Thermal Load Effect on Vibration on a Reactor Feed Water Pump (FWP)

By:

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Maki M. Onari:

- Mechanical Solutions, Inc. – Manager of Turbomachinery Testing Sr. Principal Engineer: responsible for all MSI Turbomachinery Testing

- B.S.M.E., Zulia University, Venezuela

- Rotating Equipment Engineer, PDVSA: responsible for the predictive maintenance of one of the largest petrochemical complexes in Latin America


- Member of ASME and the ISO TC108/S2 Standards Committee for Machinery Vibration

- Presented tutorials, case studies, and lectured at the Texas A&M Symposia since 2007 as lead instructor on vibration short courses.
General Information

Constellation Energy – Exelon Corp.
Nine Mile Point Nuclear Station (NMPNS) Unit 2 – 1150 MW (Oswego, NY)

Application: Reactor Feed Water Pump (FWP)
Type: 20x20x22 – 2 Stage (barrel type radial split)
Capacity: 8,000 gpm (min flow) to 22,870 gpm (max flow)
Normal operation steady slightly above BEP
Suction Press.: 550 psig
Discharge Press.: 1,200 psig
Speed: 3,339 rpm (55.7 Hz)
Temperature: 382 °F
Normal Load: 10,500 to 11,500 BHP
Driver: Induction Motor (16,500 HP @ 1785 rpm (29.8 Hz)
Gearbox: Speed Increaser (Gear ratio 1:1.87)
Repetitive failure mechanical seals since 1987 (MTBF of 6 months on Alpha FWP). Possible axial shuttling of the pump rotor.

Analysis performed by the OEM, the pumps required a series of modifications to improve seal reliability and also increase plant capacity by 15%.

Extended Power Upgrade (EPU)

Background

Former Design Cross Section
20x20x22 – 2 Stage
Background

FAT vibration on the order of 1.0 to 1.5 mils pk-pk

June 2010: High synchronous vibration was detected only at the IB end of the pump shaft (over 4.2 mils pk-pk).

Redesigned mechanical seals

360º drip-pockets

Flow path

Inboard (IB) suction cover

New impellers

Modified in Spring 2010
Initial Testing June 2010
2FWS-P1A Pump Typical FRF Plots

Horizontal Direction

Frequency Response (Signal 4, Signal 17) - Mark 1 (Magnitude)
Working: O1h rec 6, Input: Enhanced

- 44 Hz
- 89 Hz

Axial Direction

Frequency Response (Signal 2, Signal 17) - Mark 1 (Magnitude)
Working: O1a rec 7, Input: Enhanced

- 59.25 Hz

Vertical Direction

Frequency Response (Signal 1, Signal 17) - Mark 1 (Magnitude)
Working: O1v rec 8, Input: Enhanced

- 395 Hz
- 89 Hz
2FWS-P1A Pump Main Mode Shapes

Lateral Rocking Mode @ 44 Hz

Twist Mode @ 89 Hz

Axial Rocking Mode @ 59.3 Hz

OBB Vertical Mode @ 395 Hz
Continuous Monitoring (CM) Testing

Motor

Low Speed DE

Low Speed NDE

Gearbox

Pump

High Speed NDE

High Speed DE

= Proximity Probe

= Long Travel Proximity Probe

= Tri-axis Accelerometer
Shaft vibration mostly at 1x rpm
Bearing housing vibration was acceptable
Pump Shaft Vibration

Shaft vibration mostly at 1x rpm
Bearing housing vibration was acceptable
Orbit Plots 20,000 GPM @ 3:56, 6-13-2010

* View from pump end unless otherwise stated
ODS Animation at 1x rpm
Possible Causes...

- **Misalignment**: Severe offset misalignment between the HS gearbox pinion shaft and the pump. Modify the cold alignment.
- **Coupling Imbalance**: Eccentricity of the coupling spacer from the coupling mounting center line.
- **Thermal growth**: Between the pump shaft and the HS gearbox pinion.
- **Verify**: The radial position of the coupling spacer for potential eccentricity that could lead to imbalance forces.
March 2011 Vibration Data
Alpha FWP Testing – Root Cause Detection

- Installed temporary thermocouples at the IB and OB faces of the pump casing to measure transient temperature field
- Installed temporary laser instrumentation to measure thermal growth of the pump casing in the axial and horizontal directions
- Modified the warm-up procedure to alleviate rubbing during high thermal gradients within the pump (reduced seal cooling water flow rate from 10 to 5 GPM)

Verified/ corrected the misalignment of the entire train

Tri-land bearings (7 mils diametral clearance)

Reduced the torque OB pump

Adjusted the turn-buckles as per OEM’s spec
GB HS DE - Shaft Vibration

Gearbox, High-Speed Shaft, Drive-End Bearing

Overall Pk-Pk Vibration [mils]

Start-up

Shut-down
Pump - Shaft Vibration

Pump Inboard Bearing

Pump Outboard Bearing

Start-up

Shut-down
Shaft Orbits

View from East (pump OBB)
Initial Recommendations:
- TIR on V-blocks and
- FEA thermal analysis of the casing
Pump OBB - Shaft Movement

Pump Outboard Bearing

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0.9 mils
Root Cause

1\textsuperscript{st} stage flow path did not allow uniform thermal expansion of the pump casing at the IB end cover. Former seal injection design allowed accumulation of condensate seal water at the bottom of the pump casing with lower temperature than the reactor feed water. This was causing distortion of the inboard cover plate and therefore internal misalignment at the IBB.
June 2012 Vibration Data FWP A/B/C Follow-Up Testing

- New rotating elements on all three pumps
- New gear set (output speed from 3,339 rpm to 3,400 rpm)

Balance drum re-dimensioned to provide unidirectional thrust load at any flow rate. (rotor at times had been under compression towards the outboard (OB) end)

Tri-land bearings

New Seal API Plan 23

Plant EPU Project

2FWS-P1A/B/C Modified by June 2012
2FWS-P1A Pump Shaft Vibration

Pump Shaft Vibration - Inboard

Pump Shaft Vibration - Outboard

2.3 mils pk-pk
Final Conclusions

1. Modifications implemented on these pumps during the outage (i.e. seal injection API plan 23) eliminated the thermal distortion effect that was causing deformation of the inboard end cover of the pump.

2. Previous seal injection design allowed accumulation of condensate seal water at the bottom of the pump casing with lower temperature than the reactor feed water. This was causing distortion of the inboard cover plate and therefore internal misalignment at the IBB.

3. The shaft vibration at the IBB used to be approximately 4.5 mils pk-pk, while the vibration at the OBB was approximately 1.0 mil pk-pk. Vibration data gathered after the outage indicated significant improvement at the IBB (2x reduction).

4. Radial proximity probe GAP voltage readings were not changing over time during the warm-up or cool-down processes, versus such changes that had been identified in previous tests.
Final Recommendations

1. Pre-installation FEA analysis (structural and thermal) would have been able to reduce risk by spotting problems before they occur (PREVENTION).

2. ODS / EMA / Continuous Monitoring Tests coupled with appropriate analysis is a powerful troubleshooting tool to identify and visually understand the most difficult vibration problems in turbomachinery and pumping systems.