	45° Left	
2X	Turbine DE	2	45° Right	
3Y	Comp DE	3	45° Left	
3X	Comp DE	3	45° Right	
4Y	Comp NDE	4	45° Left	
4X	Comp NDE	4	45° Right	

Alarm set point: 50 µm
Trip set point: 75 µm

Problem Description

- The compressor train tripped at about 4,825 rpm after first commissioning from cold startup and going through 30 minutes of slow roll (1,000rpm). Highest vibration recorded at 1Y: 91 um pp.
- Four startups were performed before successfully rolling the machine to normal operating speed in the fifth attempt.
- In each re-start, the machine tripped by Bearing-1/-2 high vibration before reaching compressor 1st critical speed. Noticeable vibration could be felt on the deck when the reading in the vibration monitoring system increased.
- 2nd and 3rd restart were attempted by manual startup with the aim of cruising through the critical speed band. Machine started with low vibration but vibration level went exponential and tripped the machine as speed was ramped towards 1st critical.
- Vibration data was collected for detailed analysis.
- Clear 1x peak was observed when the trip occurred

Problem Description

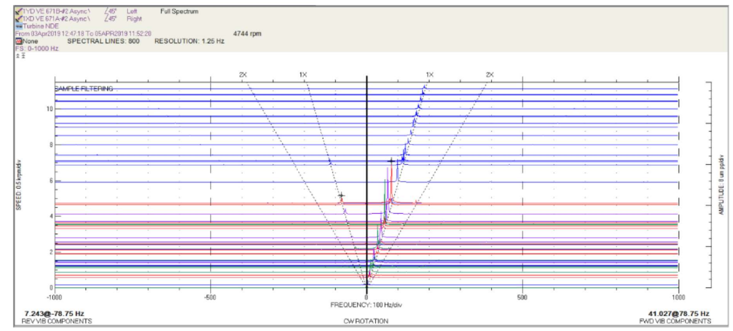


Y: 91.6 µm pp
X: 84.2 µm pp

Y: 77.7 µm pp
X: 63.6 µm pp

Y: 5.12 µm pp
X: 5.61 µm pp

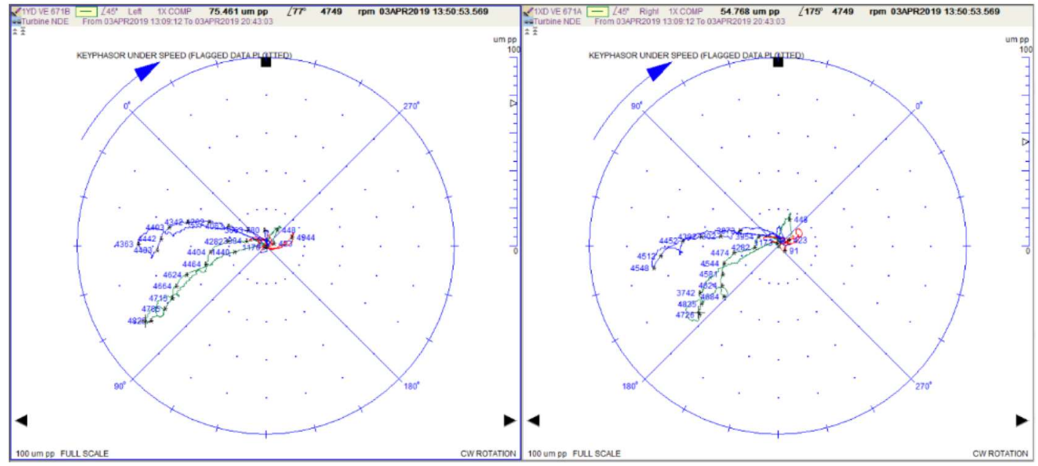
Y: 7.42 µm pp
X: 11.07 µm pp



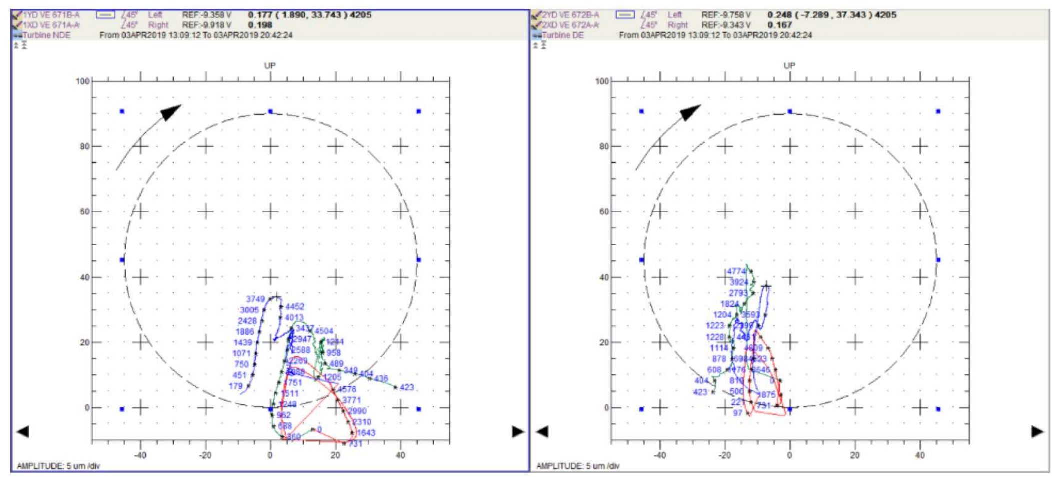
- High vibration occurred at steam turbine, especially Bearing-1.
- All frequency spectrum indicates sign of dominant 1x vibration.
- Initial suspect: tight internal clearance between labyrinth seals and rotor.

Vibration Plot Analysis

1. Vibration plots in the first 4 startup were collected from System-1 to study the cause of tripping.
2. Polar Plots:
   - Continuous drastic change of 1X phase within a narrow speed range (4500~4700 rpm) in every startup.
3. Turbine shaft center line (SCL – Bearing-1) plots showed symptom of insufficient lift when the turbine was cruising toward critical speed.



Polar plot for Bearing-1 at 4th run

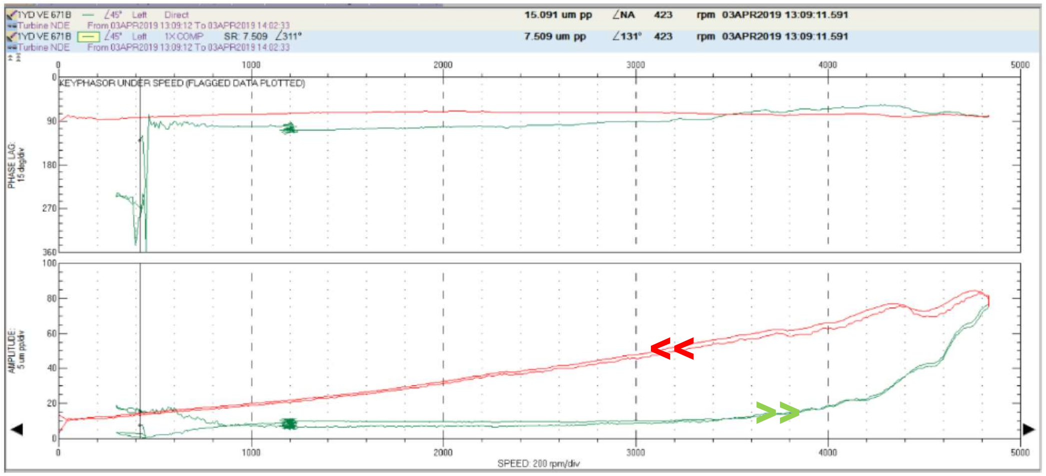


Turbine SCL plots at 4th run

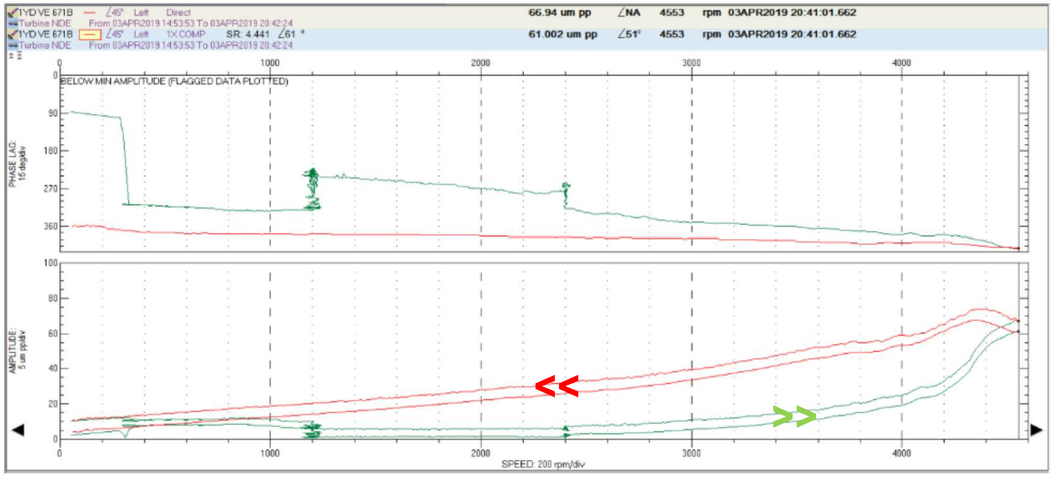
Note: 1st run (green) 2& 3rd run (red) 4th run (blue)

Vibration Plot Analysis

**Green line: Startup*
**Red line: Shutdown*



Bode plot for Bearing-1 in 1st run.



Bode plot for Bearing-1 in 4^{th} run.

Vibration Plot Analysis

1. Bode plots for (cold) startup and shutdown were different in 1st and 4th run.

2. Phase lag of the system was found “interrupted” before critical speed.

3. Direct cause of vibration was suspected due to “uneven ” interference in every startup. Preliminary assessment pointed at potential of internal rub.
   - Rotor lift was restricted when turbine speed increased.
   - Internal rub could have induce spring stiffness during startup and relieve after coast down.
   - Rub causes thermal bow of rotor and modified heavy spot location in every startup.

4. The vibration response from a light rub due to thermal bow of rotor is usually a pure 1X response without any harmonics, which explain the trends picked up in frequency spectrum.

Vibration Symptoms Analysis

The vibration characteristics indicate rubbing symptom is cause of high vibration.

Rubbing is secondary effect of other problem(s).

Parametric analysis was performed to identify the source of rubbing.

Excessive Radial Preload	Assessment
Tight clearance for newly installed labyrinth seals or wrong installation.	Overhaul record showed no tight spots. Labyrinth seal and rotor clearance is within the range.
Compressor train misalignment	Post overhaul alignment record within specification.
Insufficient bearing clearance	Bearing clearance is within the specification
Inadequate rotor support by bearing hydrodynamic pressure.	Same turbine rotor and bearings were used previously and no change in lube oil system.
Turbine casing uneven thermal growth	1 out of 4 hold down bolts in the turbine top casing was found tight

Direct Cause Assessment

Four (4) hold down bolts are installed in the turbine top casing. Each bolt is mounted to the casing foot via a washer ring.

All washer ring have approximately 0.1mm clearance and free to move under cold condition.

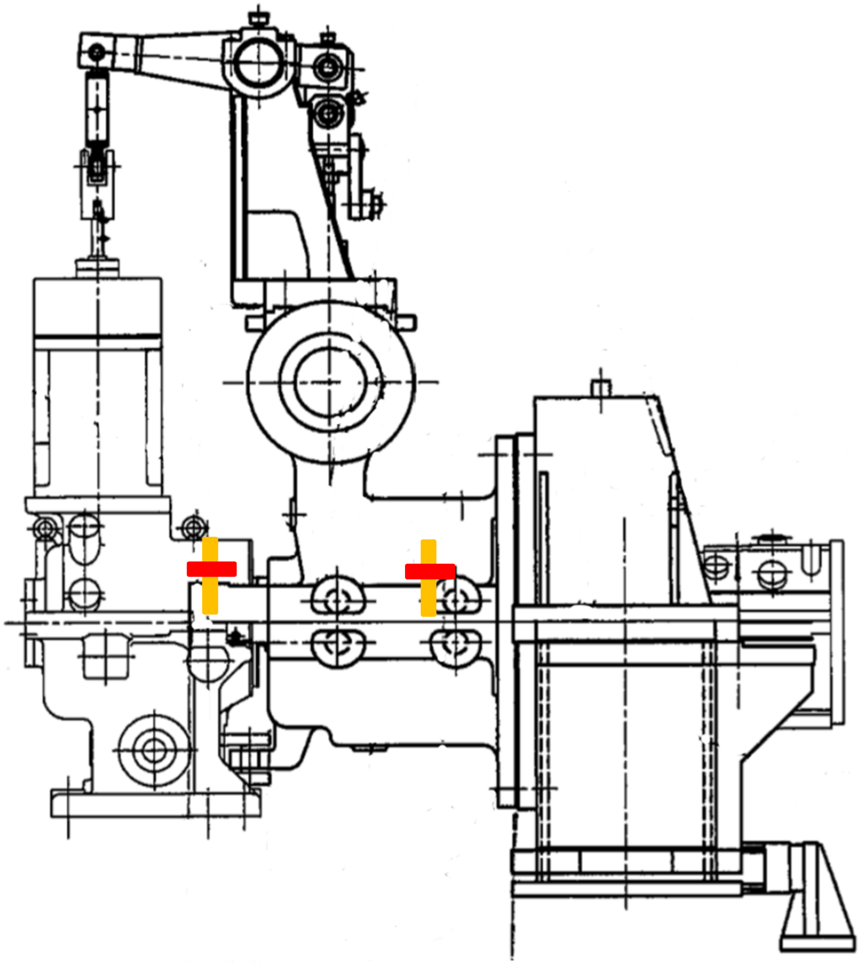
When the turbine is in operation, the clearance will be closed up by casing thermal expansion.

Without this clearance, casing expansion will be restricted and lead to rotor rubbing against the internals.

During turbine overhaul, the top casing was lifted to extract the rotor assembly for inspection. Most probably the as-found clearance was not checked by OEM rep prior to removal.

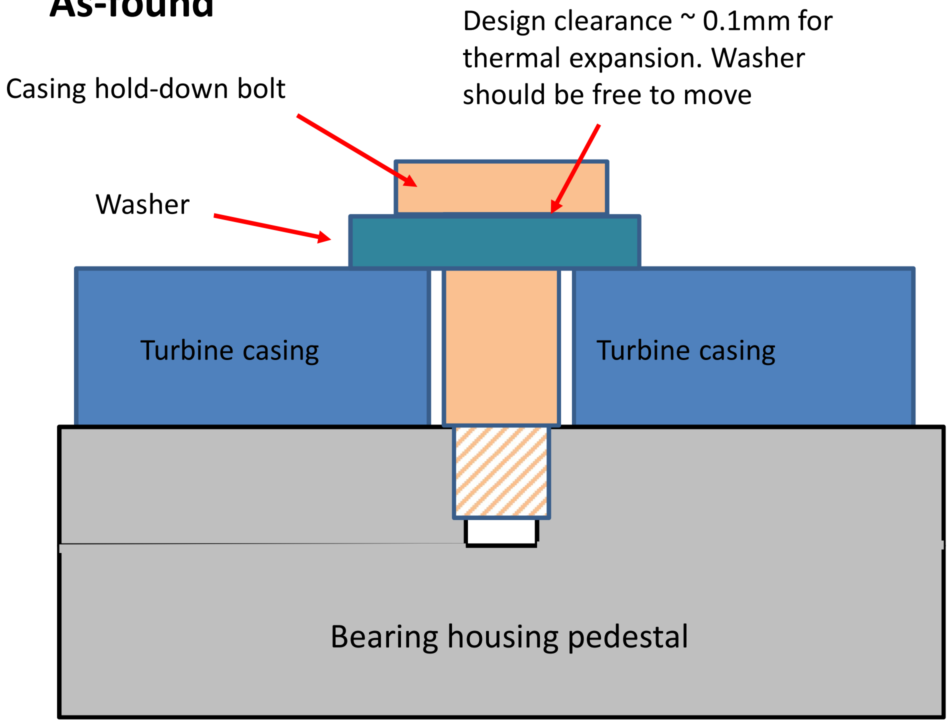
One of the hold down bolts at the turbine NDE was found tight.

Direct Cause Assessment

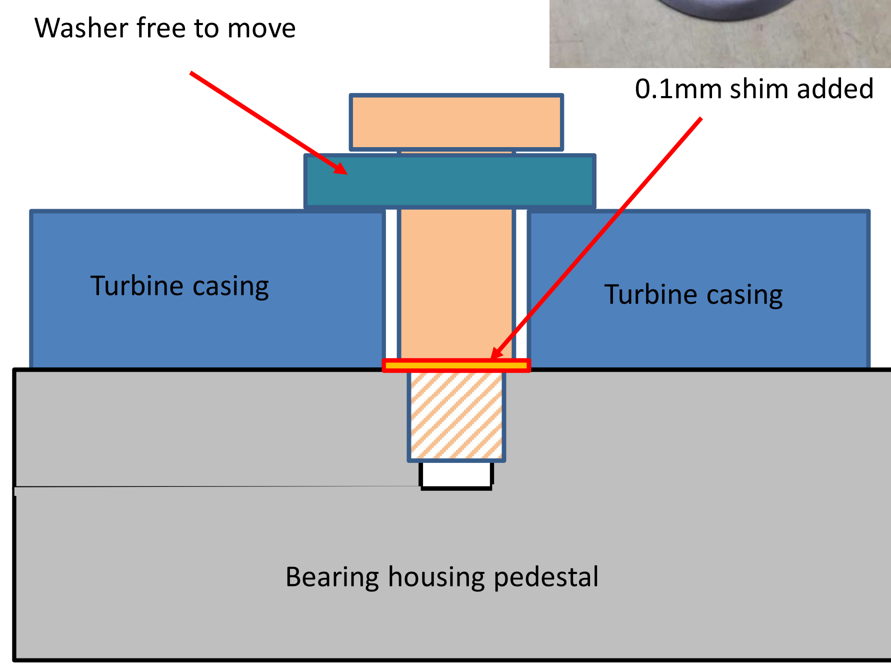


Findings and Mitigations Implemented

As-found

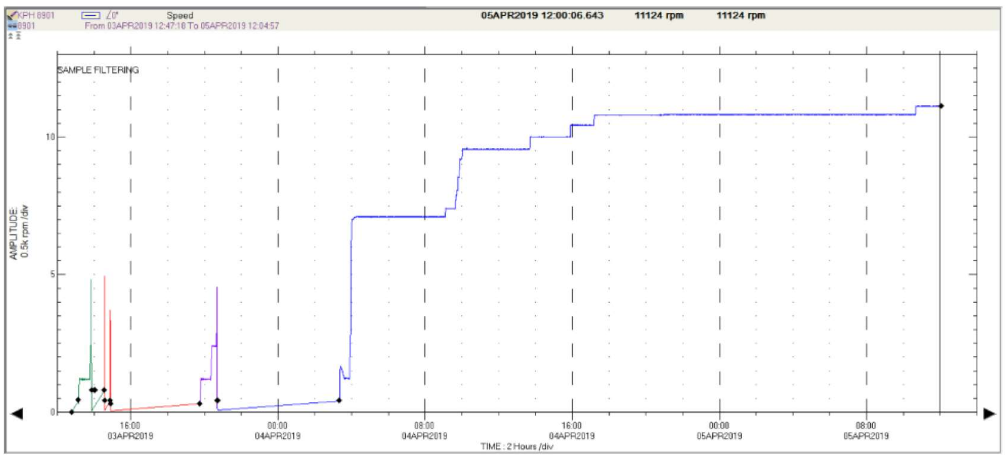


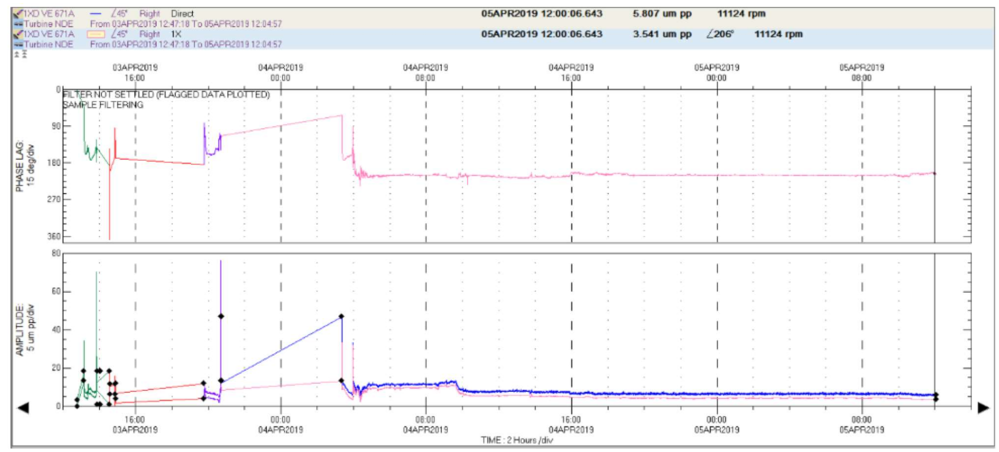
Mitigated



Result

- The compressor train was restarted up successfully after addition of shim.
- Vibration through critical speed was lower than 25μm pp.
- Ramp up of speed was smooth and vibration on deck could no longer be felt
- The compressor have been running stably for 6 months since then.





Key Learning

- Compressor OEM did not check bolt tightening condition during overhaul. Bottom casing was not removed and hence bolts were not touched
- Repair checklist did not capture this as a critical check point
- Special purpose steam turbine, with flexible shafts and tight internal clearances, can be very sensitive to constraints for thermal expansion

End of Presentation
Questions?