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Investigation & Solution of Steam turbine Governor Valve Repetitive Failure

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Authors & Presenter's Details

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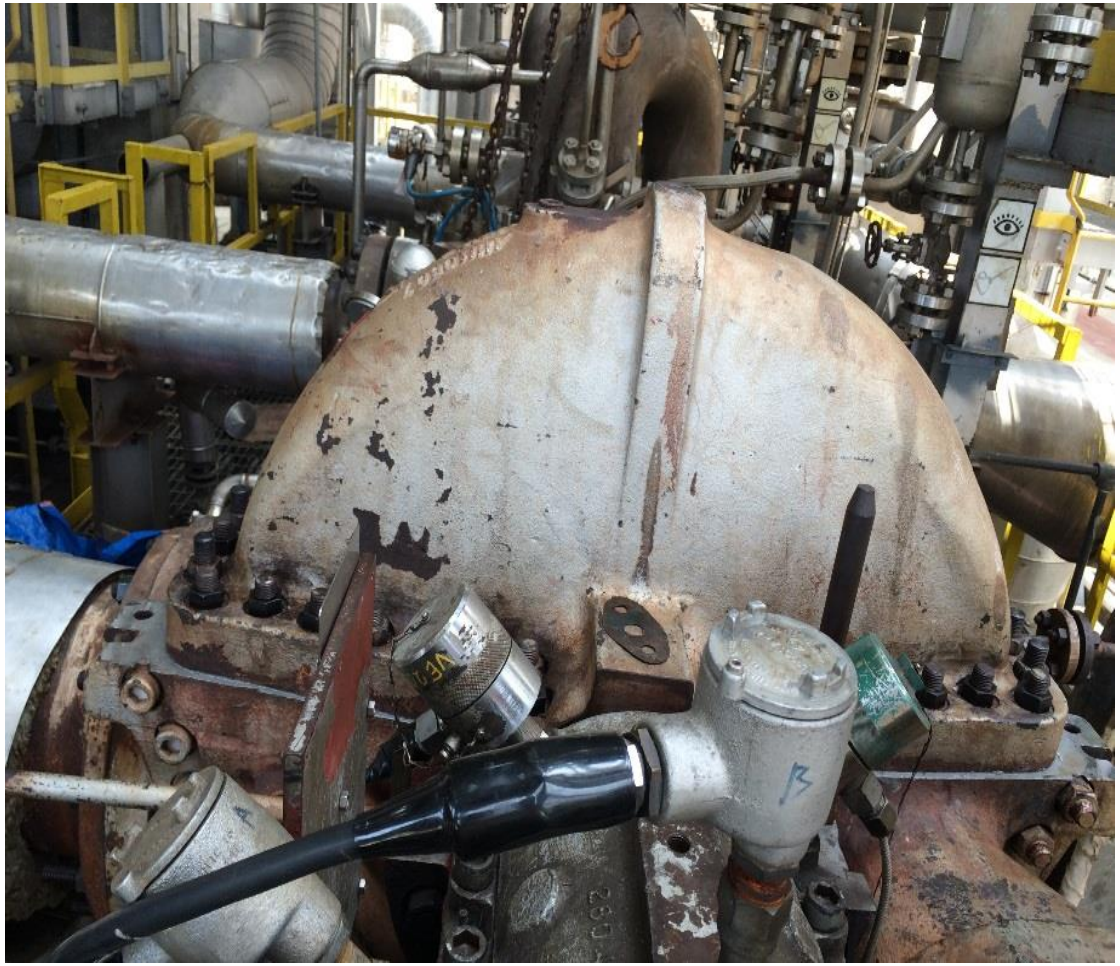
ABSTRACT

A group of 3MW back pressure steam turbines have experienced a common and repetitive mechanical failure for its dual port steam governor valve. Fracture surface analysis at the failed valve stem reveals a distinctive sign of fatigue breakage. The valve stem is highly subjected to distressed cyclic bending mode. Site vibration data gathering at the valve stem revealed some common peaks at 230-290 Hz, 400-600 Hz and 800-1000 Hz. Validated impact testing with Finite Element Analysis (FEA) modal and unsteady Computational Fluid Dynamic (CFD) simulation had supported a good agreement for the failure mechanism. Improvement was done through FEA optimization with valve modification in order to allow sufficient separation margin between stem natural frequency bending modes and steam flow vortex shedding frequencies.

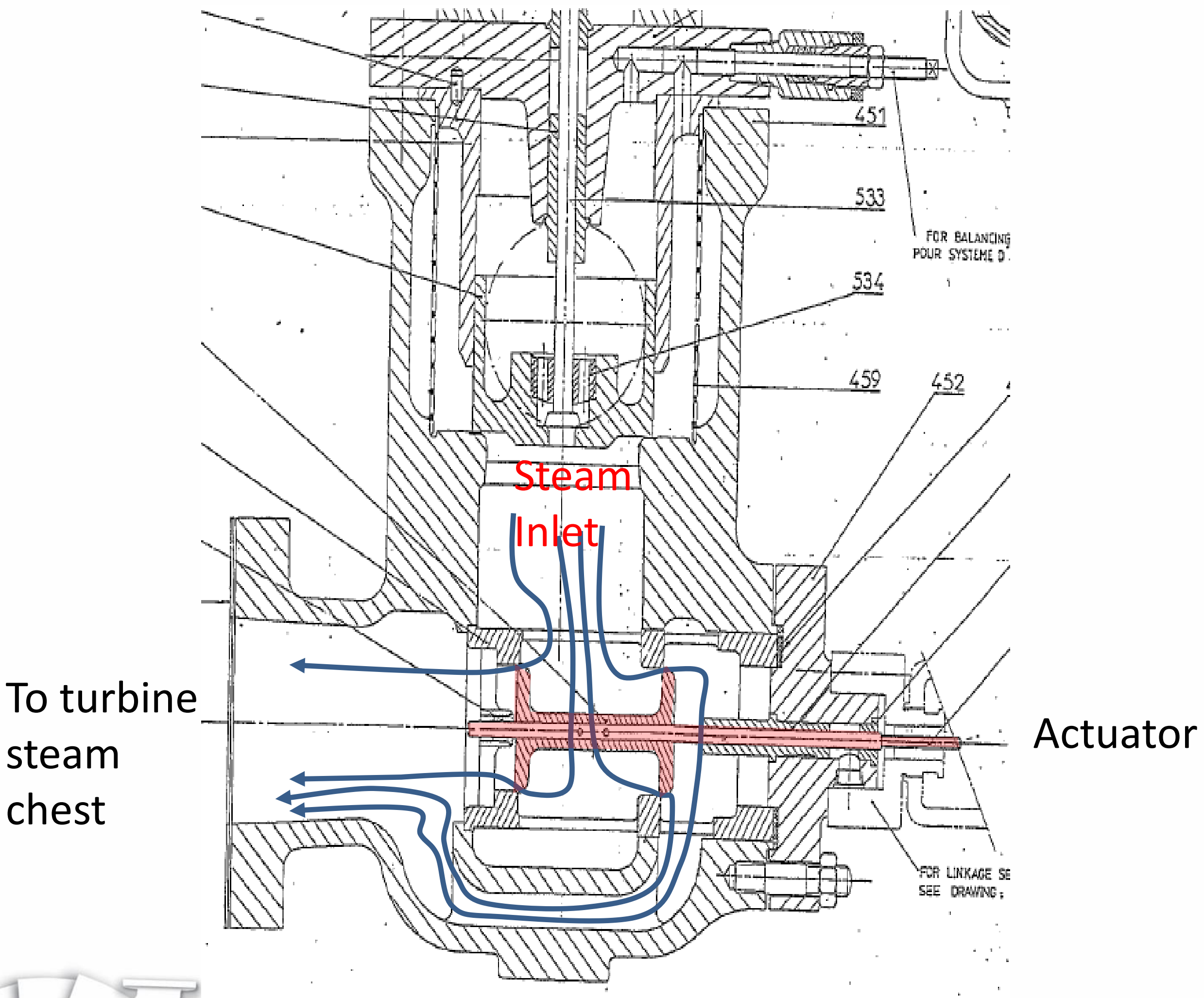
CONTENT

Problem Background

- Train consists of a 1st driver steam turbine & 2nd driver Hydraulic Power Recovery Turbine (HPRT) driving multistage BB1 pump (2 running modes for steam reduction)
- Operating speed is 4515 rpm
- Total 8 units of identical turbine experiencing repetitive governor valve failure since commissioning 2001
- Average MTBF of less than 2 years
- Same failure pattern and mechanism were observed

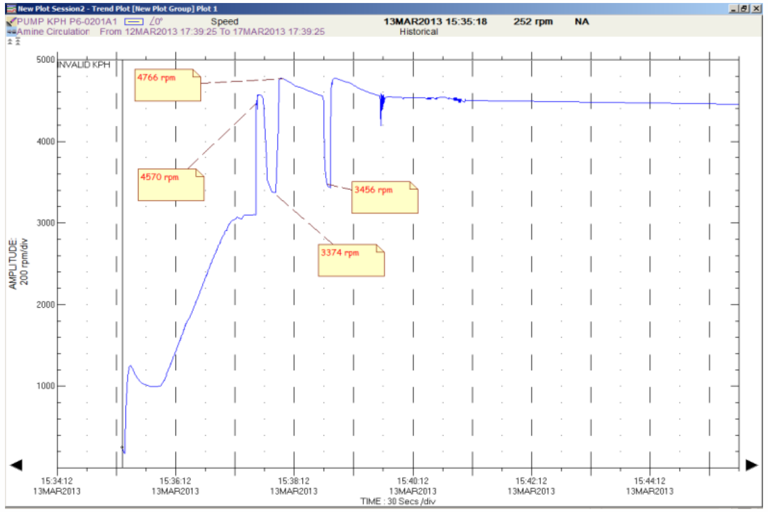


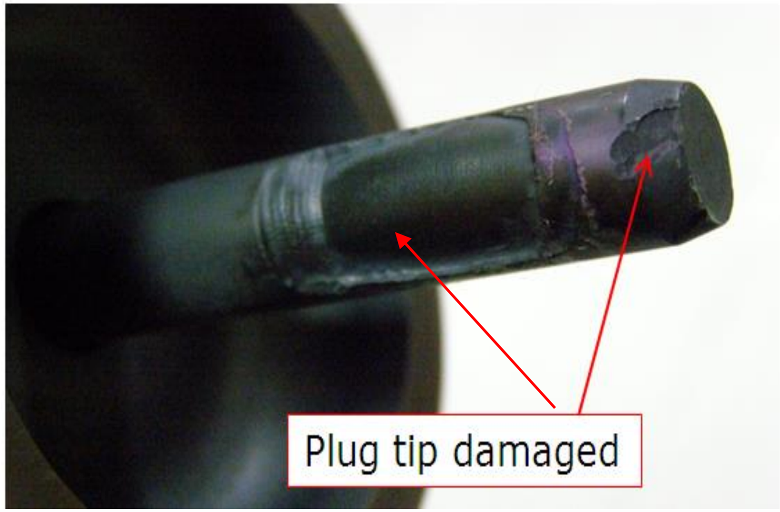
Dual Port Governor Valve Configuration



Findings : Failure Mechanism

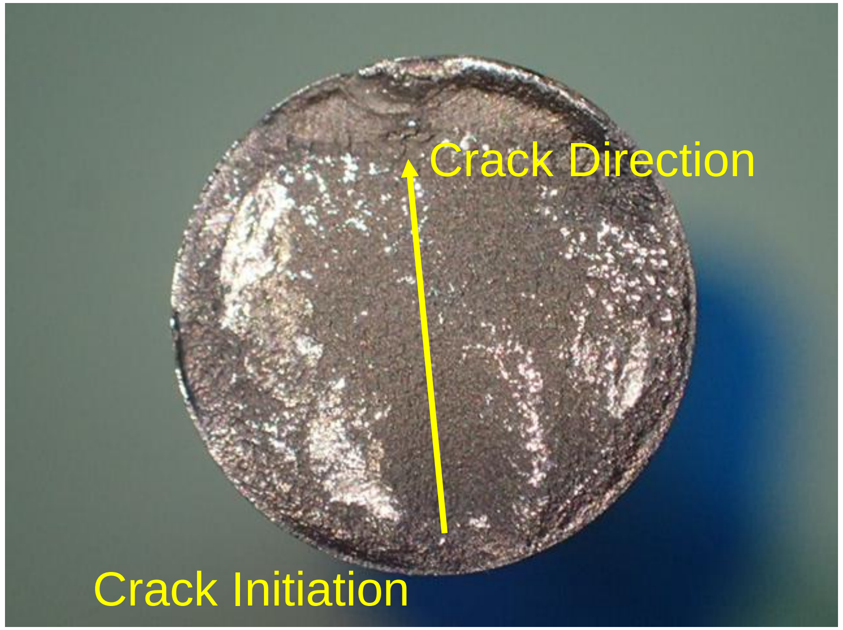
- Steam admission unable to be regulated leading to speed fluctuation.
- Evidence of excessive radial wear on the valve cage ID bushing.
- Evidence of excessive surface wear and thinning at the valve stem surfaces lead material losses.
- Valve stem found broken either at the short end (steam chest side) or long end (actuator side) causing steam turbine to trip.



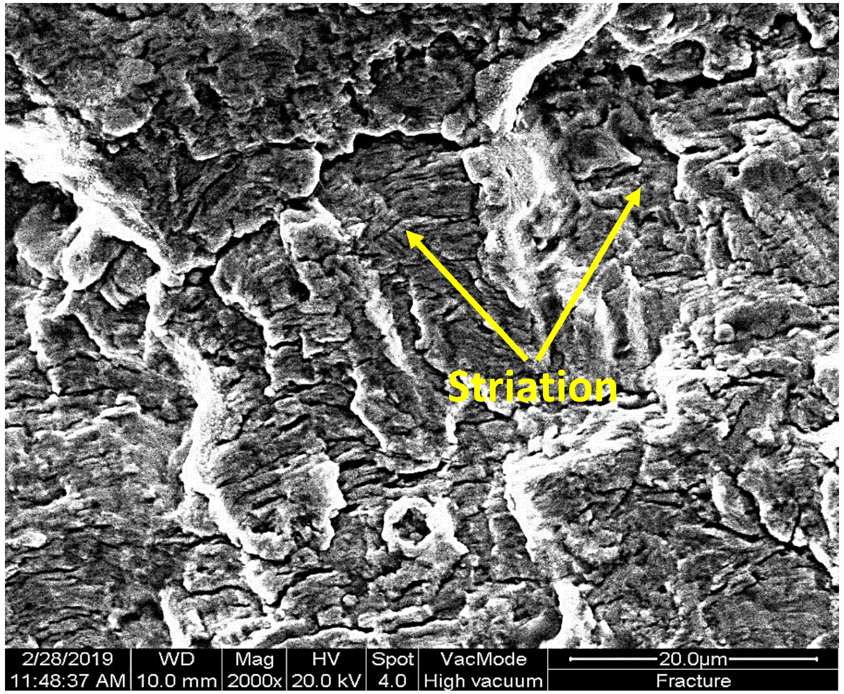


Findings: Fracture Failure Analysis

1. **Fracture Mechanism**
    - Fatigue failure – flat and smooth surface with light beach mark pattern
    - Crack initiated at single point from external surface of the valve stem
    - Final rupture region was quite small – fatigue caused by small cyclic load

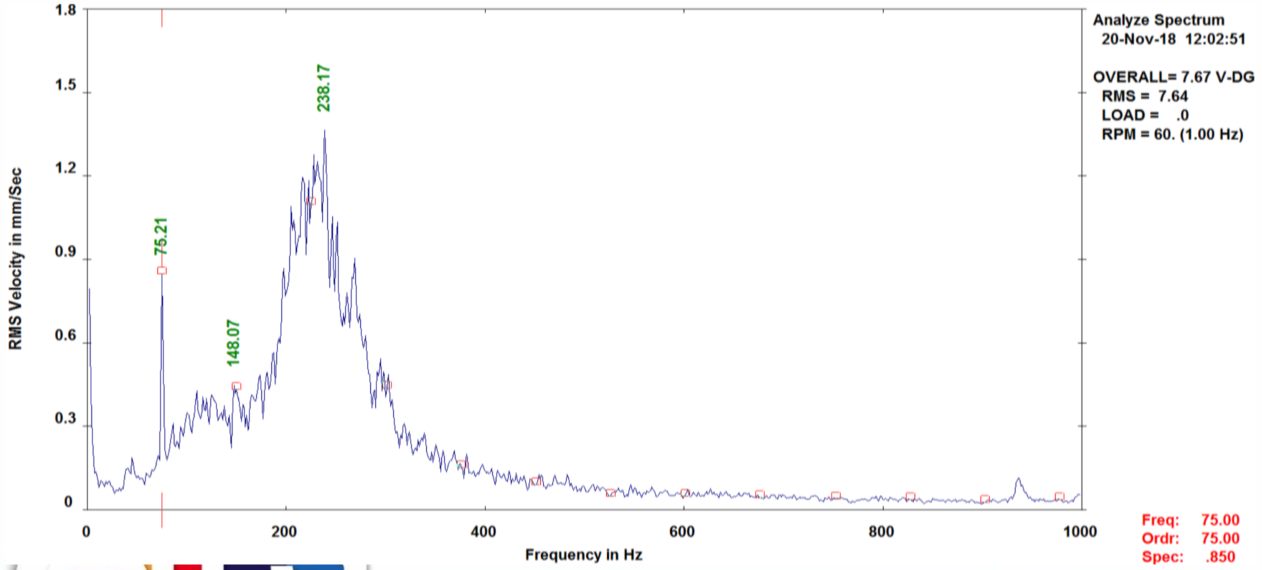


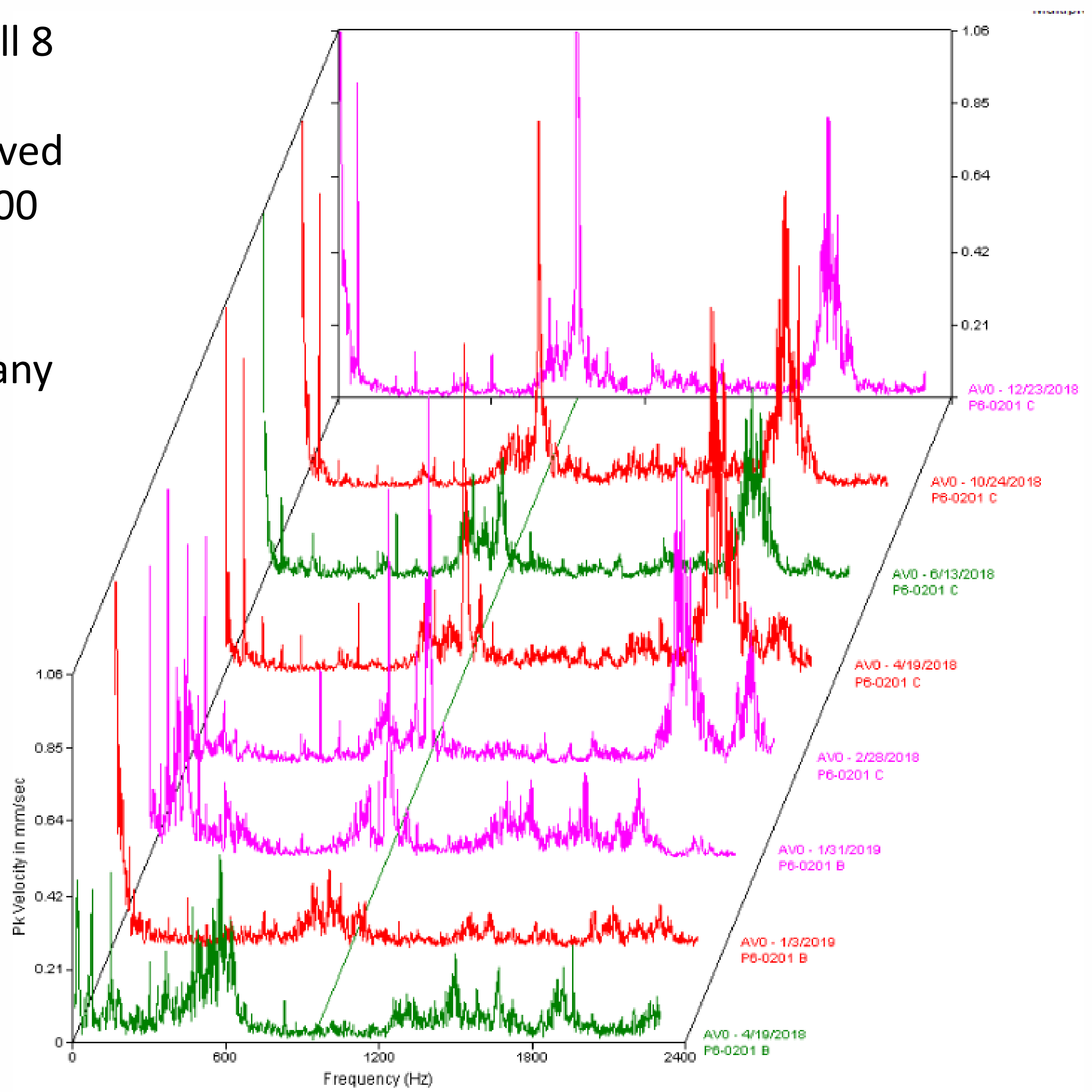
2. **Root Cause**
    - NDT result show several parallel crack growths – indicate the stem experiencing bending stress



Site Vibration Gathering

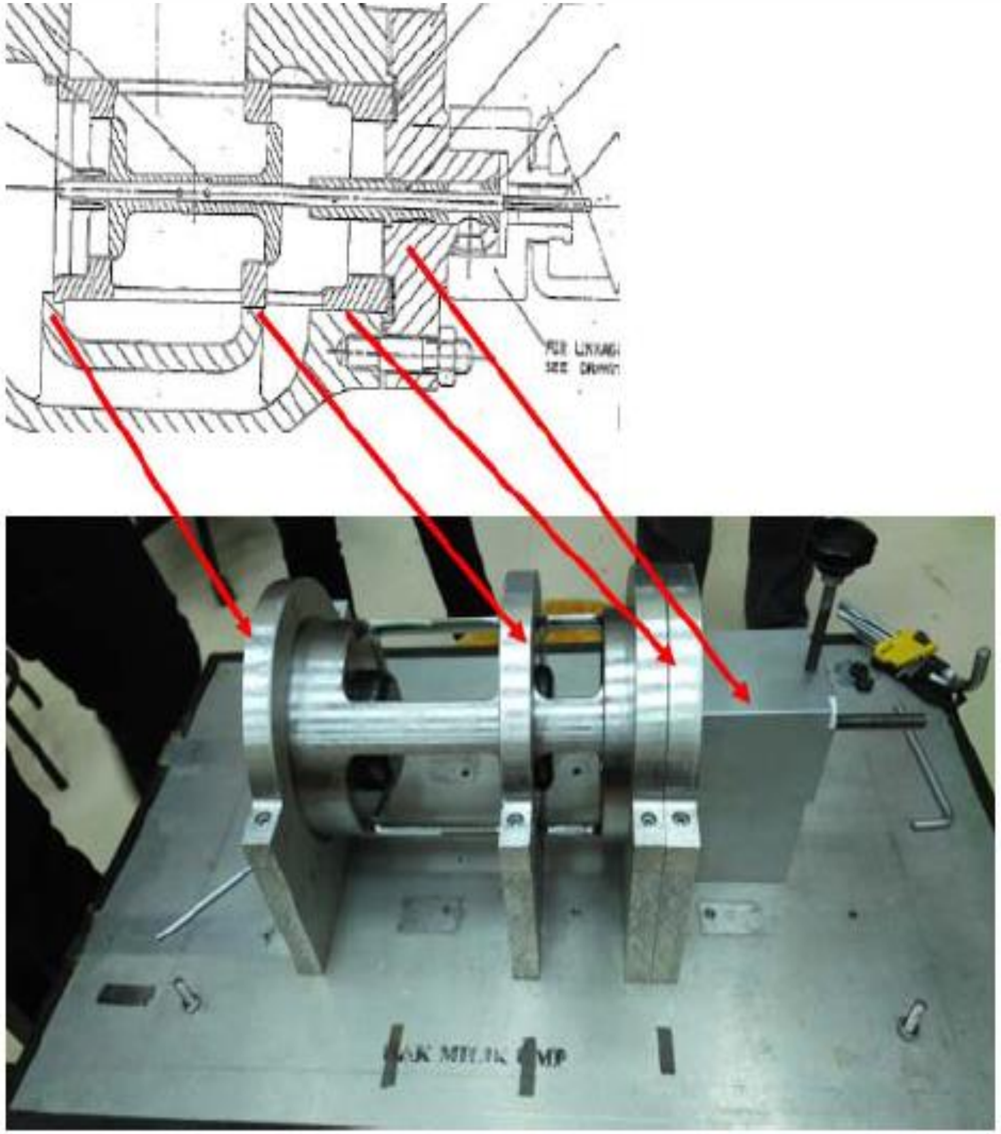
- Vibration data at valve stem collected and monitored for all 8 running turbines
- Broad band high peaks observed at 3 spectrum regions : 200-300 Hz, 400-600Hz, 800-900 Hz & 1800-2000 Hz
- The peaks not coincide with any synchronous components of turbine speed





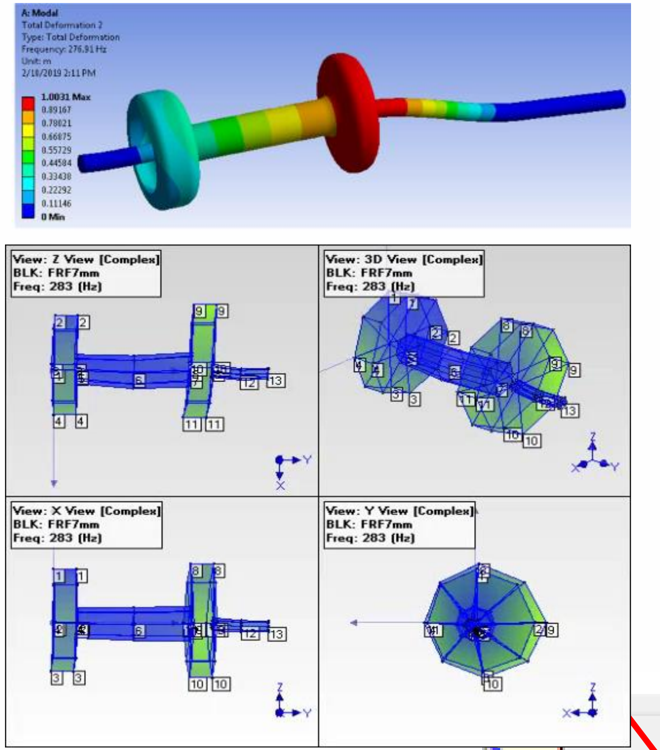
Experimental Modal Impact Testing

- Verification of valve stem natural frequency and mode shape using impact testing.
- Fabrication of special jig to replicate actual valve mounting at site.
- 3 different opening condition simulated for the testing ; 0% opening (fully close), 15% opening (turbine running with HPRT) and 30% opening (turbine running w/o HPRT).
- Valve stem natural frequency and mode shape validated with FEA modal simulation.

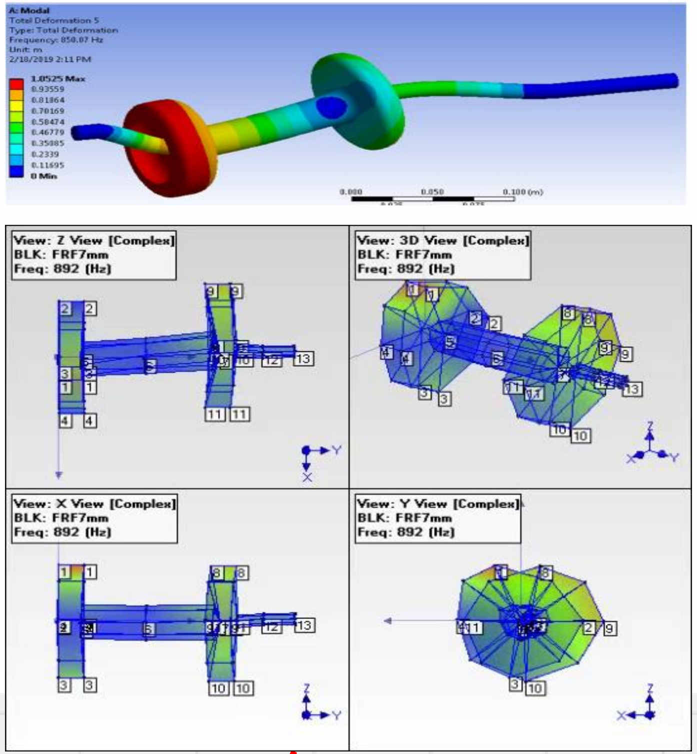


Validation : Impact Testing + FEA Modal Analysis

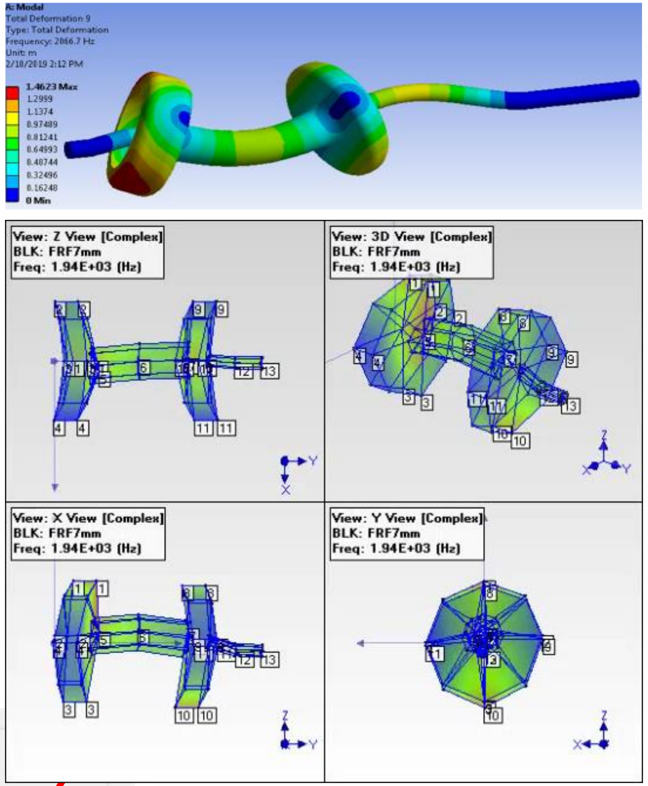
1st bending mode (long stem)



1st bending mode (short stem)



2nd bending mode



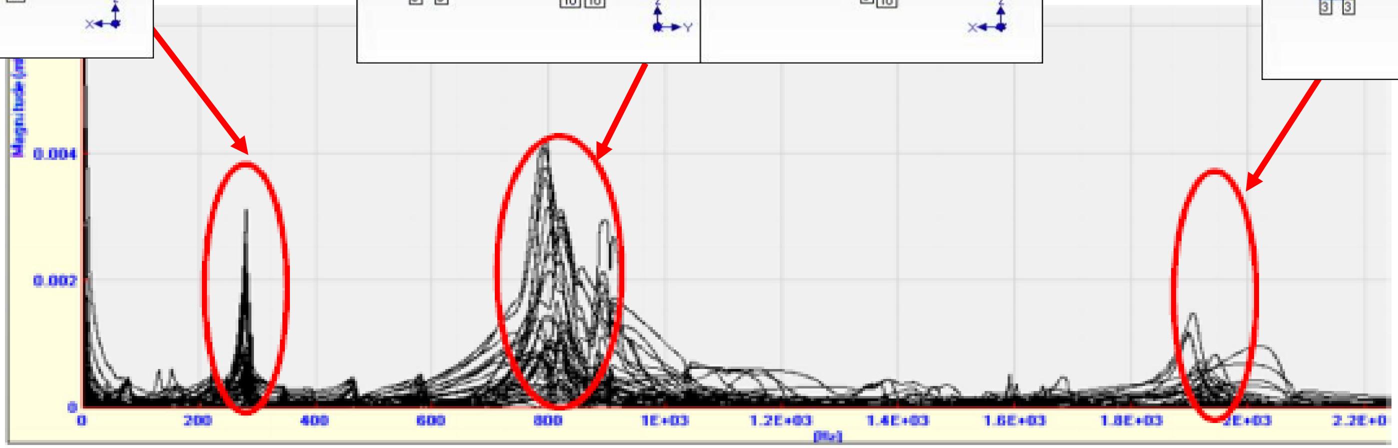
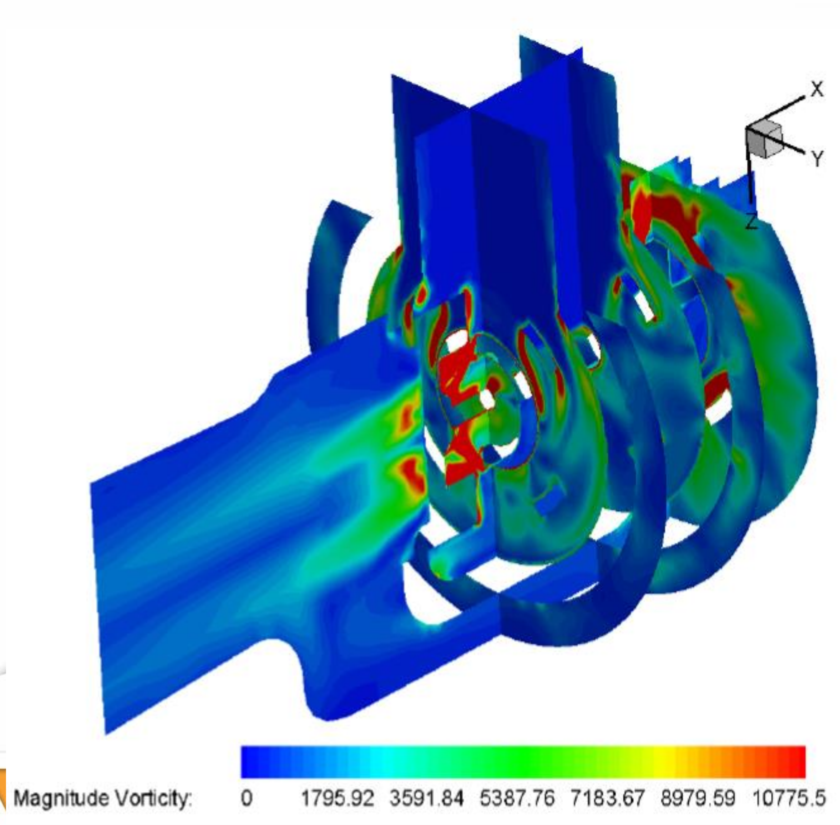
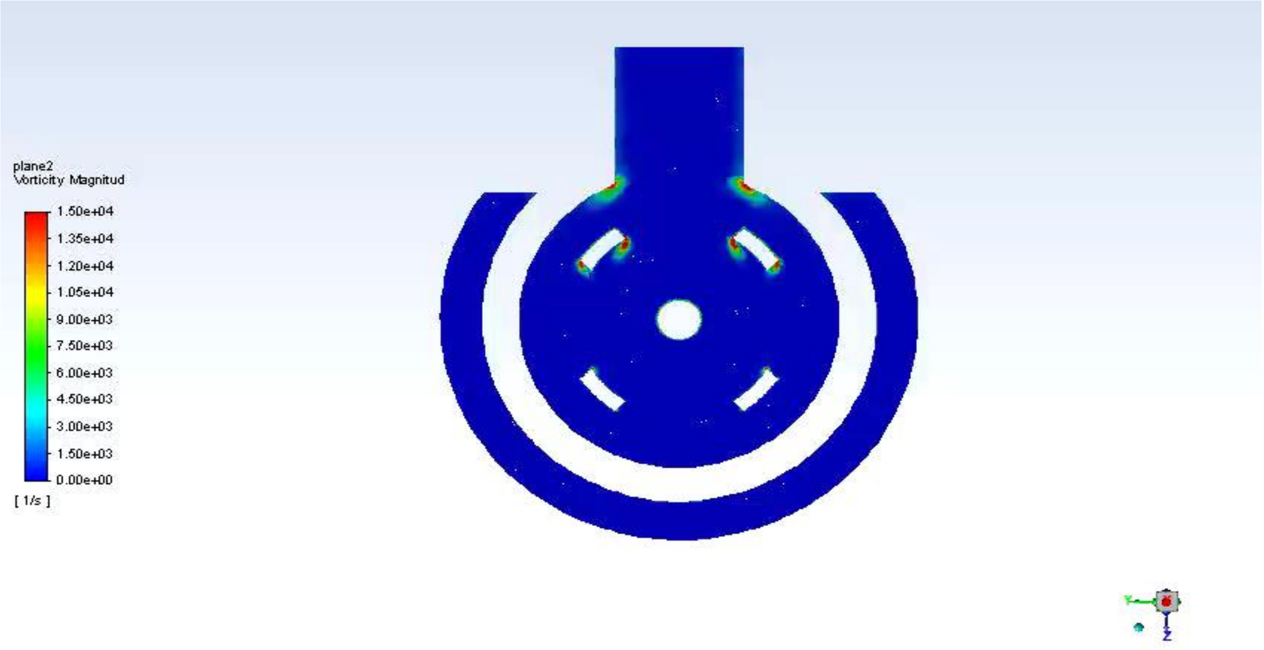


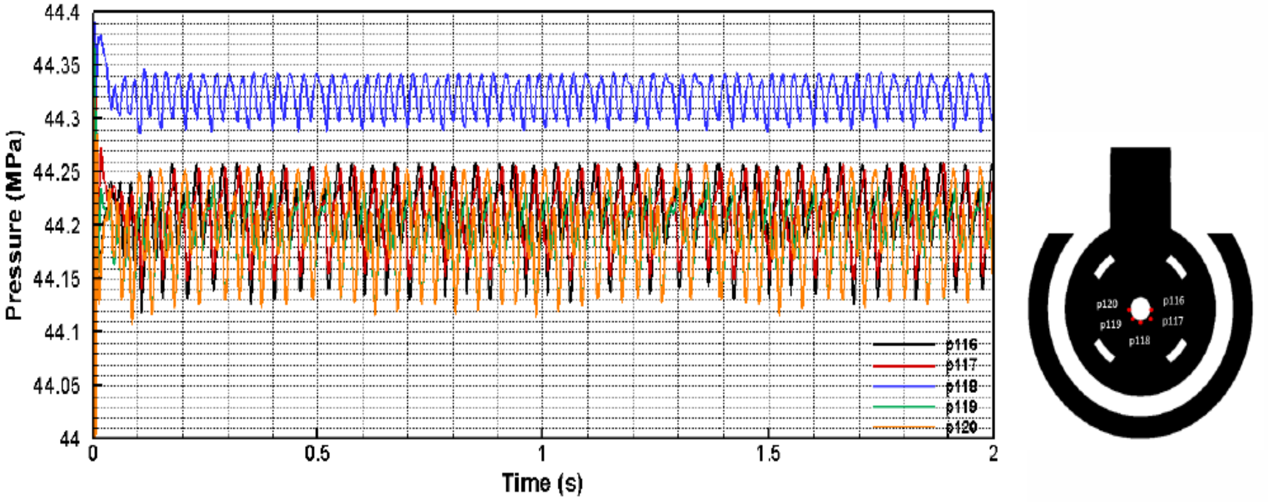
Figure 6: EMA FRF, critical NF around 270-290 Hz, 800-900 Hz, and 1900-2100 Hz.

CFD Analysis

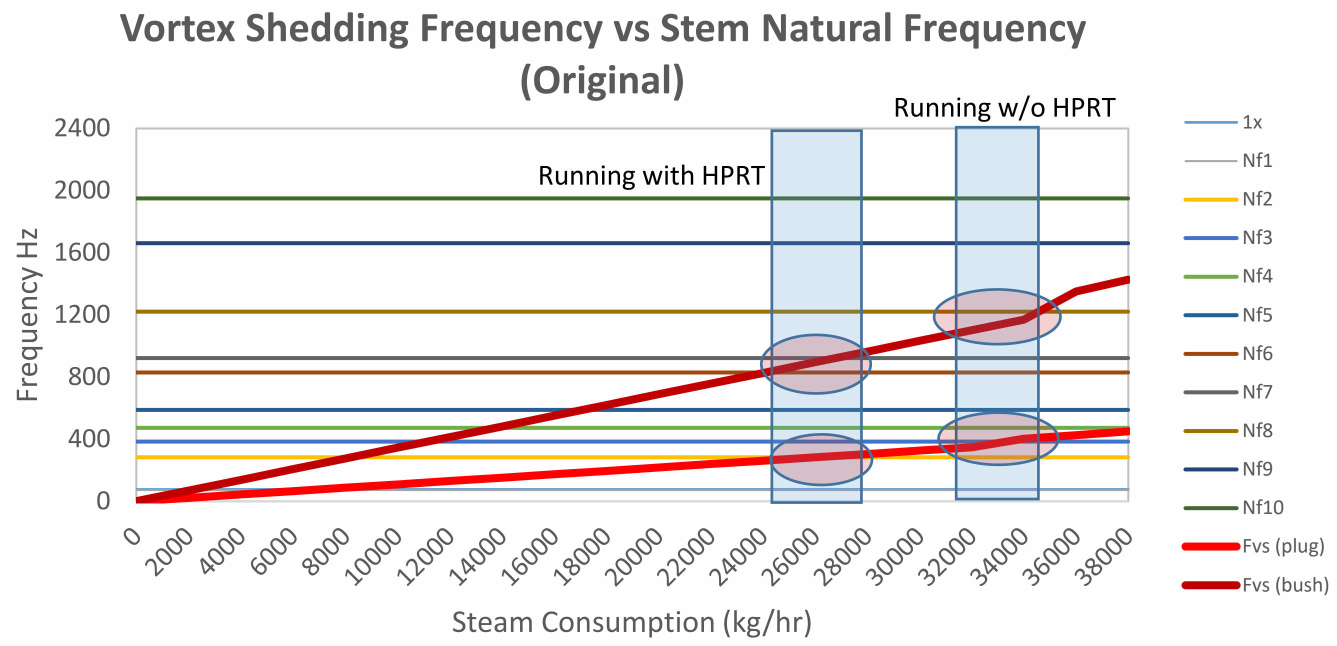
- Evidence of fluid cyclic motion when the steam flow pass through the valve stem which introduce vortex shedding frequency
- Local pressure pulsation measured at the bottom surface of the valve stem

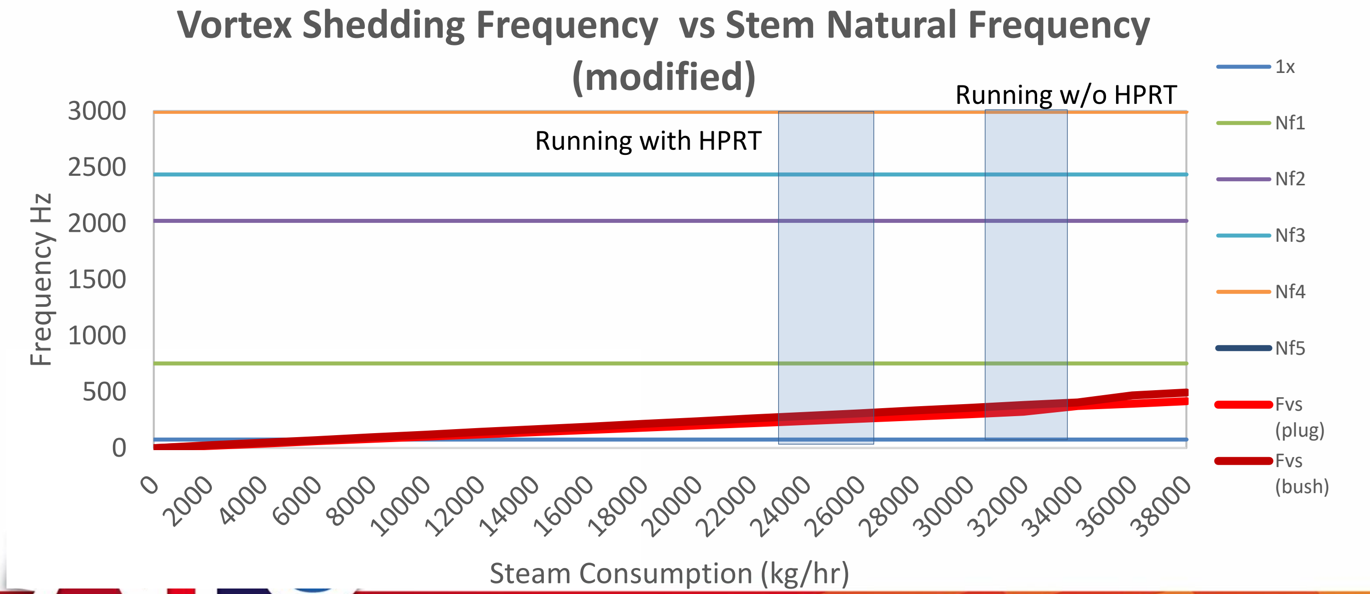




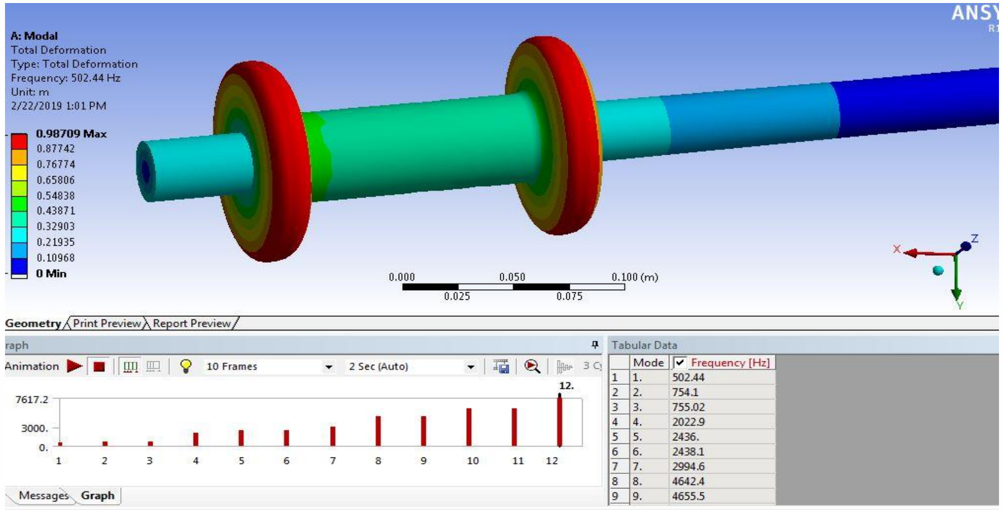


Vortex Shedding vs Stem Natural Frequencies





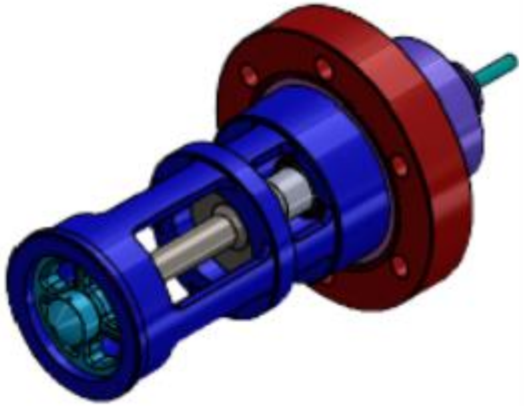
- Vortex shedding frequencies, F_{vs} plotted against stem natural frequencies, $Nf_{1,2,3...}$
- Structural resonance (bending mode) – close separation margin between Nf and F_{vs}
- Modification of valve stem geometry to push further the stem natural frequencies resulted from higher stiffness
- Bending modes natural frequency of modified stem separated from vortex frequencies (for all running modes)

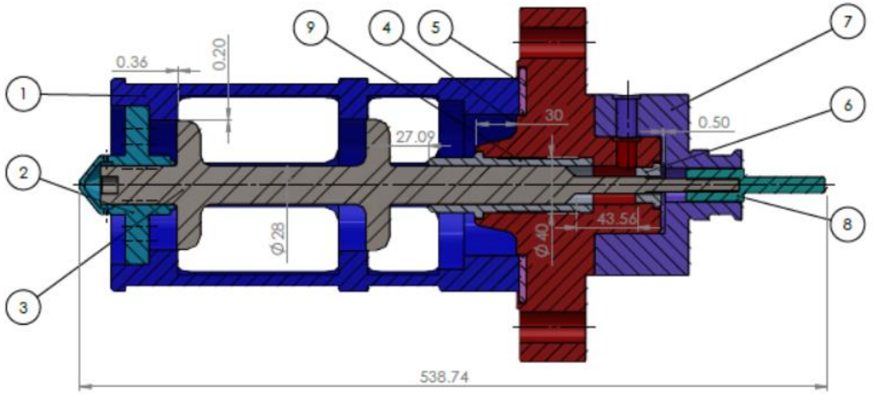


	Mode	Frequency [Hz]
1	1.	502.44
2	2.	754.1
3	3.	755.02
4	4.	2022.9
5	5.	2436.
6	6.	2438.1
7	7.	2994.6
8	8.	4642.4
9	9.	4655.5

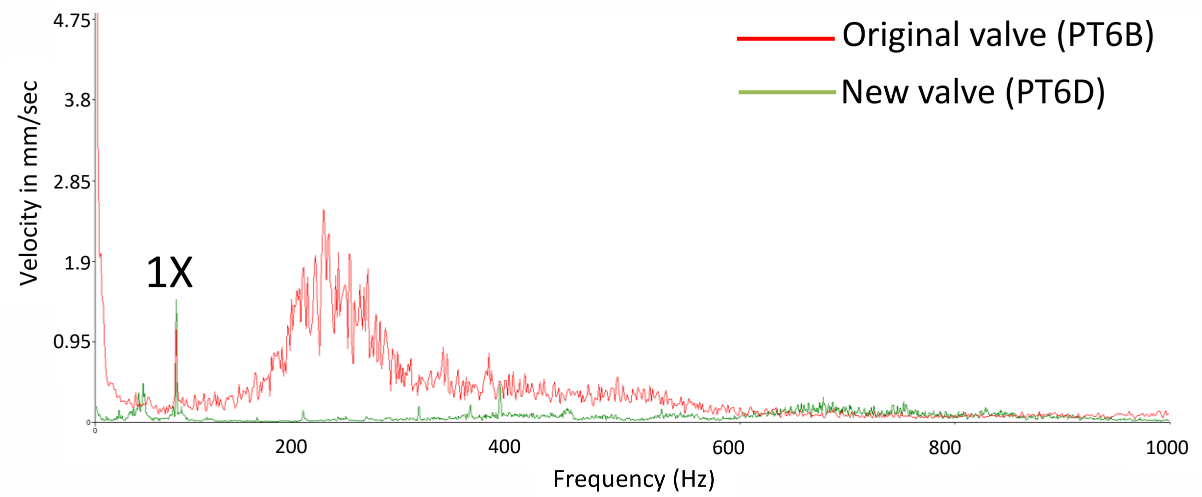
Valve Set Redesign & Installation

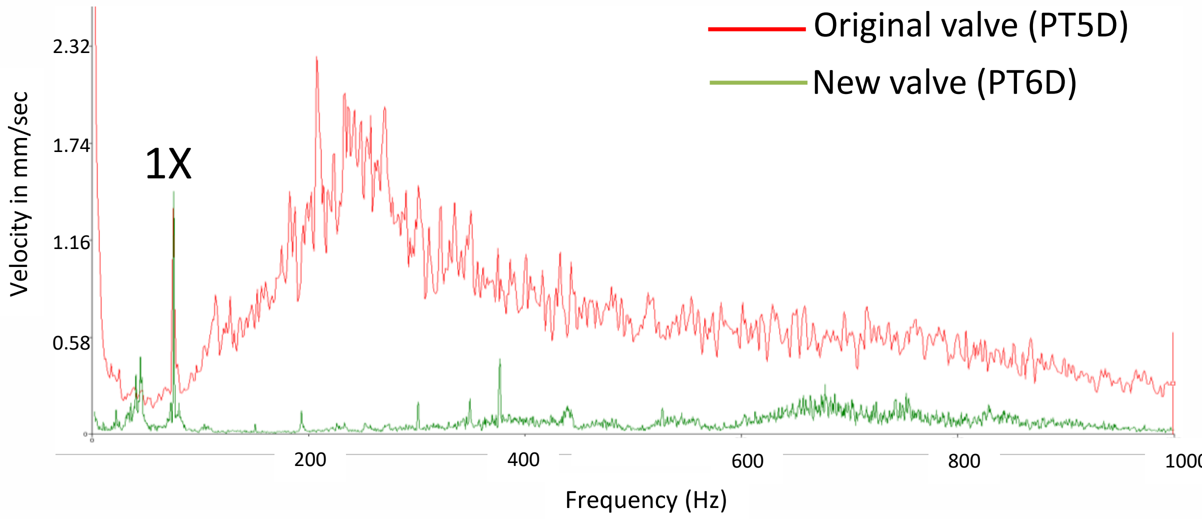
- Larger valve stem diameter to increase stiffness
- Extended length of front-end bushing to increase support area
- Surface hardening process through plasma nitriding and positive vapor disposition (PVD) process to retain the high hardness level within 1700-1900 HV

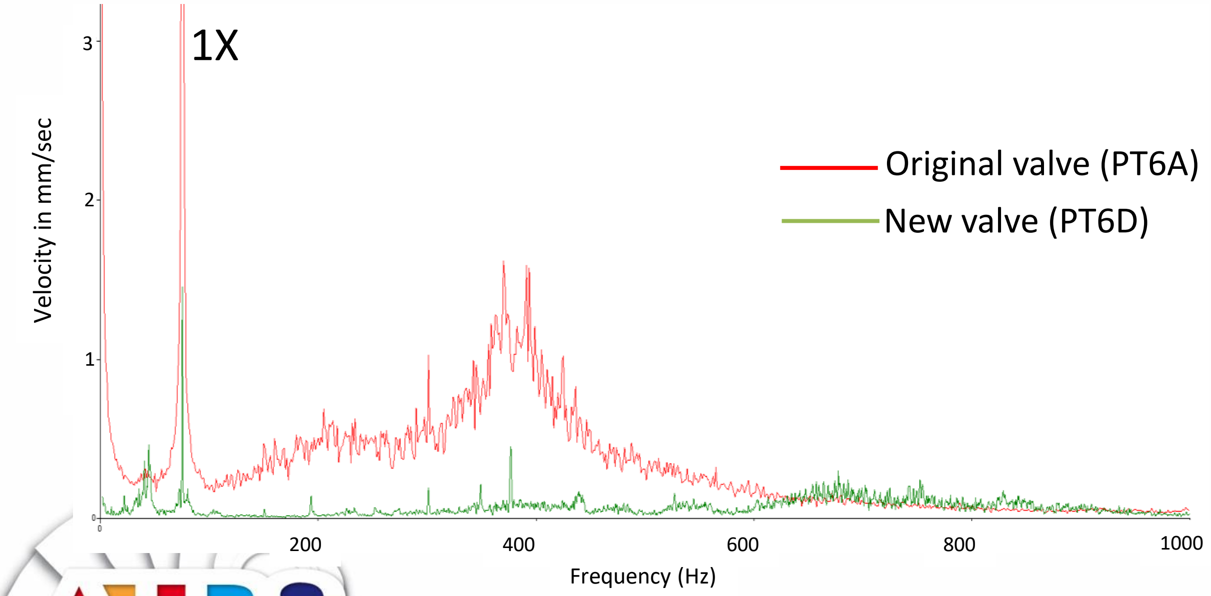




Vibration Result – Post Modification







- Previously dominant broadband peaks (between 200-800 Hz) have been eliminated
- Overall stem vibration for new valve is attenuated as compared to original valve under similar running condition

Post Modification Result

- Improvised geometry of governor valve was installed in 2019 and no broken stem was recorded
- First bending mode of stem natural frequency shift to 754 Hz which is giving more comfort separation margin (> 25%) from calculated vortex shedding frequencies for all running conditions
- Dominant peaks (broadband) have been eliminated with new governor valve stem

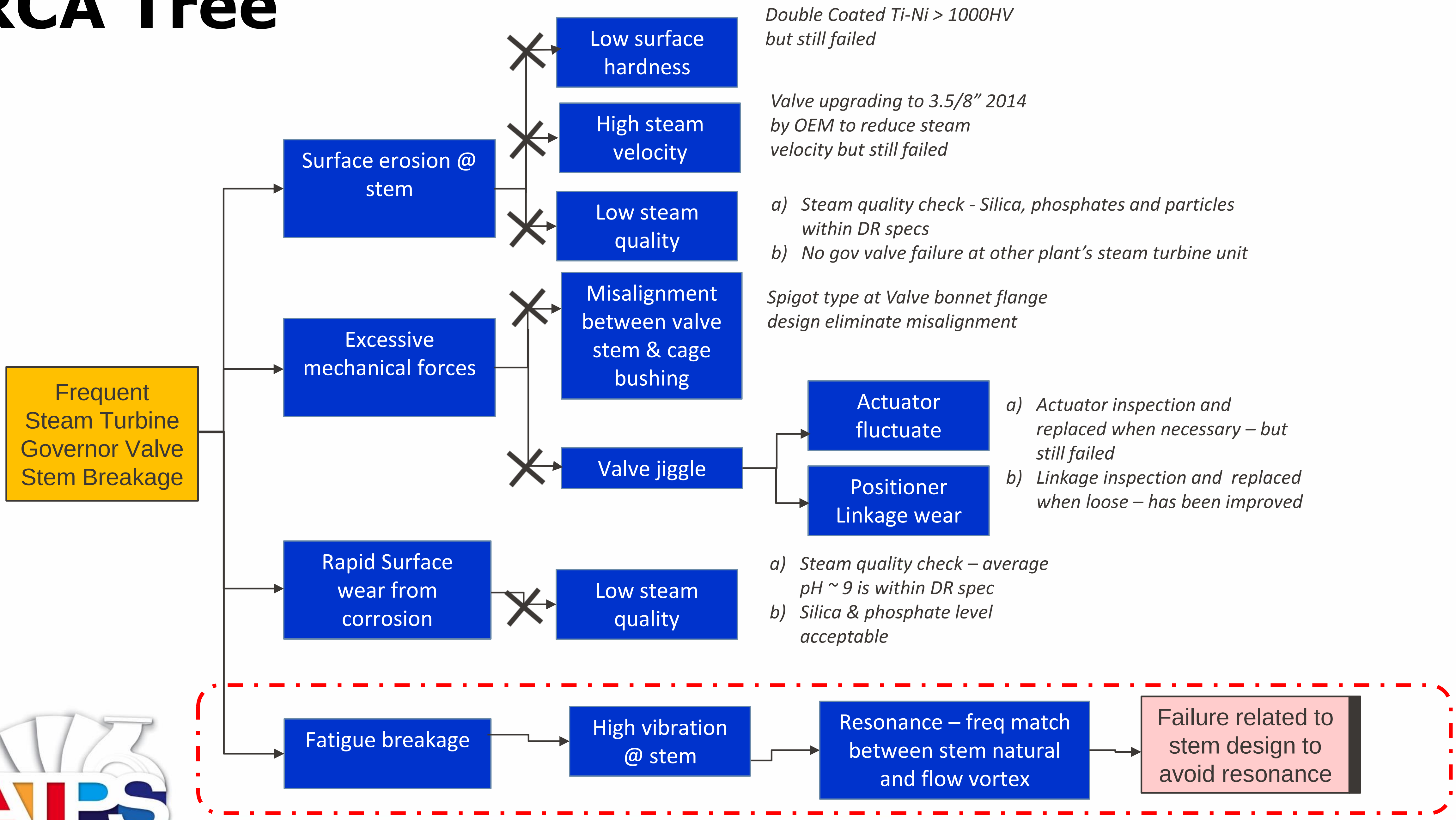
Lessons Learnt

- Resonance effect – close separation between steam flow vortex shedding frequencies and stem natural frequencies (bending modes) led to the valve stem fatigue failure
- Site vibration survey, metallurgy analysis, modal impact testing, FEA & CFD analysis are very useful techniques to unlock the real root cause and validate the design improvement.
- Repetitive failure would stay unresolved until the real root cause is known and addressed

THANK YOU

TERIMA KASIH

RCA Tree



Frequent Steam Turbine Governor Valve Stem Breakage
Surface erosion @ stem
Low surface hardness
Double Coated Ti-Ni > 1000HV but still failed
High steam velocity
Valve upgrading to 3.5/8" 2014 by OEM to reduce steam velocity but still failed
Low steam quality
a) Steam quality check - Silica, phosphates and particles within DR specs
b) No gov valve failure at other plant's steam turbine unit
Excessive mechanical forces
Misalignment between valve stem & cage bushing
Spigot type at Valve bonnet flange design eliminate misalignment
Valve jiggle
Actuator fluctuate
Positioner Linkage wear
a) Actuator inspection and replaced when necessary – but still failed
b) Linkage inspection and replaced when loose – has been improved
Rapid Surface wear from corrosion
Low steam quality
a) Steam quality check – average pH ~ 9 is within DR spec
b) Silica & phosphate level acceptable
Fatigue breakage
High vibration @ stem
Resonance – freq match between stem natural and flow vortex
Failure related to stem design to avoid resonance