Material Challenges and Suggestions for Pumps in Hot Naphthenic Acid Containing Crude Oil Services

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Abstract:
As the global demand for fuels continued to grow, refineries changed to accommodate heavier crude oils. Many of those heavier oils contained Naphthenic acid which posed further corrosion challenges at the high process temperatures required.

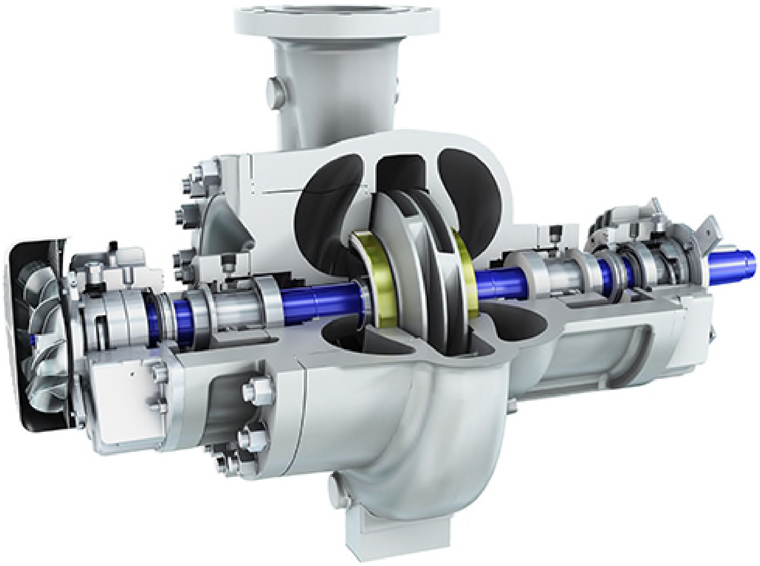
These challenges included moving from pump materials that are typically stable at high temperatures, such as CA6NM, to less stable higher nickel stainless steels. Those have a higher propensity to distort under high thermal stresses and have variable rates of thermal expansion that increase with process temperature.

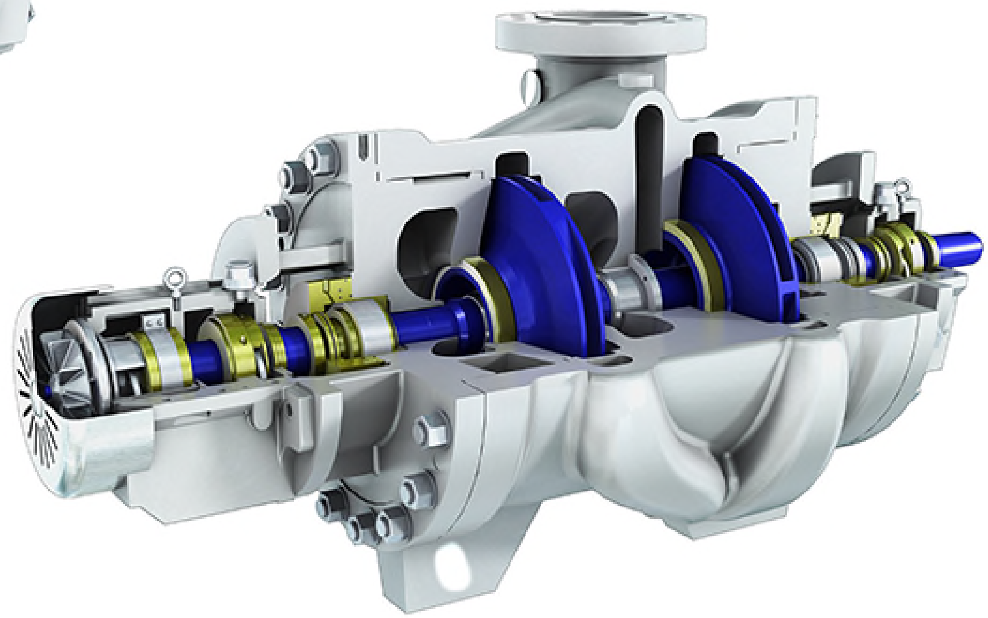
This case study lists the challenges and discuss the changes in material selection, dimensional stabilization procedures, machining methods and suggestions for changes to process start-up and shut-down procedures to improve reliability of the pumps.

Problem Description

- Single and Two Stage Between Bearing Pumps (BB2)
- Vacuum Bottoms and Atmospheric Residue Services
- High Temperature Operation – up to 360°C (681°F)
- Potentially Corrosive Pumpage – Crude oil with Naphthenic Acids
- Pump Construction – 317L Stainless Steel
- Thermal transients for start-up and shut-down are very fast and enact high thermal stresses in the pump case and shaft, causing major distortion
- Distortions due to thermal stresses resulted in rotor lock-up and extensive repairs to return casing registers and fits to proper sizes
- MTBR has been as little as 6 months or less
- Repairs are long leadtime and very expensive

Typical Pump Design





Pumps are quite large. Discharge sizes vary from 6” to 10” and impellers can be up to 690mm (27”) diameter. Shafts can be over 2m (6 ft) long and up to 115mm (4.5”) in diameter.

As-Purchased Pump Materials of Construction

- Pump Case – 317LSS (ASTM A351 Gr. CG-3M)
  - Standard solution annealed material

- Impeller – 317LSS (ASTM A351 Gr. CG-3M)
  - Standard solution annealed material

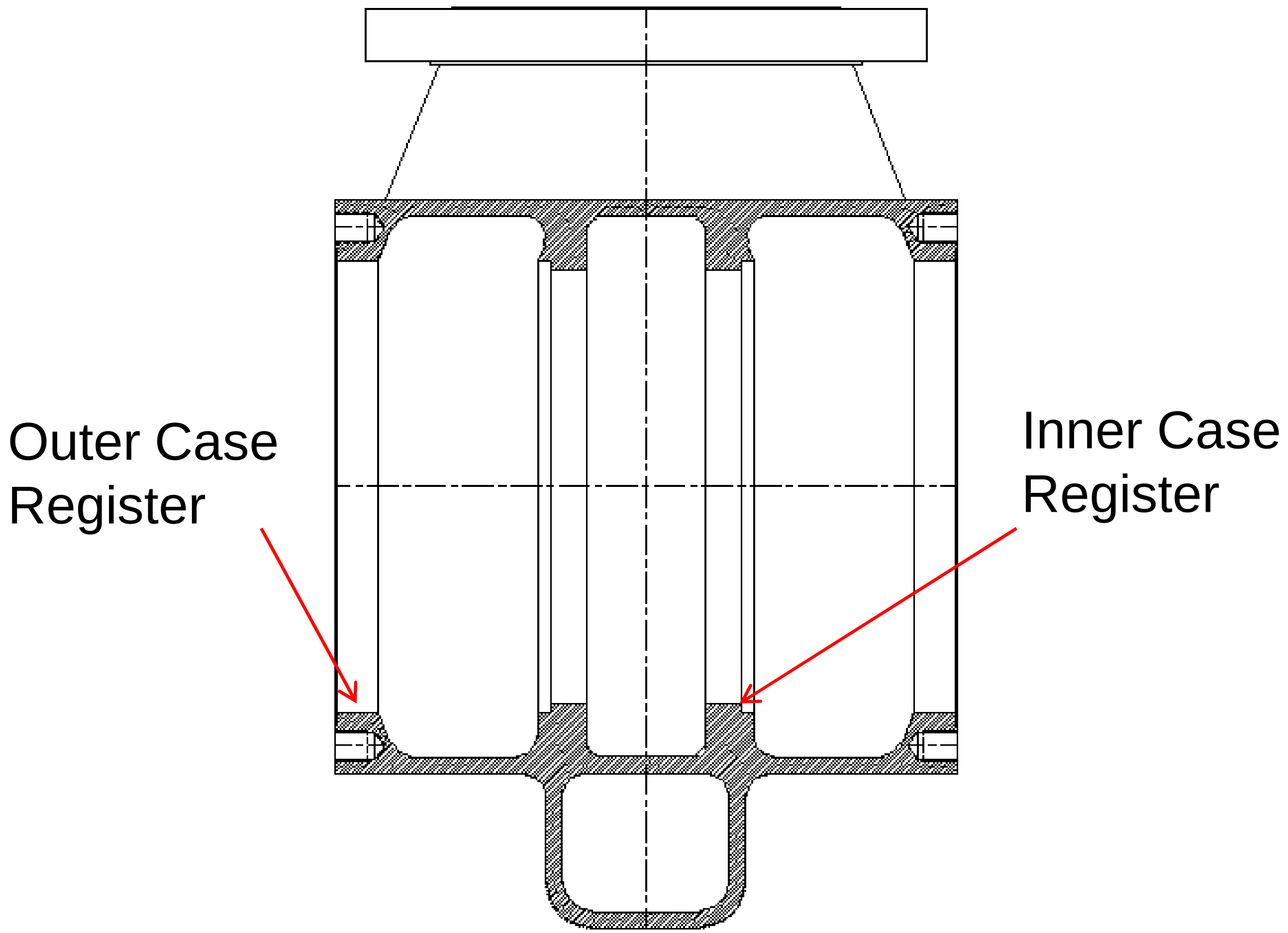
- Shaft – 317LSS (ASTM A276 Type 317)

Original Unit Start-Up and Shut-Down Procedures

- The original heat up process:
  - Line up purge oil to the seal flush.
  - Open suction valve
  - Open all warm up lines and discharge line.
  - Allow pump to warm up to within 55^{o}C (100°F) dT of running temp 260^{o}C (500°F).
- Problems with the original procedure:
  - Opening the suction first allowed the purge oil to travel into the suction of the sister pump. That then flashed in the hot running pump and caused extreme cavitation.
  - There were no real steps to control or monitor the temperature rise in the pump.
- The original procedure did not call for a cool down process.
  - The pump was simply shutdown; discharge, suction and seal flush valves were closed.
  - The pump was then flushed with 93°C (200°F) kerosene. After 2-4 hours of flushing the pump was then steamed to the vacuum tower for 8 hours.
  - The operator would then allow the pump to cool for 2-3 hours and perform a gas test.
  - If the gas test was bad they would repeat the steps until they got a good gas test.
  - This was normally repeated several times with the end result being a warped shaft.

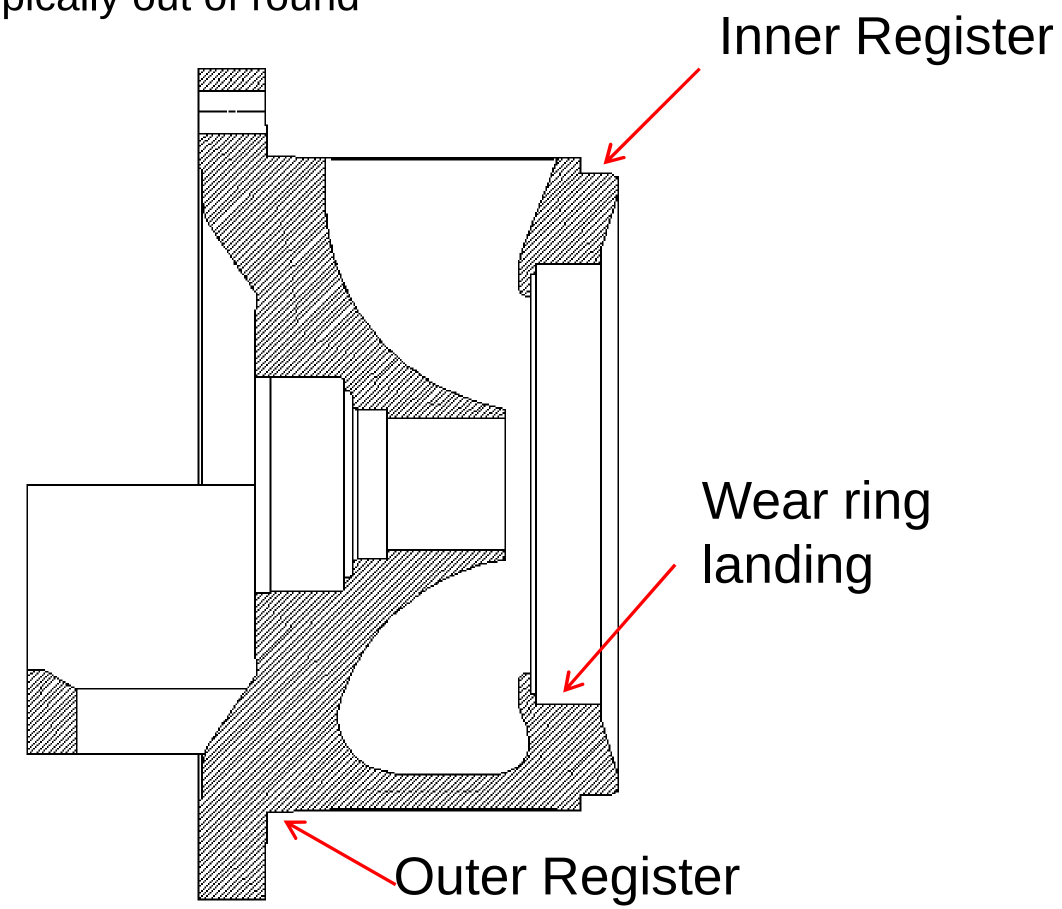
Typical As-Found Deviations

- Case Registers
  - Case registers at the outer case gasket became out-of-round by nearly 762 µm (0.030”)
  - Inner case register that seals suction from discharge is out-of-round by 280 µm (0.011”)



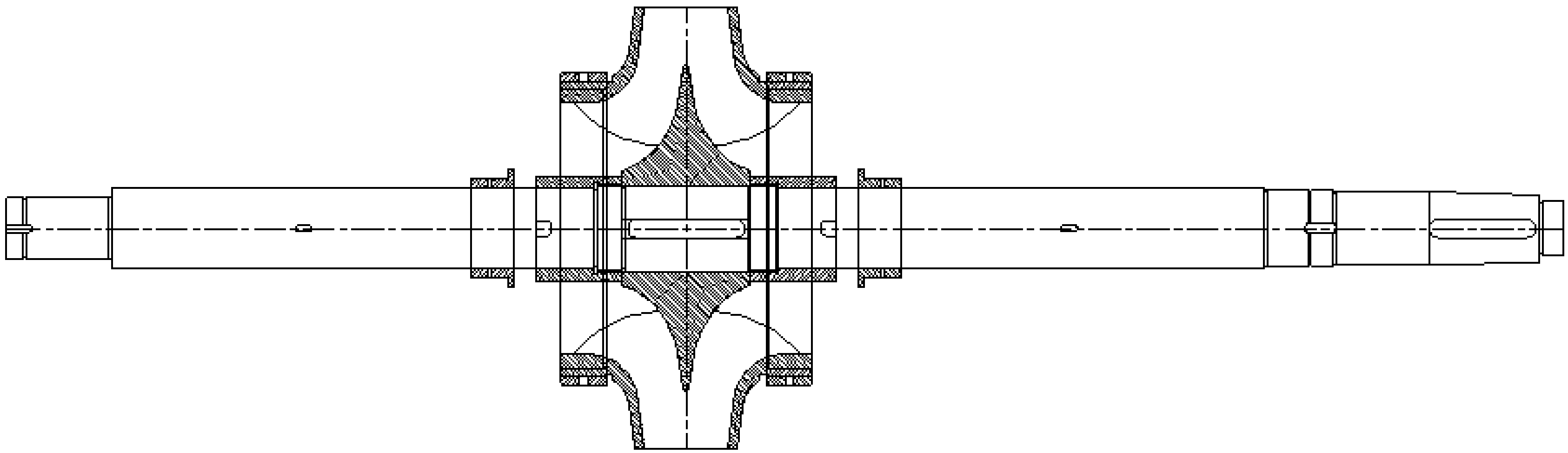
Typical As-Found Deviations

- Case Cover Registers
  - Outer cover registers not grossly out of round
  - Inner cover registers out of round by 203 μm (0.008")
  - Wear ring landing typically out of round



Typical As-Found Deviations

- Shaft
  - Shaft had developed a bow of nearly 1016 µm (0.040”) which exceeded the wear ring and bushing clearances
  - Rotor was locked-up in casing and would not rotate



Recommendations for Material Selection and Manufacturing – Pump Shaft

- Material Change of Shaft from 317LSS (ASTM A276 Type 317LSS) to Nitronic 50 (ASTM A479 Type XM-19)

	317LSS	XM-19
UTS @ Ambient	75 ksi	100 ksi
Yield (0.2%)	30 ksi	55 ksi
CTE	10.1 µin/in/°F	10.1 µin/in/°F
PREN	34.4 – 41.7	28.7 – 39.8

- Nitronic 50 has a much higher Tensile and Yield strength and is less prone to distortion due to thermal shock
- Coefficient of Thermal Expansion is similar to 317LSS
- The corrosive nature of the Naphthenic Acid is intensified with higher fluid turbulence and velocity. Although the Nitronic 50 moly content and PREN range is lower than 317L, peripheral velocities around the exposed areas of the shaft are much lower than at the impeller vane tips and volute throats. Therefore use of Nitronic 50 shaft material is not a primary concern for life expectancy of the pump.

Recommendations for Material Selection and Manufacturing – Pump Shaft

- General Manufacturing Process
  - Rough machine shaft
  - Rest shaft for several days
  - Normalize shaft at a temperature above the process temperature
    - NOTE: Ramp rates up and down, must be very carefully controlled
  - Rest shaft
  - Check Runout
  - Finish machine, taking very little material with each pass
  - Rest shaft
  - Perform final inspection

Recommendations for Material Selection and Manufacturing – Pump Case Components

- Pump Case and Case Covers are currently 317LSS (ASTM A351 Gr. CG-3M)
- Due to the varying crude products that may be refined, the pump case materials have not been changed.
- Manufacturing procedures similar to shaft
  - Rough machine critical fits
  - Normalize / stress relieve case
    - Very slow ramp up
    - Long soak at temperature exceeding product temperature
    - Very slow cool down
  - Finish machine
  - Final inspection
- Per API 610 11th ed. para. 8.3.2.10, any full pressure hydrotesting required must be done in rough machined state due to potential for material distortion

Changes in Processes for Start-up

Warming and Lining-up Pump

- Fully open all warm-up lines including case drains.
- Confirm the line from the pump vent into the Vacuum Tower is clear.
- Open the seal flush and set at 15 l/m (4 gpm). This will allow a warm-up of approximately 42°C (75°F) dT per hour. Monitor the case vent line to confirm there is purge oil flowing through the pump.
- Do not allow the case pressure to exceed 3.5 Bar (50 psi) to protect the mechanical seals.
- When the case temperature reaches 150°C (300°F) open the discharge bypass valve.
- This will allow hot resid to enter the pump via the warm up line around the check valve.
- Monitor the temperature until it reaches 200°C (400°F).
- Open the suction valve and close the vent line on top of the pump.
- Allow the pump to heat soak for 2 hours. There should be a temperature increase of 28°C (50°F) dT.
- Close discharge valve bypass line. The pump is now ready to start.

Changes in Processes Shut-down

- Cooling Pump for Shutdown and Repair.
  - Confirm all warm- up and vent lines are open and clear.
  - Confirm the seal flush is set at 15 l/m (4 gpm). Close the suction valve and allow the pump to cool to 200°C (400°F).
  - At 200°C (400°F) close the discharge valve and continue cool down with the seal flush of 15 l/m (4 gpm).
  - Have the coupling guard and spool removed. Install components required to turn pump.
  - At this point the pump is to be turned 1-1/2 turns per hour.
  - Flush with seal oil at 15 l/m (4 gpm) for 3 hours. This will cool the pump to 180°C (350°F).
  - Reduce the seal flush flow to 11 l/m (3 gpm) for 2 hours.
  - Reduce the flush flow to 8 l/m (2 gpm) for 2 hours. This will reduce the pump temperature to around 150°C (300°F).
  - Reduce the seal flush flow to 4 l/m (1 gpm) for 2 hours. The pump temperature will be below 150°C (300°F). Close the seal flush and allow pump to cool to 120°C (250°F). Begin the Kerosene flush.
  - After 12 hours of Kerosene flushing close valve and begin steaming the pump for 4 hours. At this point the pump is ready for repair work to begin.

Results of Process and Manufacturing Changes

- Case Register Runout
  - After implementation of the heat treatment and site process changes, register runouts after shut-down have measured significantly less.
    - Prior to normalizing / stress relief procedure – 762 µm (0.030”) runout
    - After normalizing / stress relief procedure – 254 µm (0.010”) max runout
- Shaft Runout
  - Shafts that have been changed to Nitronic 50 material show no run-out at inspection after change in manufacturing procedures and site commissioning and decommissioning procedures. They are reusable.
  - Shafts manufactured from 317L material that has been subjected to the same manufacturing procedures and start-up and shut-down procedures show 25 µm (0.001”) runout max. They are reusable in many cases.
  - Prior to implementing the new procedures, pump would be locked-up at every seal maintenance interval. Now it can be turned with little effort.