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# Vertical Turbine Pump Reliability Improvement

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Yve Zhao is a Rotating Equipment Engineer working for BP Upstream Engineering Center. Having worked in the turbomachinery field for 25+ years, in her current capacity, Yve provides support to the upstream business lines within BP with expertise on vibration diagnostics, rotor/thermodynamics, failure analysis, and health monitoring of rotating equipment.

Prior to joining BP, she worked as a Rotor Dynamicist at CONMEC supporting centrifugal compressor, steam turbine, expander and axial compressor product rerate projects, as a Principle Rotating Equipment Engineer at Air Products and Chemicals on Air Separation, HYCO and Chemical projects, and as a Staff Rotating Equipment Engineer for BHP central engineering and midstream production unit.

Yve Zhao earned a BSME (1992) and a MSME (1997). She has authored papers on turbulent flow seals, bearing dynamics, and case studies on machinery failure and root cause analysis. Currently, she holds positions in the Vibrations Institute - training committee.

# Abstract

The subject pump was designed and installed when pipeline pressure was estimated high based on a higher production volume. The selected multistage vertical turbine-pumps are **generically** prone to vibration issues due to its flexible shaft design.

Due to the deviation between the pump design condition and its actual operating condition, flow turbulence and recirculation in the pump impellers produced enough vibration excitation forces that caused the mechanical seals to fail prematurely and to leak.

**Pump restaging** was not implemented due to the relatively high cost and uncertainty of a future line pressure. Since the pump is used for batch services, not its entire operating flow/pressure range is necessary to meet production needs.

**Performance and Reliability Mapping (PRM)** conducted instead thus ensuring a higher MTBF on the pump and seal components.

# Sequence of Events

- Vertical Turbine/Pump used for pipeline transport service experienced high level of vibration that caused premature seal failures and condensate leakage.
- Radial Vibration produced severe damage of top two bushings (last two stages). 1st stage bushing showed edge loading wear pattern.
- Rotor dynamics report indicated rotor resonance at lower end of the operating speed range.
- During pump repair, tighter clearance bearing bushings were installed (3rd party repair shop). Rebuilt pump ran with loud metal scratching noise and leaking condensate from the mechanical seal over most of its operating speed range.

# Sequence of Events – cont.

- Reviewed pump curve and compared with other transport pumps for similar service. The review indicated pump re-staging would bring pump to operate closer to its rated condition and enable an extended operating range. This recommendation was not implemented.
- Vibration signatures at various speed and back pressure taken to generate Performance & Reliability Map (PRM) to set a "**safe to operate range**".
- Transitional seal flushing orifice installed to reduce a turbulence flow effect on the rotor but results were marginal.
- In addition, a review of thrust loading showed absence of balance orifices in the impellers for VFD drive pump. Motor bearing selection needs to be reviewed to consider thrust load to prevent frequent bearing failure.

# Pump System Configuration

**Two (10 stage) pumps for on-stream backup.**

Back pressure control valve.

VFD for speed control.

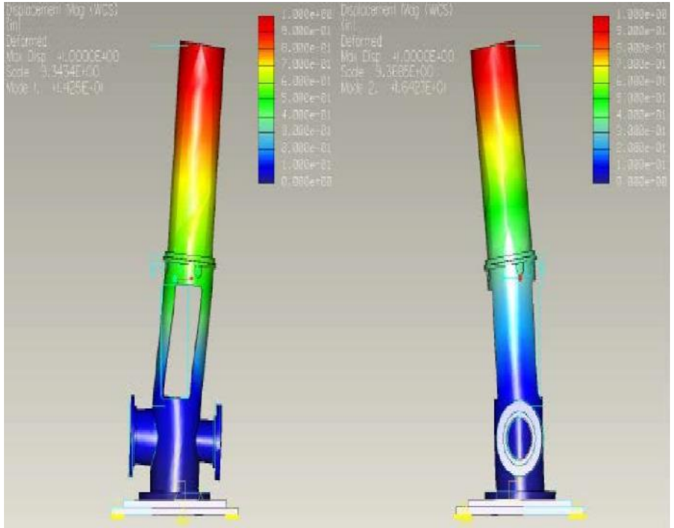
One pump with slightly higher system resistance – on the right.

# Rotor Resonance

- Narrow operating speed range (885 – 985 RPM)
- Pump critical speed is highly reliant upon bushing clearances.
- Large clearance bushings were originally installed
  - Typical bushing clearance (per OEM):

    6 - 13 mils diametral (1.7” journal, Cd/D= 3.5~7.6 )
  - Actual bushing clearance:

    11 - 21 mils diametral (1.7” journal, Cd/D= 6.5~12.4)

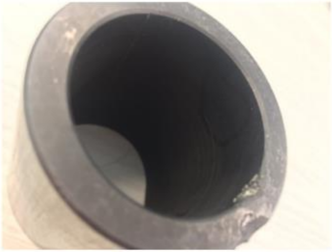


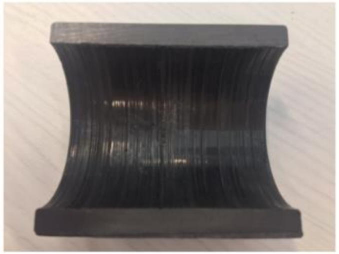
**Operating Deflected Shapes at Resonance Speed**

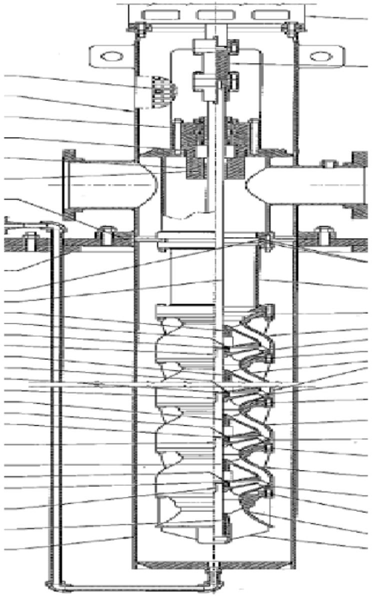
# Wear Pattern – Shaft and Bushings

Flow recirculation on the top stage caused more damage to the top two bushings.  Bottom 1st stage bushing was edge loaded.

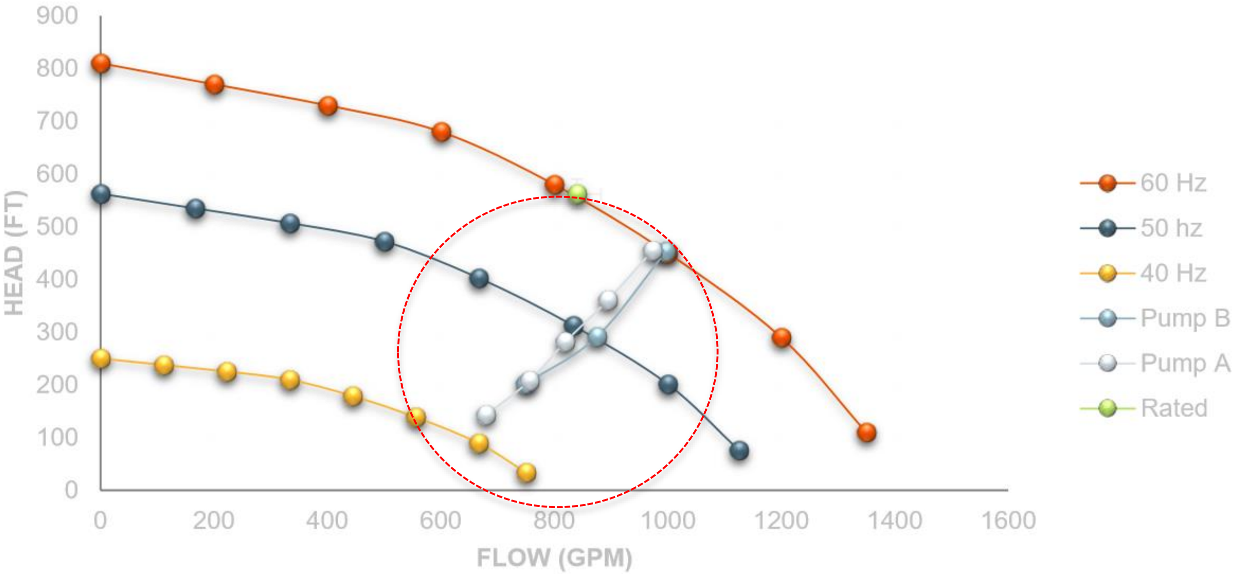
**Pump has 10 stages. Catalog picture used to show configuration:**



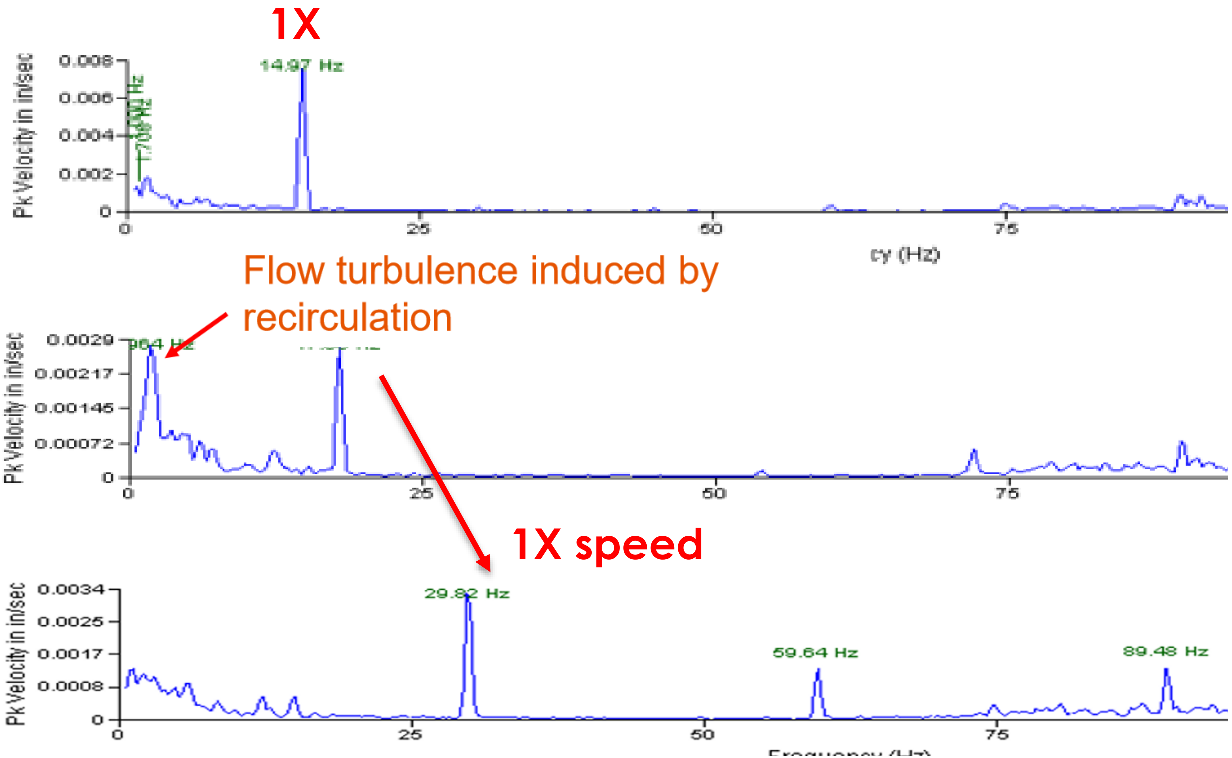




# Pump Curve and Operating Points



# Vibration Spectra At Various Speeds



# Performance & Reliability Mapping (PRM)

speed

| Frequency | Valve | Pump B |
|---|---|---|
| | | Vibration |
| 30 Hz | 50% | good |
| 30 Hz | 100% | good |
| 35 Hz | 50% | good |
| 35 Hz | 100% | good |
| 40 Hz | 50% | good |
| 40 Hz | 100% | good |
| 48 Hz | 50% | light rub |
| 48 Hz | 100% | light rub |
| 50 Hz | 50% | - |
| 50 Hz | 100% | - |
| 54 Hz | 50% | rub |
| 54 Hz | 100% | rub |
| 60 Hz | 50% | rub |
| 60 Hz | 100% | - |

## Pump A

| Frequency | Valve | Pump A |
|---|---|---|
| | | Vibration |
| 30 Hz | 50% | - |
| 30 Hz | 100% | - |
| 35 Hz | 50% | light rub |
| 35 Hz | 100% | light rub |
| 40 Hz | 50% | good |
| 40 Hz | 100% | good |
| 45 Hz | 50% | good |
| 45 Hz | 100% | light rub |
| 48 Hz | 100% | light rub |
| 50 Hz | 50% | good |
| 55 Hz | 50% | good |
| 55 Hz | 100% | - |
| 60 Hz | 50% | good |
| 60 Hz | 100% | - |

## Pump B

# Thrust Load

- Variable Speed Drive.
- Unbalanced impeller Thrust.
- Rigid Drive Shaft
- **Motor Bearing takes Thrust Load!!!**

**Turbine/Pump Impellers** – No Balance Orifice

# Summary

**Issue:**

Vertical pump prone to vibration issues due to its flexible shaft design, highly turbulent flow and high pressure application with variable operating condition. Issue caused seal leak due to vapor created by heat generated when seal rubbed.

**Solution:**

Pump restaging was not implemented due to relatively high cost and uncertainty of future line pressure. As the pump is used for batch services, not the entire operating range is necessary, hence **performance mapping was performed instead of a reliability improvement**. Seal leaks stopped once implemented speed envelope.

**Other Learning:**

- Proper seal design is key to reliability of the vertical pump.
- VFD driven pumps need to be performance and reliability tested for their intended service→ to establish "good/safe to operate range."
- Thrust loading need careful reviewand results utilized for a proper motor bearing selection. Current system has a rigid drive coupling and lacks a thrust load control.

34h Pump Case Study:

# Vertical Turbine Pump Reliability Improvement

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# Questions (?)