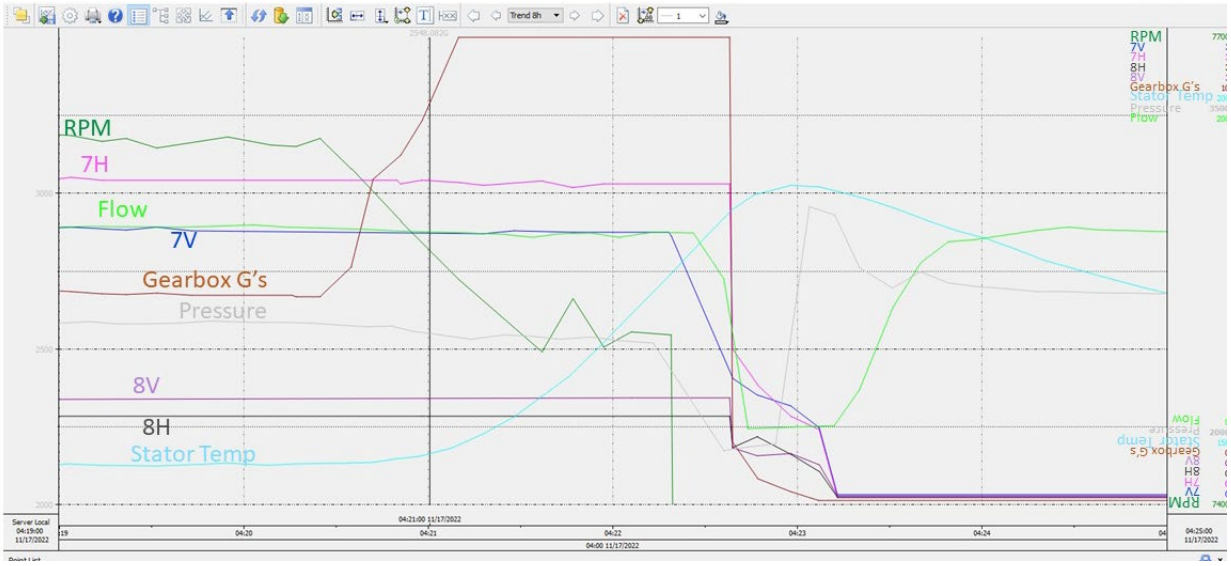
Problem Statement: At 0421 on 11/17/2022 pump PUMP2A tripped on time overcurrent. The trip was preceded (within 2 minutes prior to trip) by increasing gearbox acceleration, decreasing speed, increasing motor winding temperature, and small drops in pump flow and discharge pressure.

Facts:

A summary of the parameter changes is below (the scales for each parameter are color coded on the right side of the plot). Note that pump vibration did not change until the pump tripped.



POST-EVENT ELECTRICAL RELAY INDICATIONS Time overcurrent trip.

- Time overcurrent alarm.
- Did NOT receive instantaneous overcurrent trip indication.
- Did NOT receive ground overcurrent alarm indication,

POST-EVENT MECHANICAL CHECKS OF ENTIRE TRAIN

- The entire train (motor, gearbox, pump) rotated smoothly by hand while coupled.
- The pump was uncoupled from the gearbox and rotation checks were repeated on the motor/gearbox (still coupled) and with the pump alone and results were still smooth.

POST-EVENT RUN WITH MOTOR + GEARBOX (NO PUMP) 11/21/22

- No unusual noise or vibration noted.
- Coastdown time until stopped rotating after motor was secured: 3 minutes

POST-EVENT PUMP INSPECTIONS

- Axial float of pump (0.010”) is normal.
- Thrust shoes were removed for measurement of axial float of the internal element for information (0.42”).

POST-EVENT GEARBOX INSPECTION

- The axial float of the gearbox bull gear (23 mils) appears normal.
- Pulled inspection cover and visually inspected gears while rotating, no evidence of gear tooth damage.

POST-EVENT MOTOR AND ELECTRICAL INSPECTIONS / TESTS

- Inspection through oil ring viewing ports did not show any oil discoloration or rotation of the bearing within its housing (as had occurred previously for PUMP 1B motor in 06-15532, 11-15707)
- Electrical checks (SAT).
    - Insulation resistance - 10,000 MegaOhms (10 GigaOhms)
    - Motor / Cable resistance (measured from switchgear) – balanced 0.545 ohms for all three measurements (T1-T2, T2-T3, T3-T1)
    - Breaker resistance checked line-to-load, 23 micro-ohms on all three phases.

MOTOR HISTORY PRIOR TO EVENT (PUMP motor serial 2S-77)

- 6/29/21 – last current signature analysis of this motor motor s/n 2S77 (when installed in the PUMP 2A position). Results indicate rotor is in good condition (no rotor electrical circuit degradation).
- 11/15/21 – removed motor s/n 2S77 from 2A position
- Fall 21 / Spring 2022 – motor refurbished offsite.
    - There were rotor conditions identified during refurbishment which were deemed acceptable. These items are bookmarked in the refurbishment report
- 3/7/22 – installed motor s/n 2S77 in motor 2B position
- 3/9/22 – uncoupled run, vib results sat
- 3/10/22 – coupled run, vib results sat.
- 3/10/22 – bearing housing temperature check <140F
- 9/8/22 – bearing housing temperature check slightly elevated 148F outboard, 141F inboard
- 9/8/22 – routine vibration survey. The higher-order harmonics of motor running speed (also gearbox bullgear speed) increased on the inboard end of the motor, but still very low levels.
- PumpPUMP 2B operated at approximately the same speed as the other PumpPUMP motors (no sign of lower / decreasing speed which might indicate degradation) up until minutes before the event.

PUMP HISTORY PRIOR TO THE EVENT

- This pump has historically had weaker hydraulic performance than the other PUMP pumps in both units. (You can see on the parameter trends above that PUMP2A provided higher pressure after the event than PUMP2B had been providing prior to the event for the same flow).

- This pump has historically had elevated vibration. Rotating element has been replaced several times.

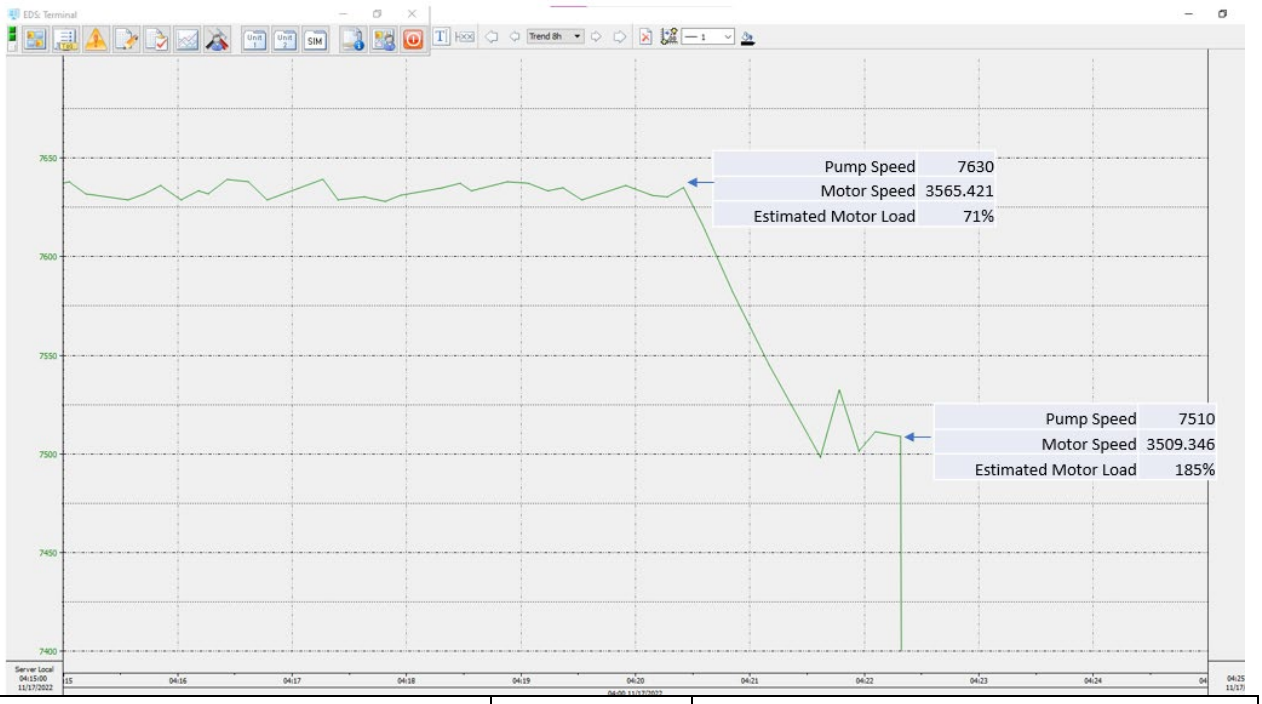
ADDITIONAL INFO:

- The pump/motor had been running continuously for 3 weeks at the time of the event (last started on 10/27/22 and tripped 11/17/22).

DISCUSSION OF POSSIBLE CAUSES:

- There is a distinctive cluster of symptoms (decreasing speed, increasing winding temperature, followed by time overcurrent trip) which corresponds to two broad scenarios
    - **Increasing mechanical load** on the motor. This causes increase in current, decrease in motor speed, increase in winding temperature and eventual TOC trip.
    - **Degradation of motor torque-speed characteristics** (lower torque for given speed). This causes the motor speed to decrease (in attempt to meet the load requirement) which causes the motor current to increase again leading to a trip.
- Increase in gearbox acceleration also occurred. This is potentially associated with either of the above scenarios
    - Increasing mechanical load transmitted through the gearbox could cause an increase in the normal gearmesh frequency vibration measured on the gearbox. Further if the source of a rotating/stationary rub was in the gearbox or nearby components, that may increase the vibration measured on the gearbox acceleration.
    - Degradation of motor torque speed characteristics could cause high gearbox acceleration if (and only if) the motor torque also included a new oscillating torque component. For the typical constant torque transmitted though the gearbox, the gearbox bearings see a constant (non-oscillating) reaction load and that reaction load causes no vibration (other than gearmesh frequency). For an oscillating torque transmitted, there is an oscillating reaction load on the bearings which would cause increased gearbox bearing vibration. Unbalanced voltage can cause reduced motor torque speed characteristics with an oscillating (120hz) torque component. Rotor circuit degradation mechanisms can cause reduced motor torque speed characteristics with a slowly oscillating ("pole pass frequency" < 2hz) torque component.
- Under the scenario of increased mechanical load, the measured pump speed can be correlated to the estimated motor load using the gearbox ratio and the motor nameplate speed. The results suggest the motor was initially at 70% load and increased to 185% load for 30 seconds (if it was an actual overload rather than torque speed characteristic degradation). Figure below

2.140 gear ratio. 3551 motor nameplate speed.



Fault Tree Steps	Likelihood	Evidence and Actions
I) Increase in Mechanical Load		
a) Increase load due to factors associated with the pump		
i) Rub between rotating and stationary elements.	LIKELY	This is a flexible pump rotor, which would be prone to rubs. It is very plausible that the dynamic characteristics of the flexible rotor are much different than the static characteristics such that pump would rotate smoothly by hand. However it is noted the pump vibration probes did not respond during the event which makes this less likely. Performed operational check of pump vib probes sat. Action 1 Perform offsite analysis of oil sample drawn from motor bearings and pump/gearbox sump (drawn 11/22/22, results expected by 12/2/22). Action 5 Review feasibility of pump boroscopic inspection.
ii) Fluid conditions caused increased pump load		
(1) Increase in pump flow	REFUTED	The only piping taps between pump

at a location not seen by the flow element.		discharge and the flow element are small diameter vent line, drain line, and instrument taps/Leakage at these paths would be into the room and would be obvious at the high flow rate required to cause these indications.
(2) Foreign material entered into pump suction	UNLIKELY	Rotated smoothly. Additionally, it is very likely that the resulting reduced flow would result in decreased mechanical loading of the motor and therefore increased speed (rather then the observed decreased speed).
b) Increased load due to factors internal to the gearbox		
i) Increased friction within the gearbox due to rub or gross degradation of teeth.	UNLIKELY	Unlikely based on inspection through cover smooth manual rotation and long coastdown time during motor/gearbox run. Action 1 Perform offsite analysis of oil sample drawn from motor bearings and pump/gearbox sump (drawn 11/22/22, results expected by 12/2/22). Action 6 Perform followup inspection of gearbox. Remove top cover at splitline, inspect accessible thrust faces, bearings, oil pump drive
ii) Slipping of teeth due to gross change in geometry causes reduction in pump speed.	REFUTED	Inspection showed no obvious tooth damage. Additionally this would not cause motor trip or increase motor stator winding temperature.
c) Increased mechanical load due to factors internal to the motor	UNLIKELY	Unlikely based on smooth manual rotation and long coastdown time during motor/gearbox run. Action 1 Perform offsite analysis of oil sample drawn from motor bearings and pump/gearbox sump (drawn 11/22/22, results expected by 12/2/22).
d) Increased mechanical load due to coupling / alignment factors	UNLIKELY	Misalignment generally results in increased vibration. The increased vibration only causes increased load if it causes mechanical damage. Such mechanical damage would be captured in other categories of this fault tree.

II) Degradation of Motor torque speed characteristics		
a) Degradation due to upstream power supply		
i) Voltage reduction in balanced fashion	REFUTED	"A" train ESF transformer does not have LTC. Malfunction of aux transformer LTC would create obvious effects on other plant equipment. Balanced reduced voltage would degrade torque speed characteristics, but would not result in increased gearbox acceleration (no oscillating torque). Computer trend indicates stable E2A bus voltage during the event. BusVoltage.pptx
ii) Voltage unbalance		
(1) Voltage unbalance due to high resistance from breaker downstream	UNLIKELY	Measurements indicated balanced resistance from switchgear through motor. Breaker contact resistance normal. Breaker cycles normally. The only way this cause could be possible is intermittent high resistance, highly unlikely.
(2) Voltage unbalance originating upstream of breaker	UNLIKELY	No other 4KV bus loads affected even though condition would have had to have persisted for 90-120 seconds. Undervoltage alarm not received. Bus voltage indicates normal (at least on the monitored phase) BusVoltage.pptx
b) Degradation due to factors within the motor		
i) Resistive unbalance within motor stator	REFUTED	Measured resistance was balanced
ii) Rotor electrical circuit degradation (including rotor bar to end ring joint degradation)	LIKELY	Rotor anomalies were noted during refurbishment but were considered acceptable. Rotor circuit degradation typically occurs during start, but this event did not happen shortly after start. Current signature analysis of this motor was satisfactory in 2021. Action 4 Remove motor and send off-site for evaluation (single phase test, load test, current signature analysis under load).
iii) Shorted stator winding turns	UNLIKELY	Motor resistance was measured as balanced. Shorted turns result in path

		for fault-level currents within the stator (driven by autotransformer effect) which typically result in ground trip/alarm within seconds on form wound motors. This motor operated for approx. 2 minutes after first symptoms on 11/17 and operated another 15 minutes during motor/gearbox run on 11/21. NOTE – Motor will be removed/tested for rotor defect. If no cause is not found when that is completed, further testing of stator turns can be conducted (surge test).
iv) Phase to ground fault in motor	REFUTED	No ground alarm. Megger sat.
III) Relay malfunction	REFUTED	Both TOC trip and TOC alarm received. High current corroborated by decreasing motor speed and increasing winding temperature.

ACTIONS:

Action 1 Perform offsite analysis of oil sample drawn from motor bearings and pump/gearbox sump (drawn 11/22/22, results expected by 12/2/22).

Action 2 Check pump axial movement (thrust) with thrust shoes removed (gives information about the clearances within the replaceable internal element) (Complete – info only)

Action 3 Perform operational check of pump proximity probes (Complete, sat).

Action 4 Remove motor and send off-site for evaluation (single phase test, load test, current signature analysis under load).

Action 5 Review feasibility of pump boroscopic inspection.

Action 6 Perform followup inspection of gearbox. Remove top cover at splitline, inspect accessible thrust faces, bearings, oil pump drive