CRANE CHEMPUMP USE IN HYPERGOLIC SERVICING SYSTEMS

EVALUATION AND RECOMMENDATION

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HISTORY

- **Titan program has had 4 oxidizer Crane Chempumps fail in service with potentially catastrophic results in the past 10 years.**
  - **2 failures were due to incompatible bearing material- new bearing material is now used**
- **Titan's response to the failures:**
  - **Install blast shields around the pumps**
  - **Perform maintenance checks every 60 hours of run time (only 2 launches remain)**
  - **Established a minimum flow rate (after last pump failure)**
- **Upon notice of the latest Titan oxid pump failure, Suspect PR's were initiated for all Crane Chempumps installed in the LC39 A/B areas (8 pumps, 4 locations).**
- **Pad B has removed and inspected the oxid and fuel pumps noting removal condition. Estimate of run time is 450 hours for oxid.**
- **New oxid and fuel Crane Chempumps have been installed at Pad B.**
- **New pumps were disassembled and inspected. All internal fasteners were torqued to the high end of vendor's recommended ranges and staked per vendor recommendation. After reassembly the pumps were leak checked at operating pressure.**
- **Meeting between USA and NASA SE, Design, Reliability, Safety Engineering to discuss hazard mitigation and Preventive Maintenance Plan.**

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FAILURE MODES

- Excessive wear or failure of the carbon graphite journal bearings causing the rotor assembly to "drop", wearing a hole through the stator, allowing propellant to contact the copper stator windings causing rapid over pressurization of the stator housing to the point of burst.
- Plugged or restricted re-circulation tube. The propellant provides the cooling, lubrication and thrust balance for the pump. Failure of the re-circulation tube will result in several conditions detrimental to pump life (stator over heating, cavitation, excessive bearing wear…)
- Pump inlet conditions not appropriate for commodity being pumped. Low inlet pressure to the pump can result in the propellant (oxid) to boil off cavitating the pump.
- Errors in manufacturing/assembly/installation of the pumps.

Failure Modes/Risk

- Safety risks associated with Hot Flow
  - Potential defects in stator housing could lead to pump failure
    - Titan experienced this failure with a pinhole defect in the stator housing- pump suffered an explosion
    - Defects could have resulted from a weld defect or by poor disassembly/reassembly techniques
    - Bearing wear could result in scoring of the stator housing and breach of the pump
  - Potential for journals and bearings to be outside vendor spec
  - Particles may enter pump with no filter on recirc line
  - Low flow rates may cause improper cooling of the pump
- To mitigate these problems:
  - Pump stator housing should be mass spec'd for defects
  - Journals and bearings should be measured and compared to vendor specification.
  - Maintain proper flow rate and document a minimum standard
  - Other unknowns

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REMOVED PUMP FINDINGS

- **Observations of note were:**
  - **During the disassembly of the oxid pump #1, two of the three front bearing retaining screws were found in the bottom of the impeller housing**
  - **On oxid pump #2, all screws were only hand tight**
  - **On oxid pump #1, pieces of graphite were missing from the front and rear bearings**
- **General Observations:**
  - **Pump #1 shows more wear than pump #2**
  - **Oxidizer pumps show more wear than fuel pumps.**
  - **Pump design allows for metal to metal contact of moving parts.**
  - **Wear on fuel pumps does not seem to be excessive.**
  - **Wear on oxid pumps indicate out of tolerance conditions.**
  - **Areas of scoring are noted on all journals.**
  - **Journal design is different between oxidizer and fuel. Why?**
  - **We suspect pumps were not properly torqued to vendor's recommended specifications prior to shipping to KSC.**

NEW PUMP DESIGN

- The new pumps installed have several new features:
  - Concentrically serrated sealing surfaces on impeller and rear bearing housing.
  - Thermal cut out (TCO) switch has been replaced with a thermocouple.
  - Dry well installed for thermocouple (eliminates leak point).
  - New pumps should have a bearing wear indicator per spec, but do not (bearing indicator would void the pumps explosion proof rating).

- New design features do not mitigate failure mode hazards.

HAZARD MITIGATION

- Several engineering and mechanical controls are in place to prevent major pump failures:
  - Thermocouple replaces the unreliable TCO and provides real time analysis of temperatures in the rear bearing housing. The PLC will be programmed to shut down the pumps if the fluid temperature is greater than 140 degrees F.
  - Stator thermal cut out provides protection for the stator winding insulation. Pump is shut down if windings temperatures are greater than 240 degrees F.
  - Axial flow inducer provides a reduction of the NPSH (Net Positive Suction Head) maintaining a high inlet pressure condition to eliminate boil off and pump cavitation.
  - Pumps are not operated outside of the design limits.
  - Pump bearings are wetted prior to initial start up.
  - All pumps will be pressurized to NOP and mass spec tested to verify no leakage greater than 1 $x10^{-4}$ scch GHE prior to initial pump start.

VENDOR ISSUES

- Upon receiving the "new" pumps several discrepancies were noted:
  - Pumps were in quality inspection for 6 months due to two receiving issues:
    - The pumps were not "clocked" as called out in the procurement spec 79K24796.
    - No evidence that supplier has an approved NHB 1c (PA51) inspection system as required by PO.
- All six new pumps were obtained by SE, inspected and configured for installation into the hyper system. SE findings during pre-installation testing were:
  - Recirculation tubes on all pumps not flared properly.
  - Two pumps had casting flaws resulting in external pin hole leaks on the rear bearing housing.
  - All pumps were not torqued (most bolts were hand tight)
  - Vendor drawings lacking detail

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CORRECTIVE ACTIONS

- To mitigate the failure mode hazards, the following actions will be taken:

  - Development of a maintenance program
    - PLC monitoring program created to provide trend data for:
      - Pump run time
      - Cumulative run time
      - Rear bearing thermocouple output
      - Flow rate
      - Pump current
      - Pump outlet pressure
    - Utilize predictive engineering tools to gather trend data (vibration, thermal…)
    - Establish a maintenance check (overhaul at 300 hr time)
    - Motor windings are checked annually for resistance decay (PMOMI).
    - Verify pump assembly and leak check prior to installation in hyper system.
    - Verify vendor quality process is adequate.

  - Establish operation limitations:
      - Max/min flow rate = 60/110 gpm (vendor recommended min is 20 gpm)
      - Max/min current = TBD by vendor
      - Max operating temp = 140 F (same as rear bearing TCO)

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CORRECTIVE ACTIONS CONT

- For the Hot Flow period, the pumps will be operated without a blast shield. Blast protection for pumps will be reviewed fully after conferring with the vendor and after review of Titan's completed failure analysis completion.
- Assess need for external pump cooling unit for oxidizer due to volatility.
- 79K24796 Pump spec will be modified to increase detail for pump ordering and PQA inspection.

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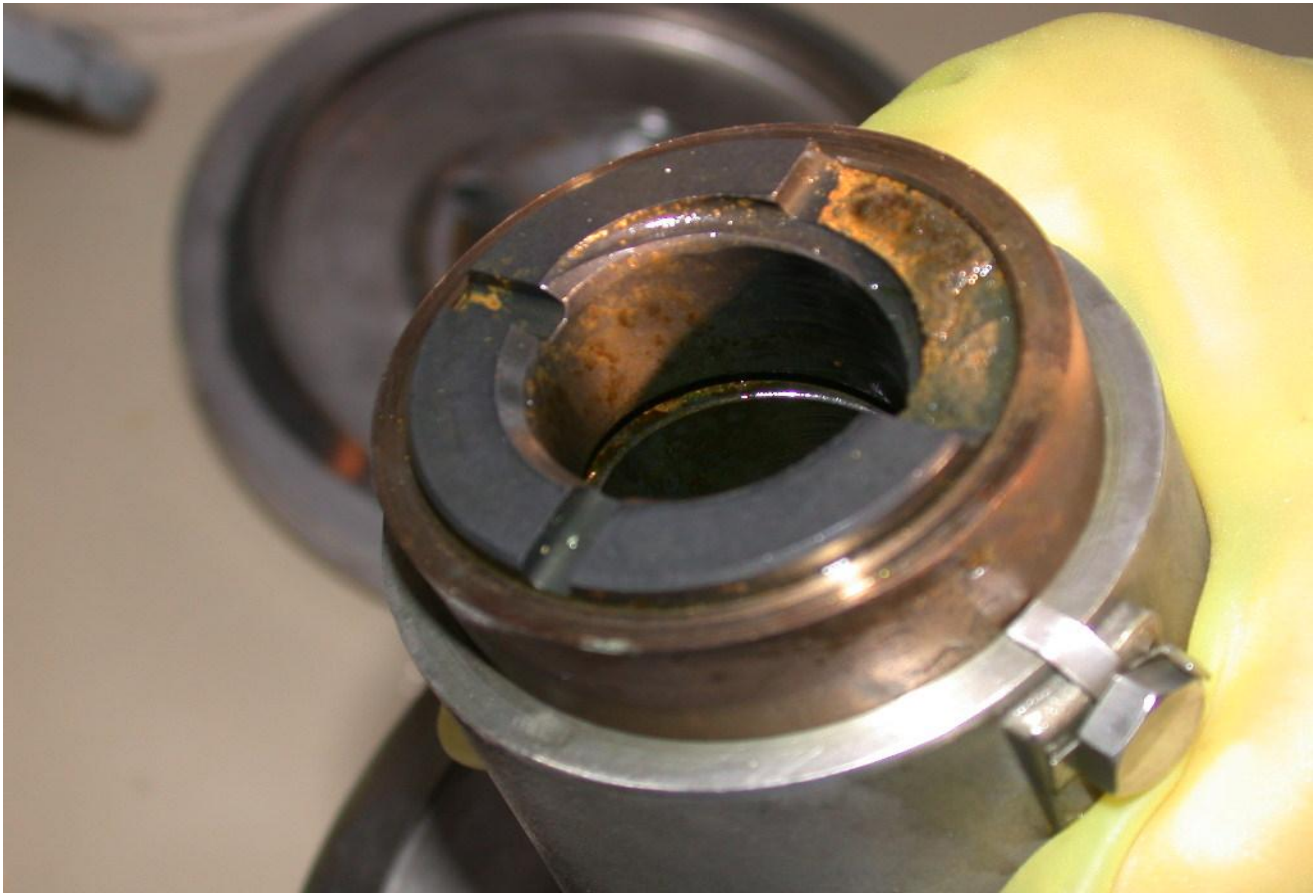
RECOMMENDATION

- USA and NASA Principal and system engineering recommend using the new Crane Chempumps (without blast protection) for this Hot Flow period. During this period, the pumps will be instrumented with preventive maintenance equipment to collect baseline and trend data.
- A request for blast protection would be submitted to design engineering if no valuable trend data can be gathered after multiple pumps runs.
- Pending meeting with the vendor to determine an overhaul time period, both pumps will be overhauled and inspected for wear. If wear is indicated on the rotor and/or stator, the pumps will be removed from service.

Oxid Pump 1 Front Bearing



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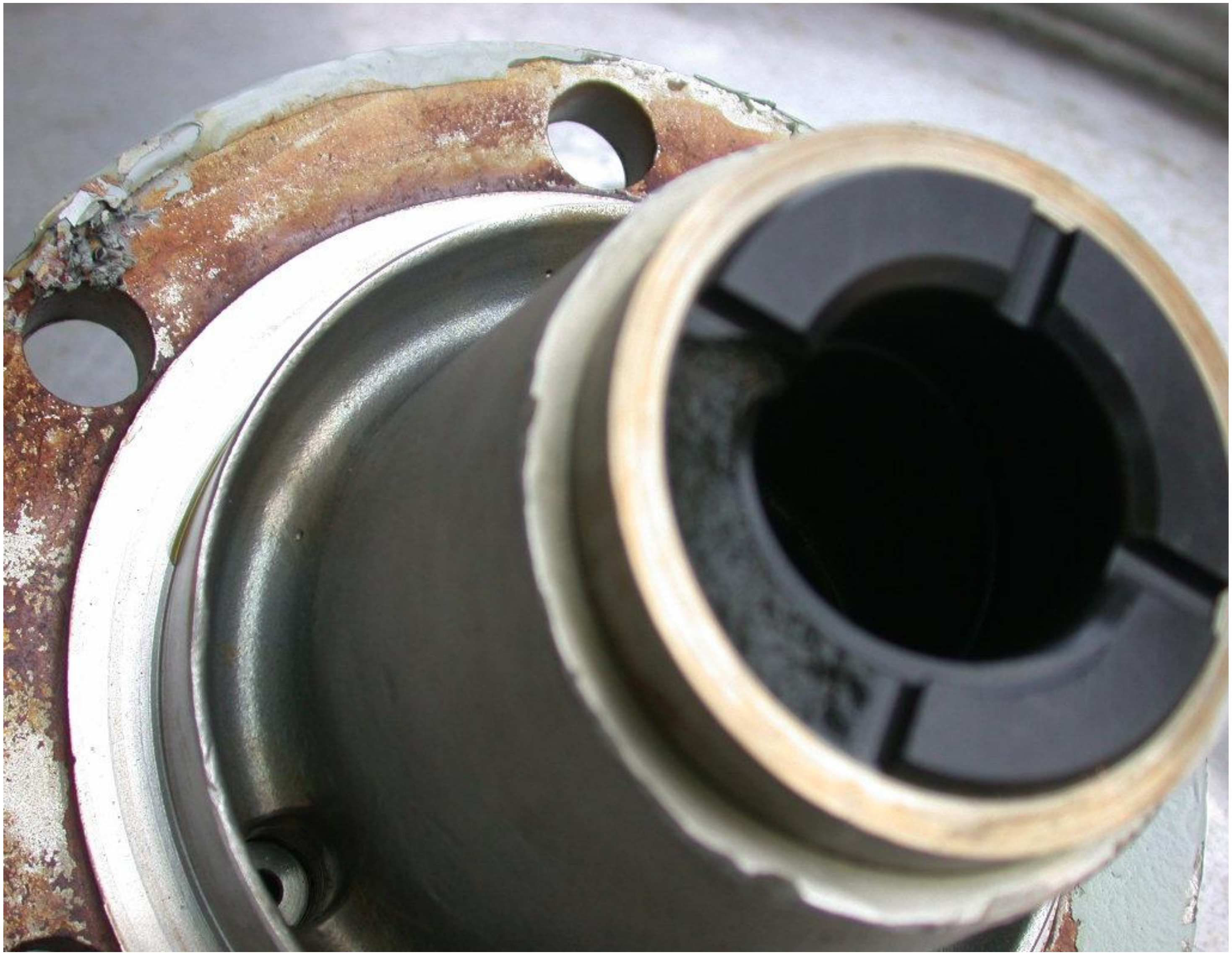
Oxid Pump 1 Rear Bearing



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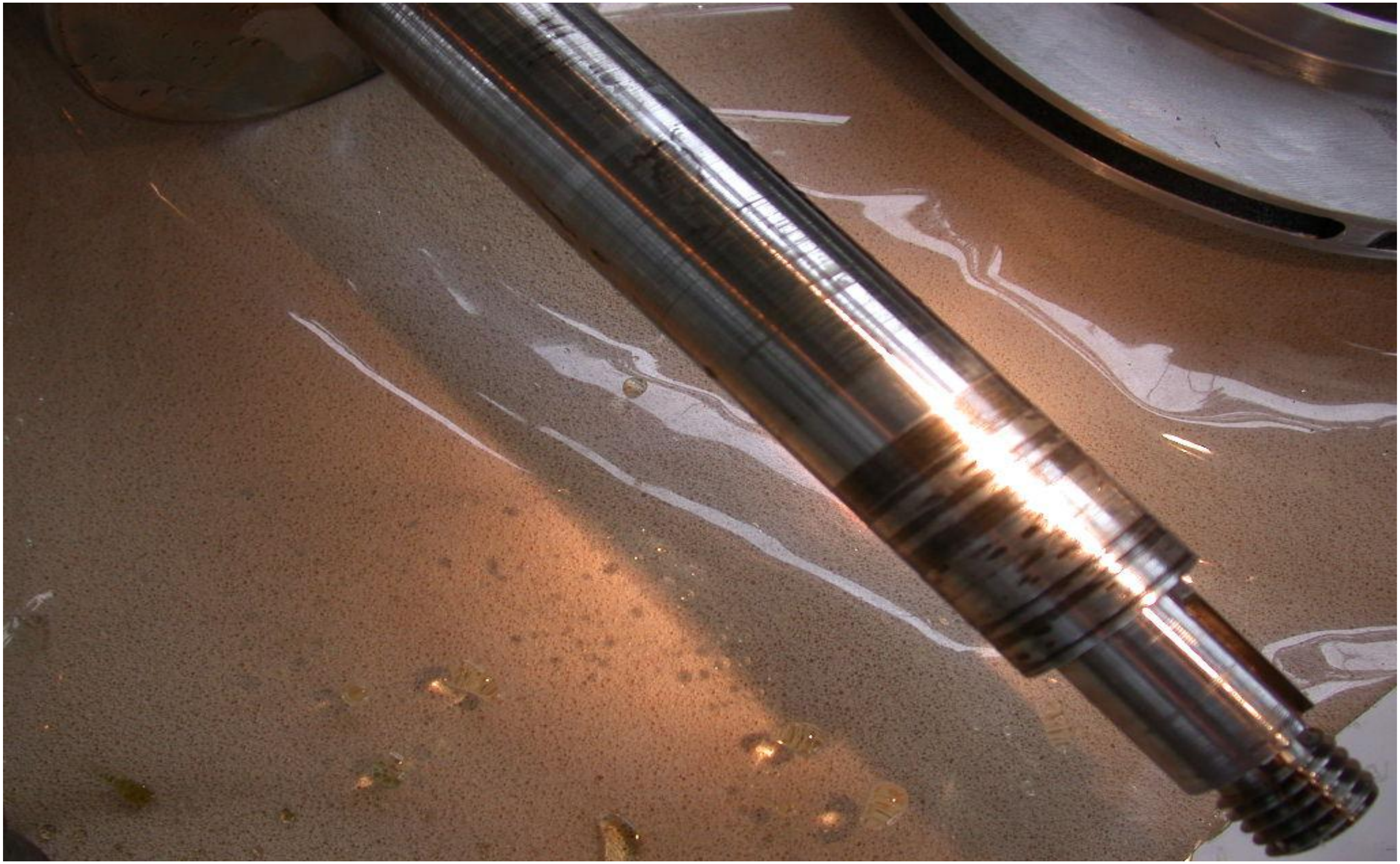
Oxid Pump 2 Front Rotor Journal



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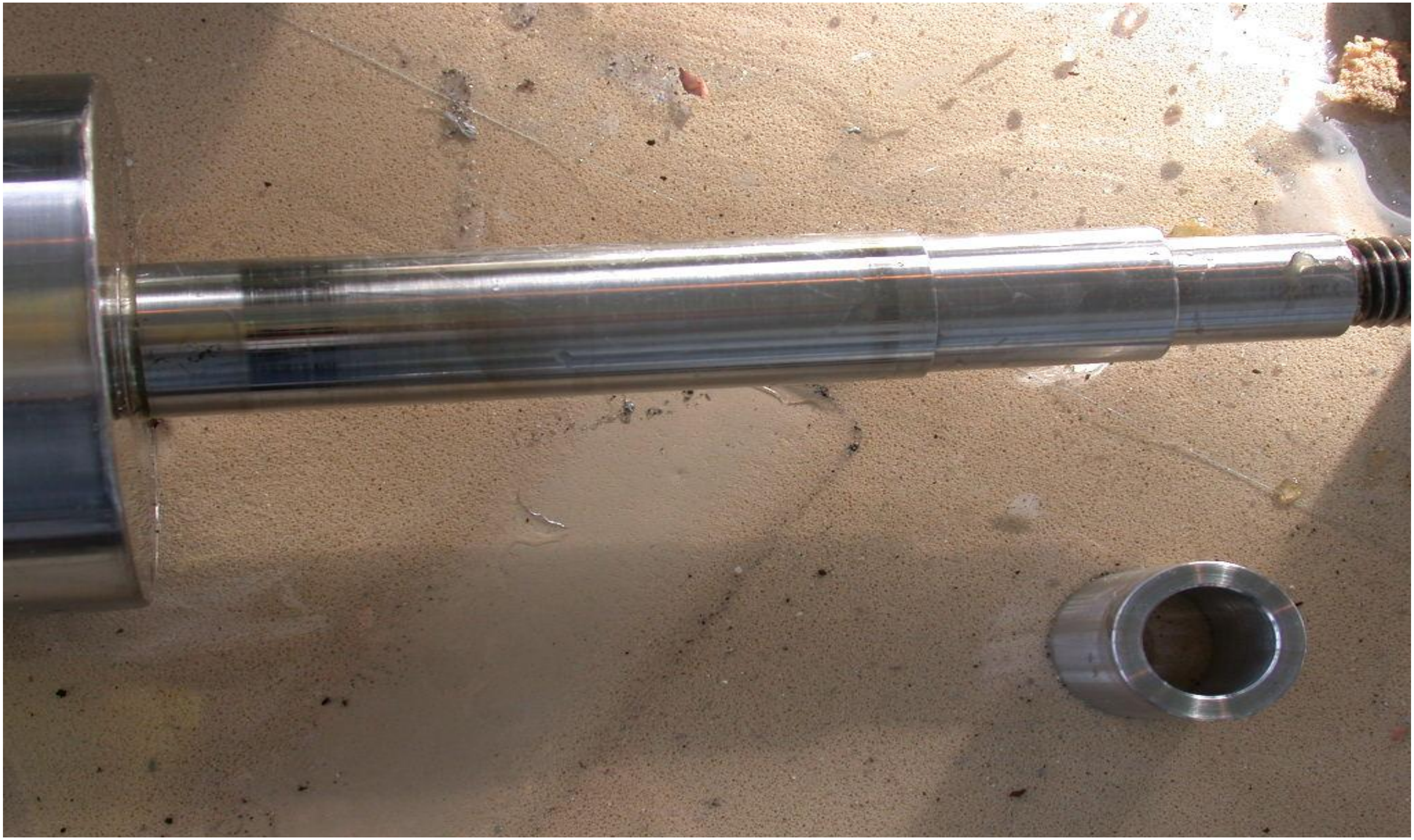
Fuel Pump 2 Front Rotor Journal



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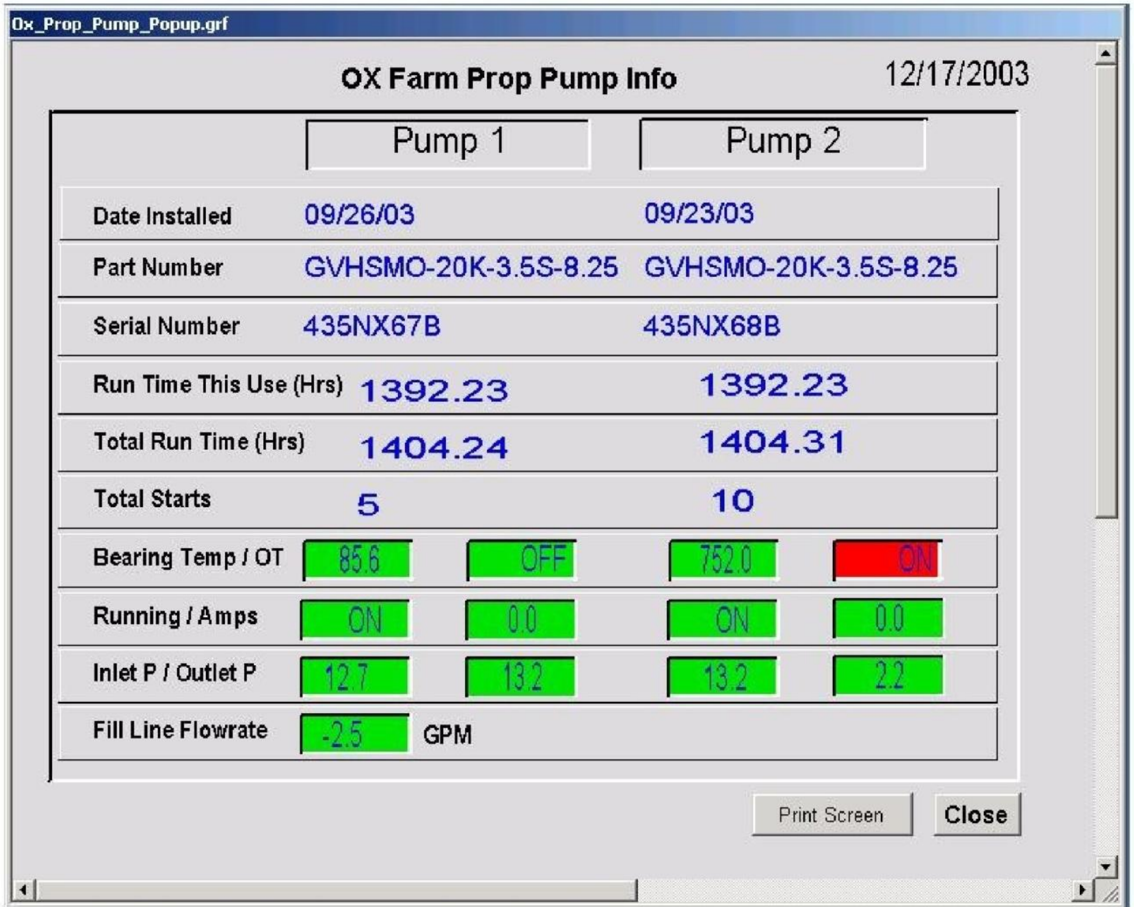
Pump Monitor Display



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