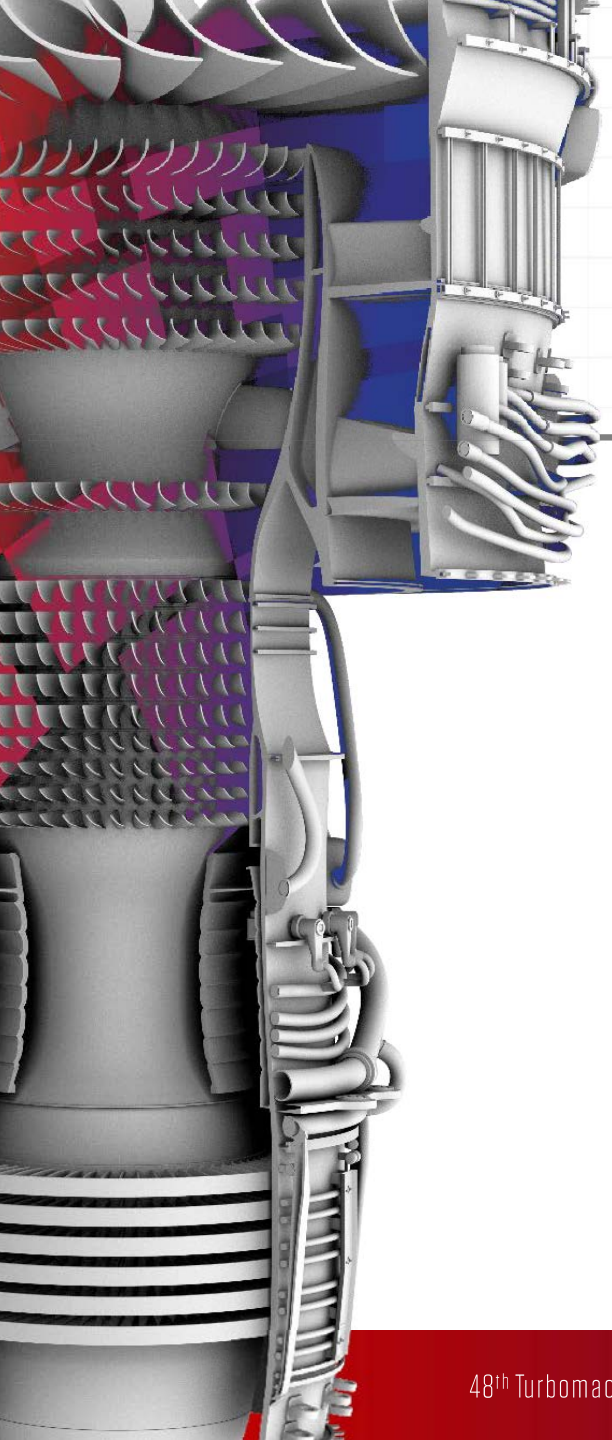


TURBOMACHINERY & PUMP SYMPOSIA

wood.

Identifying the cause of a plunger pump shutdown

Data logging to the rescue

Kelly Eberle, Michal Gaca

Wood

woodplc.com/vdn

Author biographies

Kelly Eberle, BSc, PEng, Principal Consultant, Wood

Kelly has worked with Wood since 1988. Kelly graduated from the University of Saskatchewan with a Bachelor of Science in Mechanical Engineering in 1986. He has accumulated a wide range of design and field experience, particularly in the area of pressure pulsation analysis and mechanical analysis of reciprocating compressor and pump installations. His experience also includes field vibration analysis, flexibility studies, structural analysis and foundation analysis.

Michal Gaca, BSc, PEng, Team Lead, Wood

Michal has worked with Wood since 2011. Michal graduated from the University of Calgary with a Bachelor of Science in Mechanical Engineering in 2012. He has worked as a design analyst conducting API 618 pulsation and mechanical studies, and is currently a team lead and field engineer. Michal has expertise in using CAD and FEA software as well as software development in the imc FAMOS environment.

Problem

- Mysterious shutdown of triplex plunger pump after seven days
- Shutdown triggered by over-voltage alarm on motor VFD
- After initial shutdown and restart, frequency of shutdowns increased

Objective

- Determine cause of unexpected shutdown
- Demonstrate effectiveness of commercially available data logging equipment

System layout

- 355 HP variable-speed motor
- Triplex plunger pump operating 110 rpm to 230 rpm
- Gearbox between motor and pump
- Nominal 50 psig suction to 3000 psig discharge
- Fluid varies between different hydrocarbons SG=0.85 to 0.95

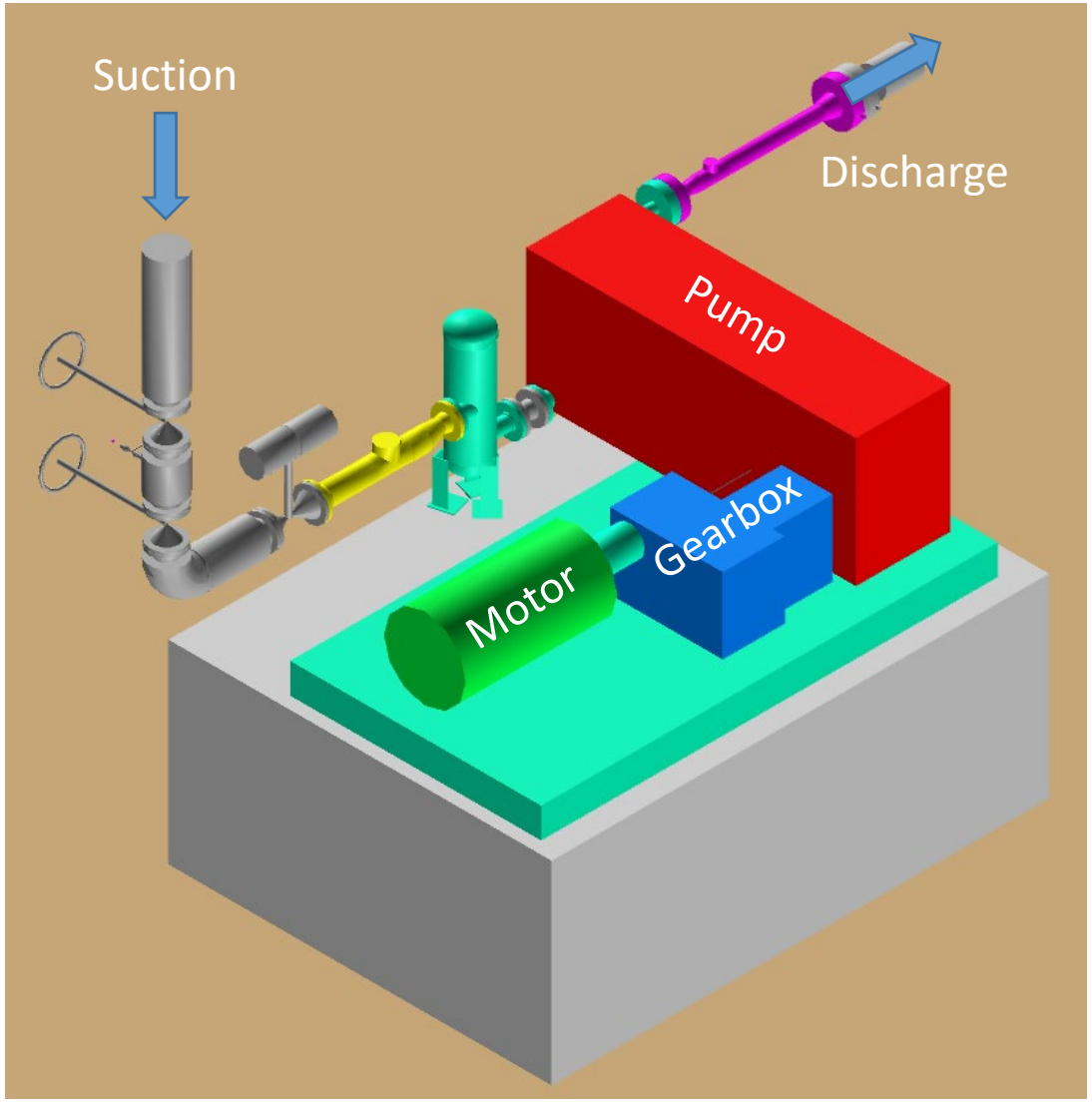


Photo of pump and motor

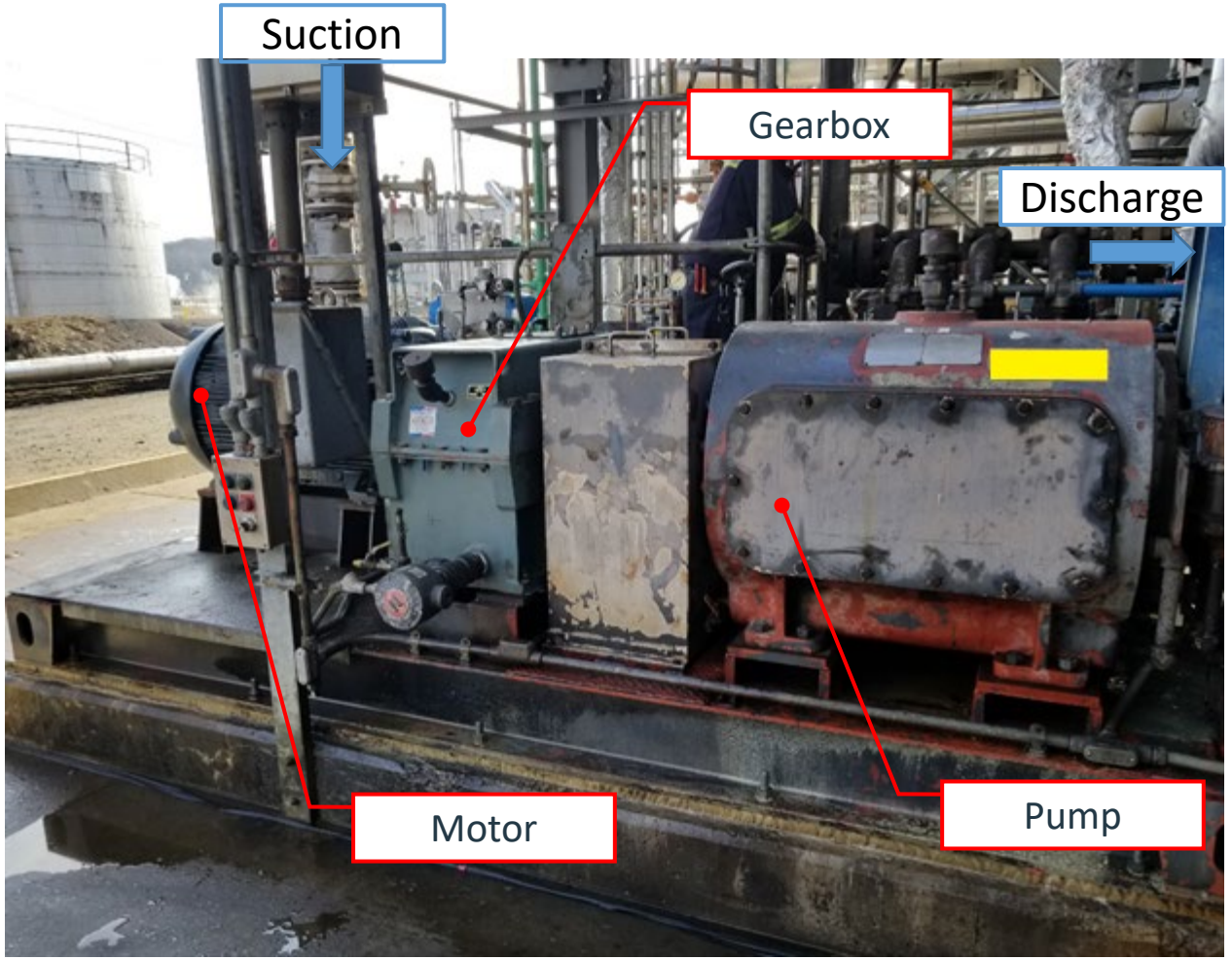
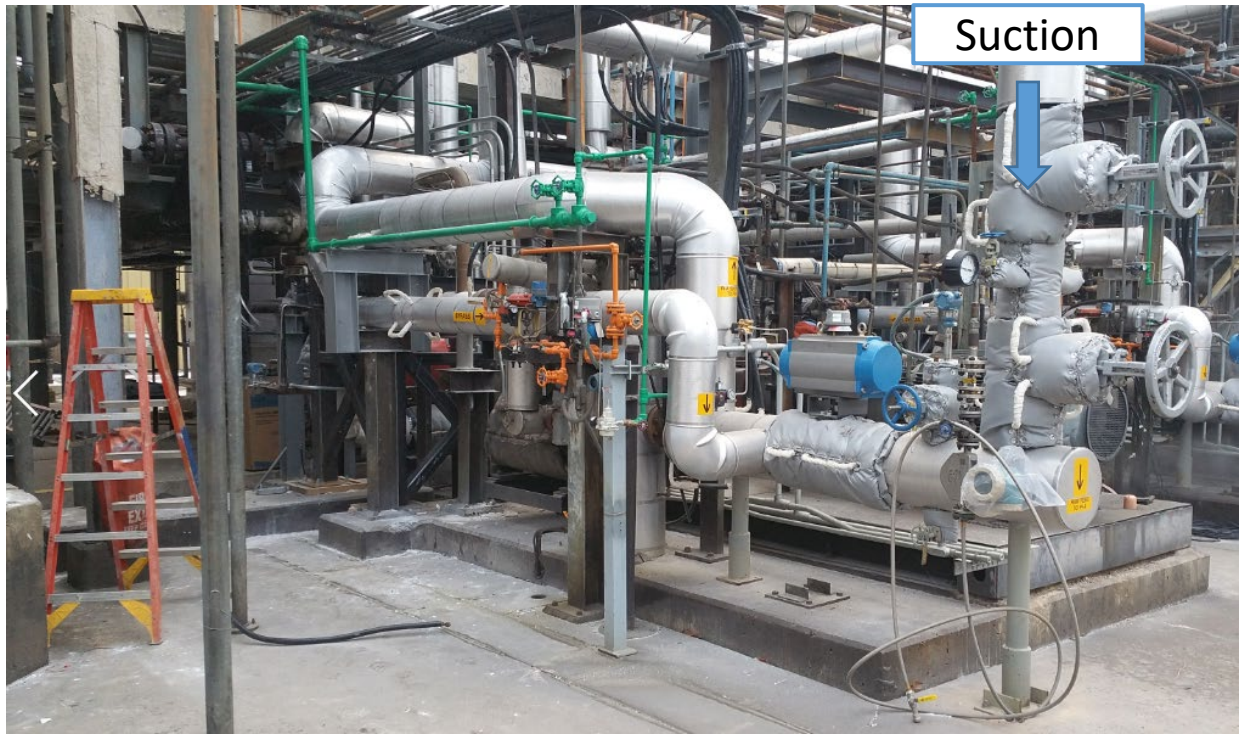
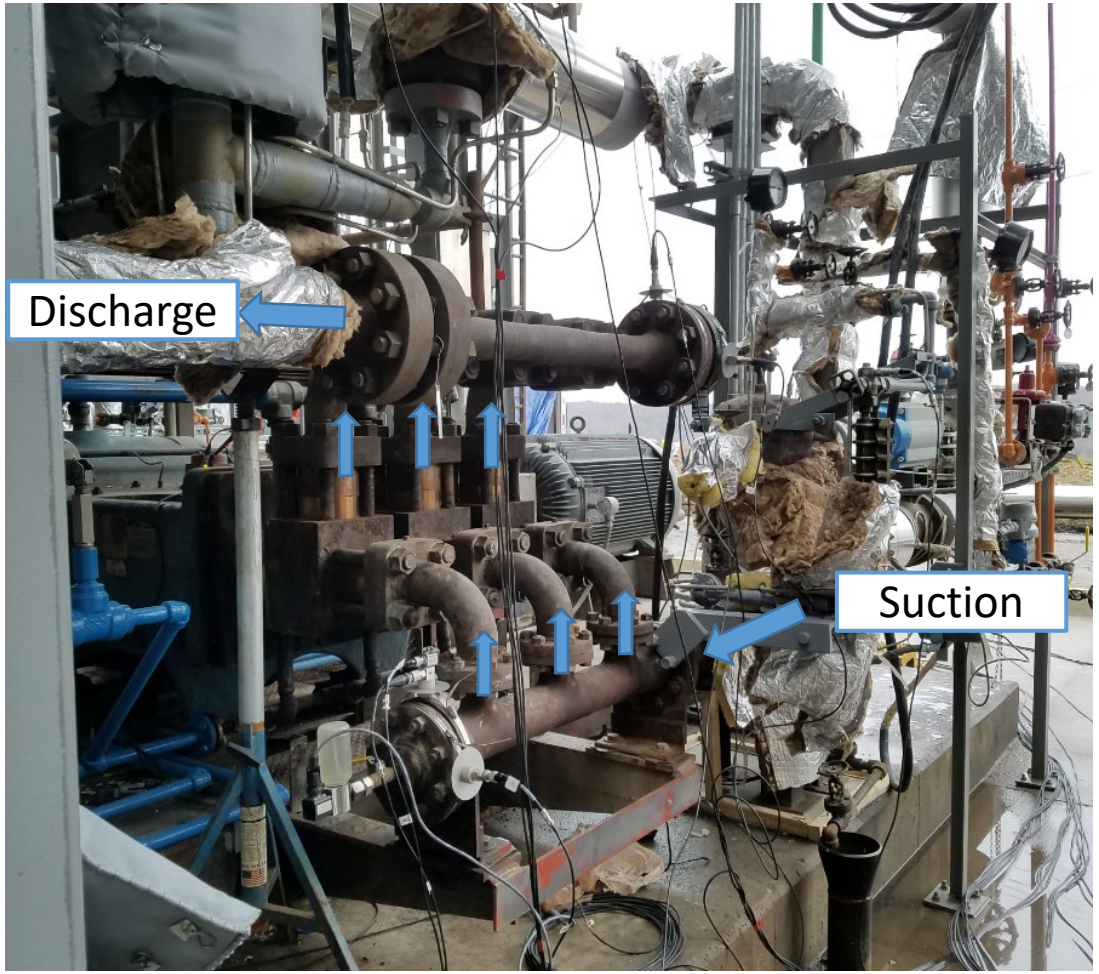


Photo of pump and motor





Investigation – part 1

- Pump trip after seven days of operation was caused by over-voltage alarm on the VFD
- Initial trip was thought to be an anomaly. Pump restarted but only ran for two days before it tripped again. Run time reduced after each subsequent restart.
- Diagnostic done on the VFD. No faults found.
- Motor had been in operation for more than 10 years. The plant practice was to replace the motor on about a seven-year interval.
- Motor was replaced with spare in storage

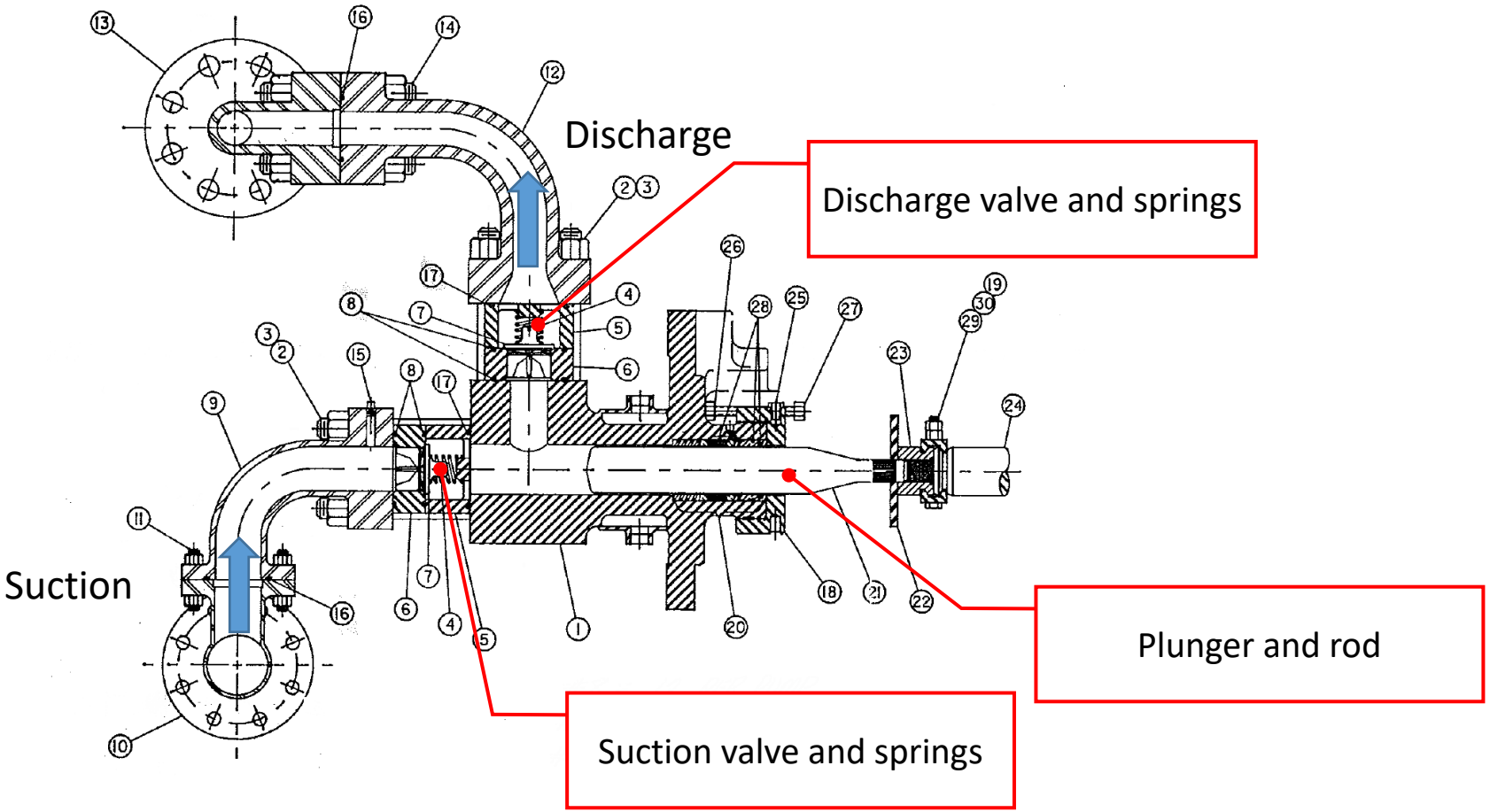
Investigation – part 2

- Pump was restarted but tripped and shut down again shortly
- Operating personal heard a “thump” from the area around the motor and gearbox immediately before one of the shutdown events
- An oil leak was noted on one seal of the gearbox
- Gearbox was replaced with a spare

Investigation – part 3

- Inspection of pump valves: wear on valves was unusual, as they had recently been replaced
- Valve closing angles: ~ 15 degrees ADC when operating at high speed (233 rpm) with original valves/springs
- Old valves and springs (40# rating) were removed
- New valves installed with higher spring stiffness (80# rating) to improve valve operation
- Valve closing angles were reduced to 8 degrees with the new (2x stiffer) springs

Pump cross-section



New pump valve

Damaged valves

Data logging system

- Pump installed in 1980s
- Little instrumentation installed that would aid in troubleshooting
- Added a data logging system to record measurements that would help diagnose why the pump was tripping on over-voltage alarm

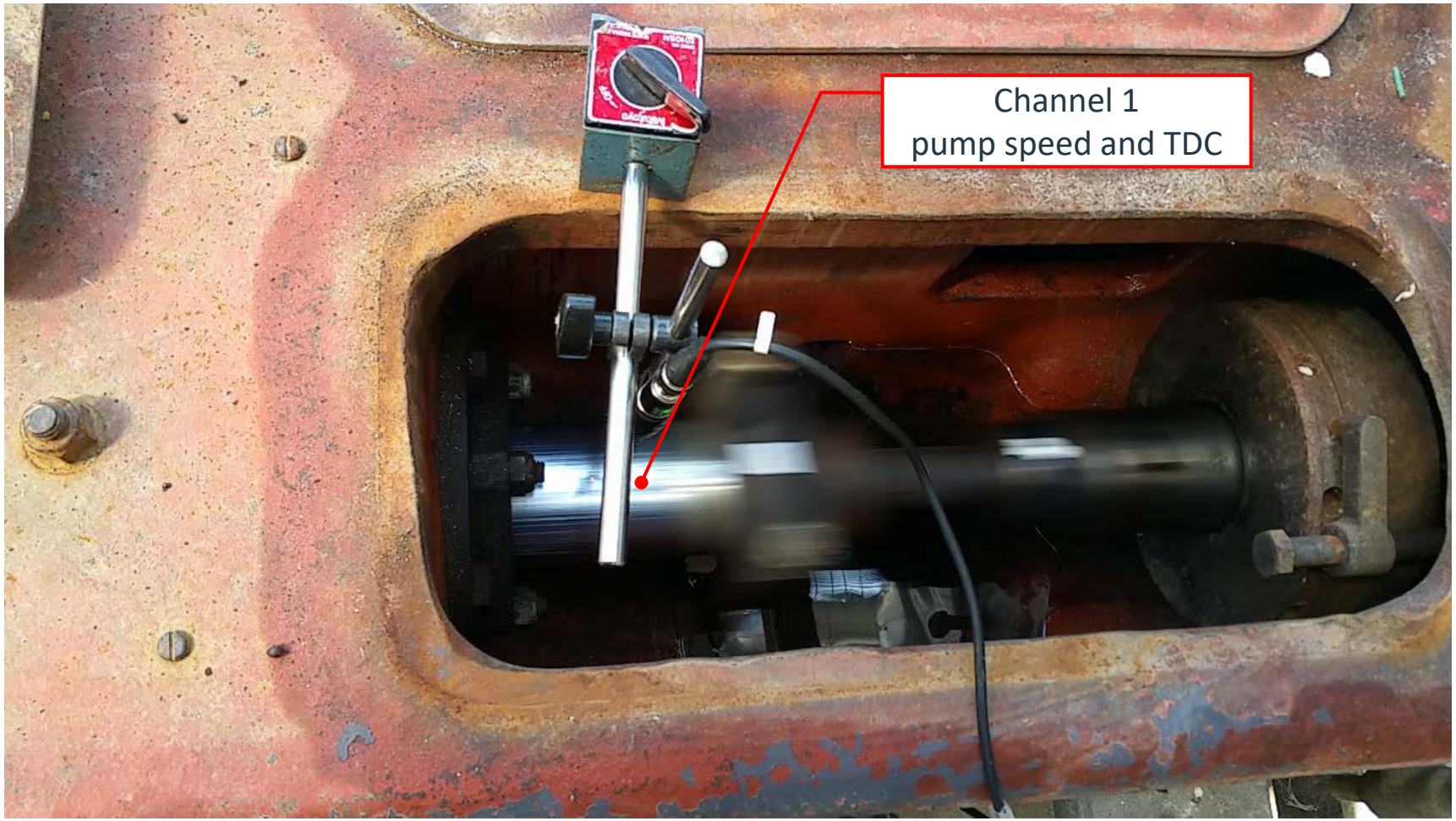
Investigation – equipment used

- Commercially available measurement equipment installed
  - Central control unit for signal conditioning and data logging
  - Vibration transducers
  - Dynamic pressure gauges (transducers) to measure mean and dynamic pressure
  - Current transformer (motor load)
  - Optical pickup (pump speed and TDC indicator)
- 10 channels of information measured
- Allow for continuous monitoring and recording of speed, TDC indication, dynamic pressure, vibration and motor current

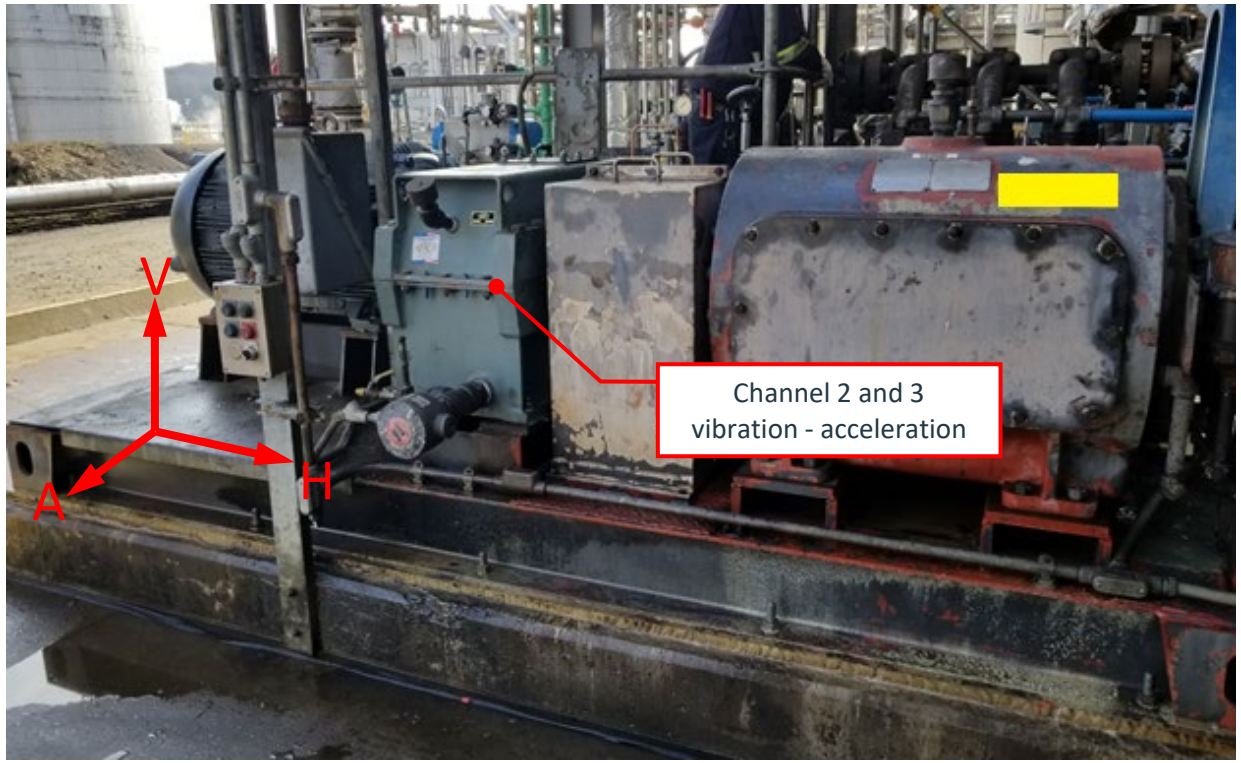
Instrumentation

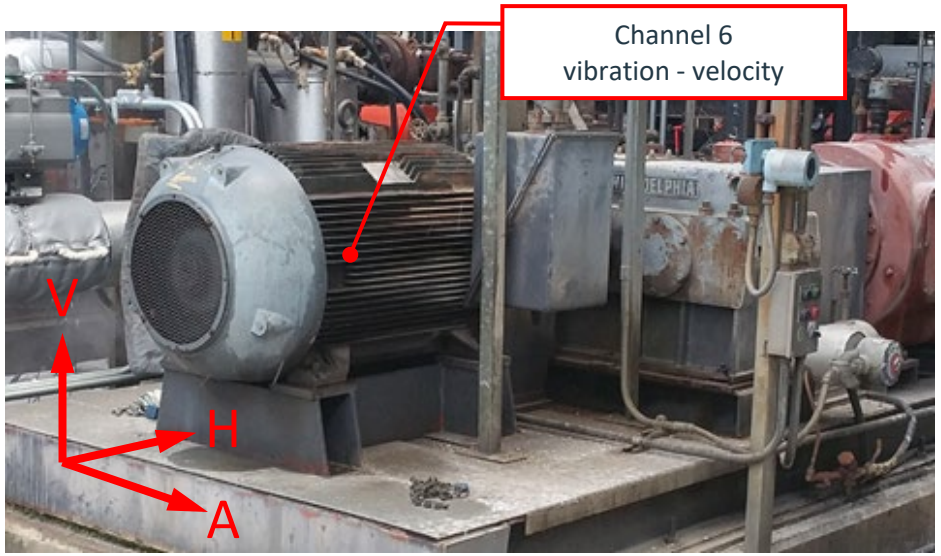
Channel #	Measurement type	Location	Direction
1	Once per turn marker	Throw #1 TDC	
2	Vibration (accelerometer)	Gear Box	Horizontal
3	Vibration (accelerometer)	Gear Box	Axial
4	Vibration (velometer)	Pump – Throw #1 Fluid End	Horizontal
5	Vibration (velometer)	Pump – Throw #1 Fluid End	Axial
6	Vibration (velometer)	Motor – Non-Drive End	Axial
7	Pressure	Suction Manifold	
8	Pressure	Discharge Manifold	
9	Current	Motor (Phase C Wire)	

Pump speed and plunger TDC position



Instrumentation – installed location





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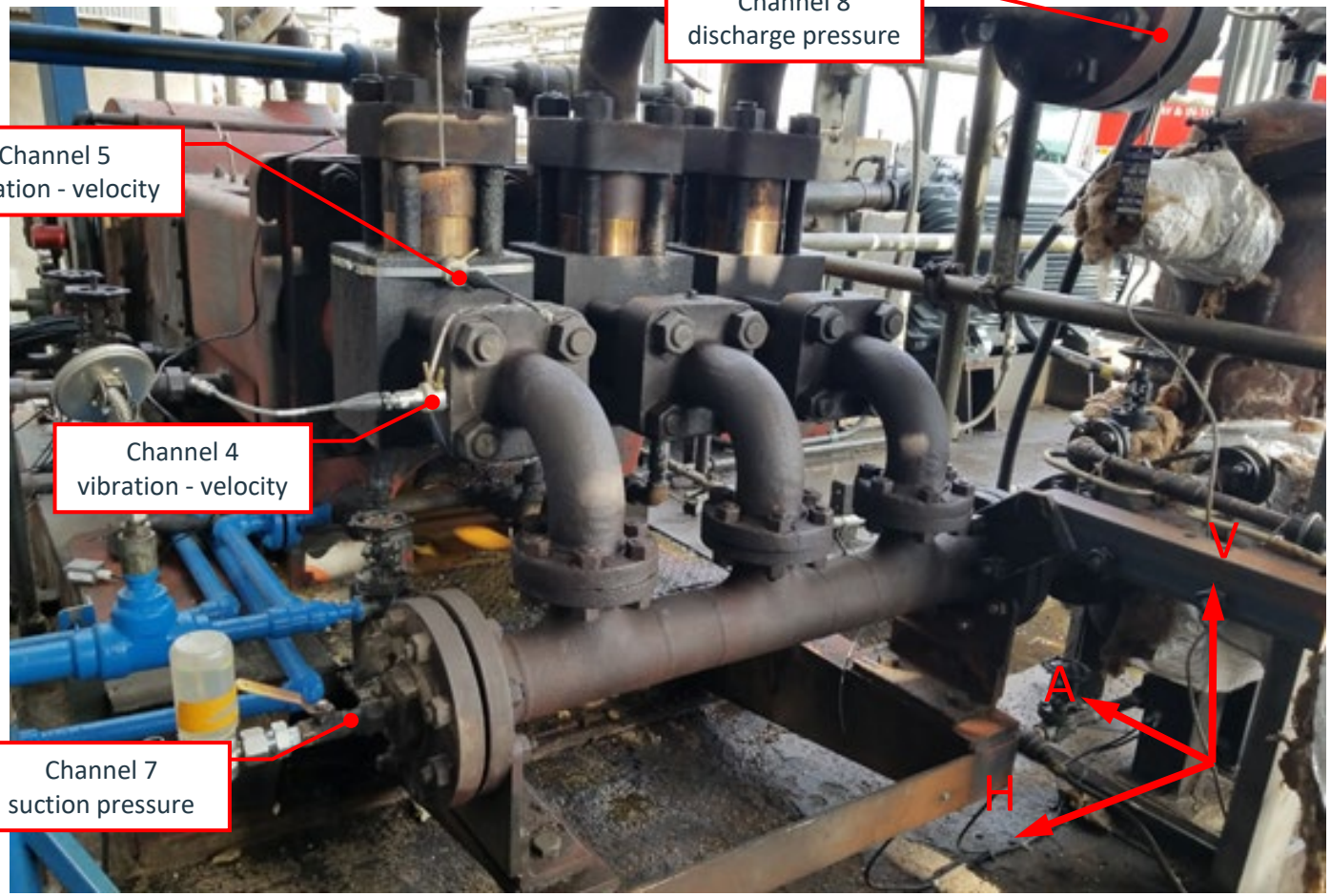
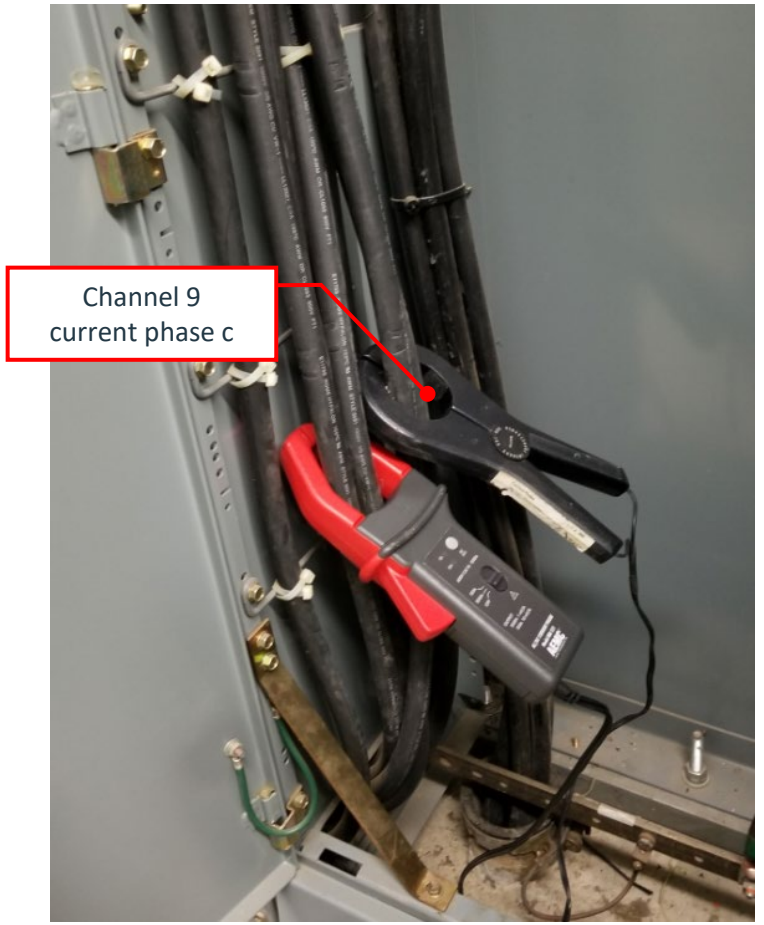
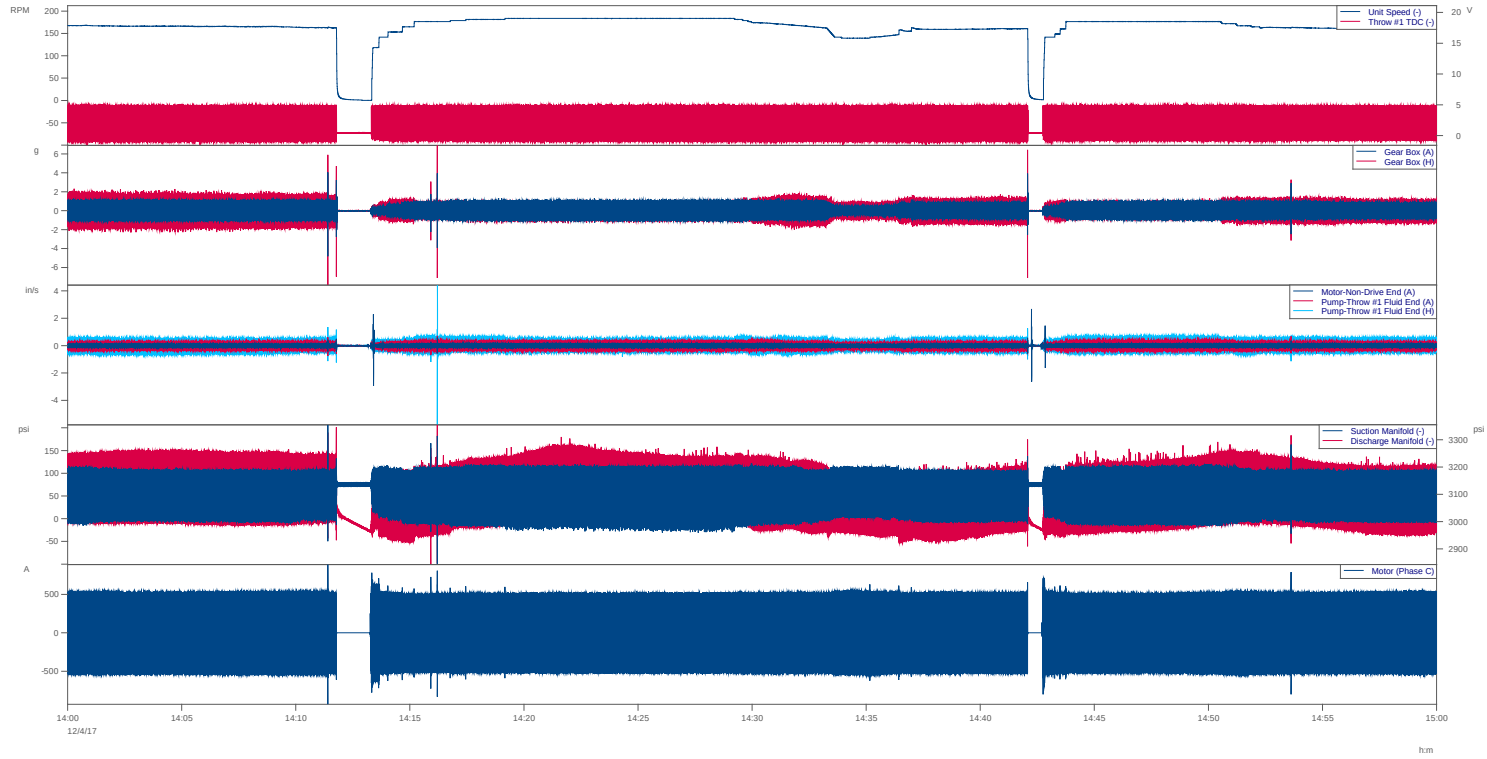
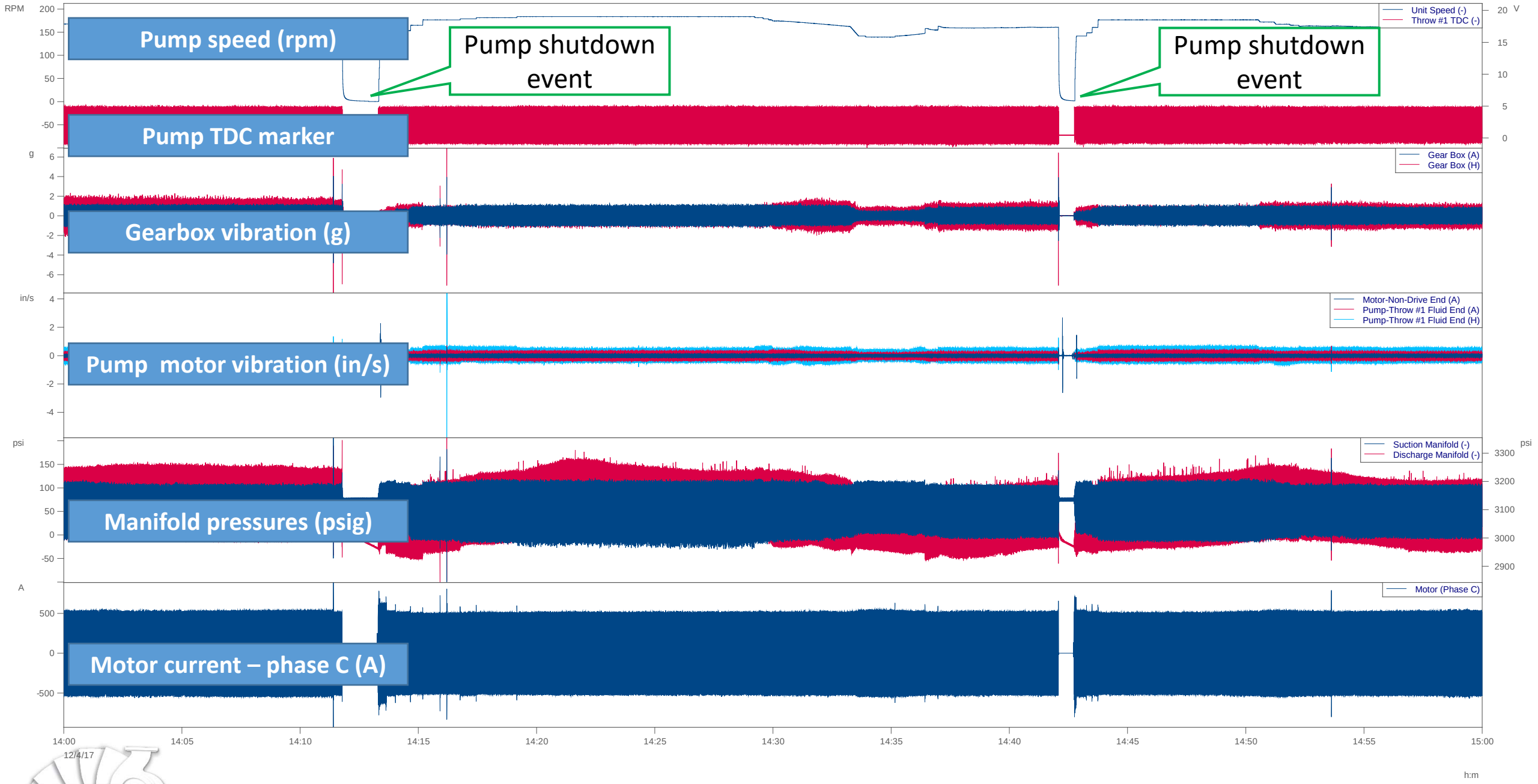


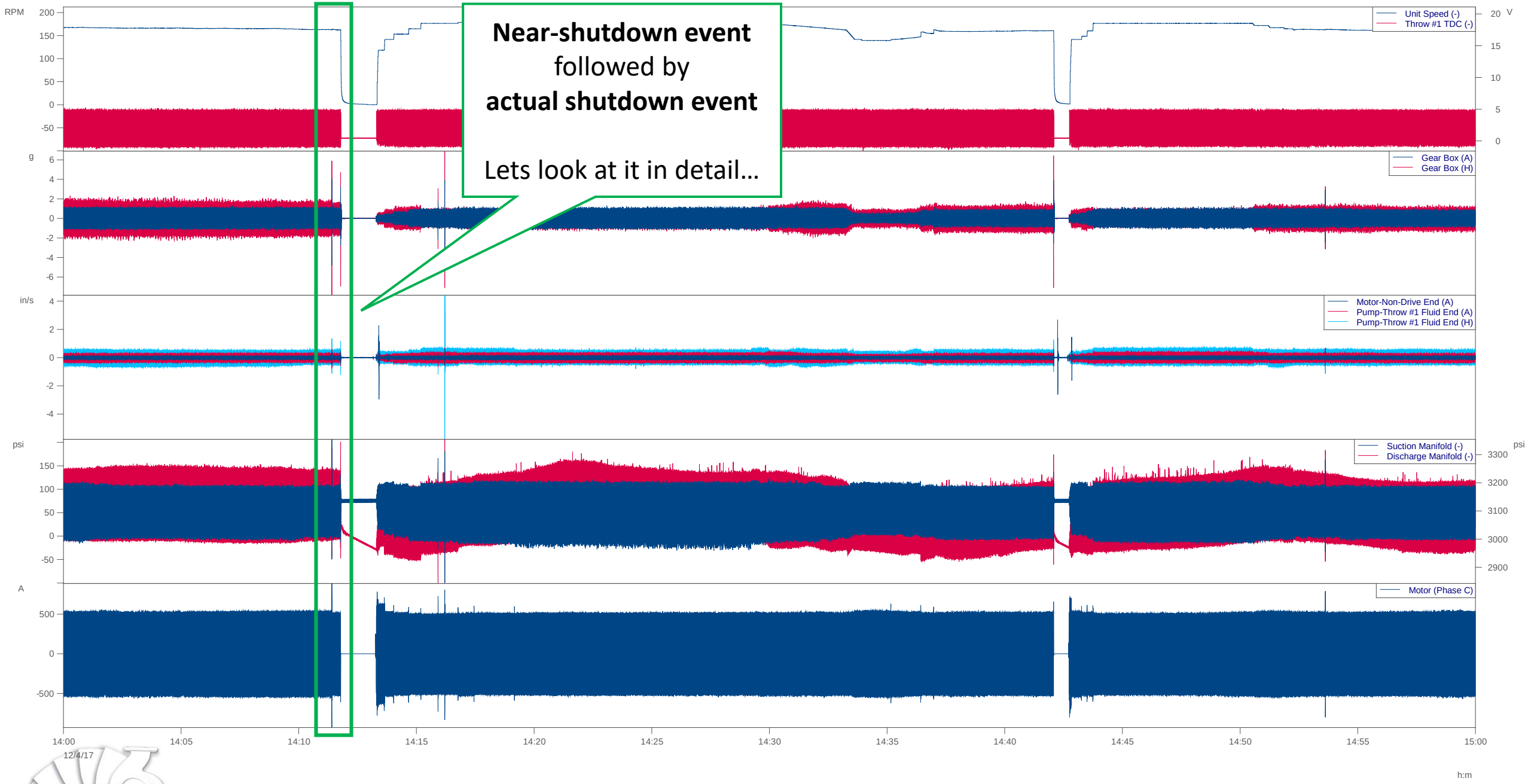


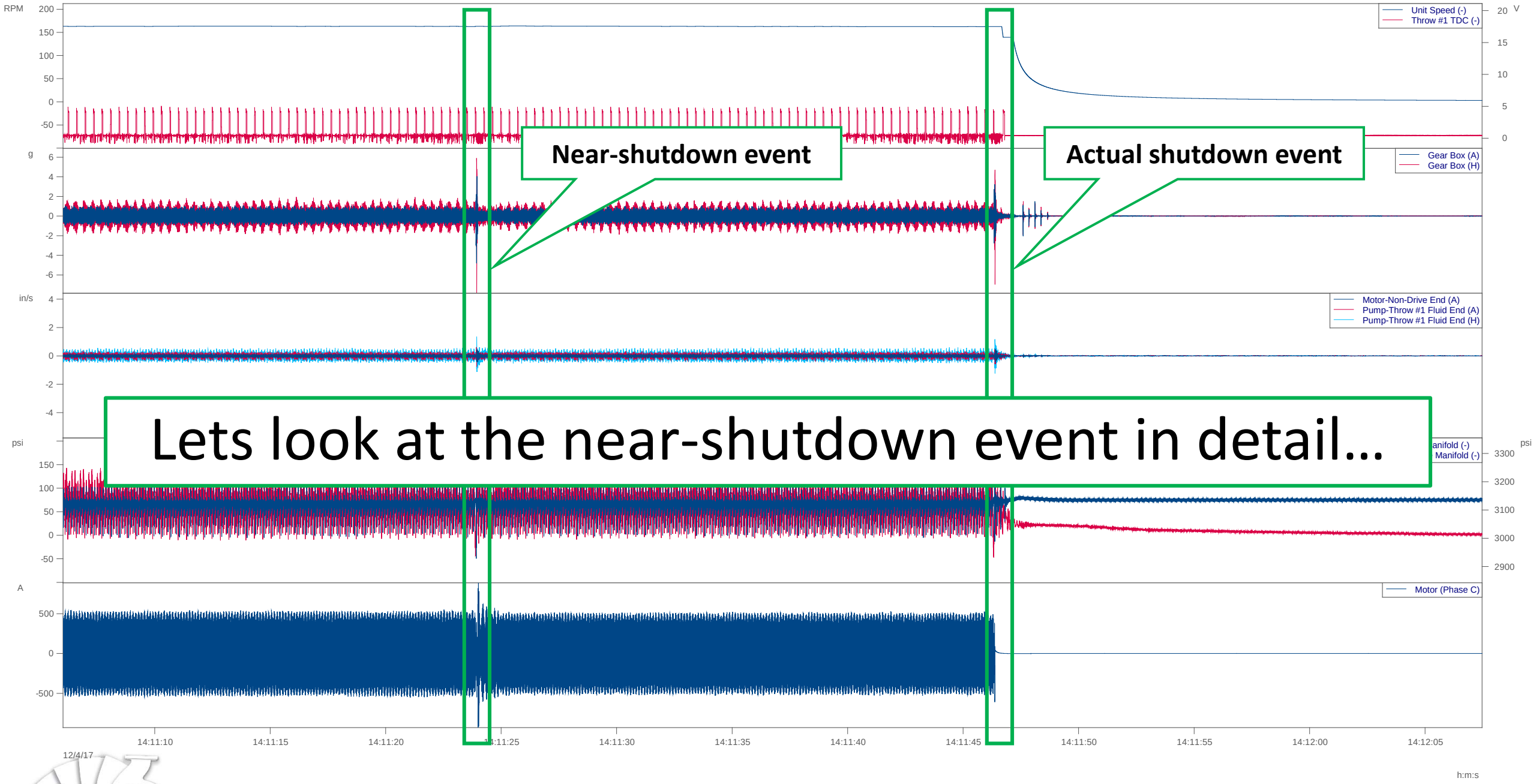
Measurements and analysis

- Measurement equipment left at site for eight days of continuous data collection
- Operation staff noted date and time of the shutdown events
- Data was loaded at the noted times for review
- Right: one hour of data collected
- Let’s look at the data in more detail…

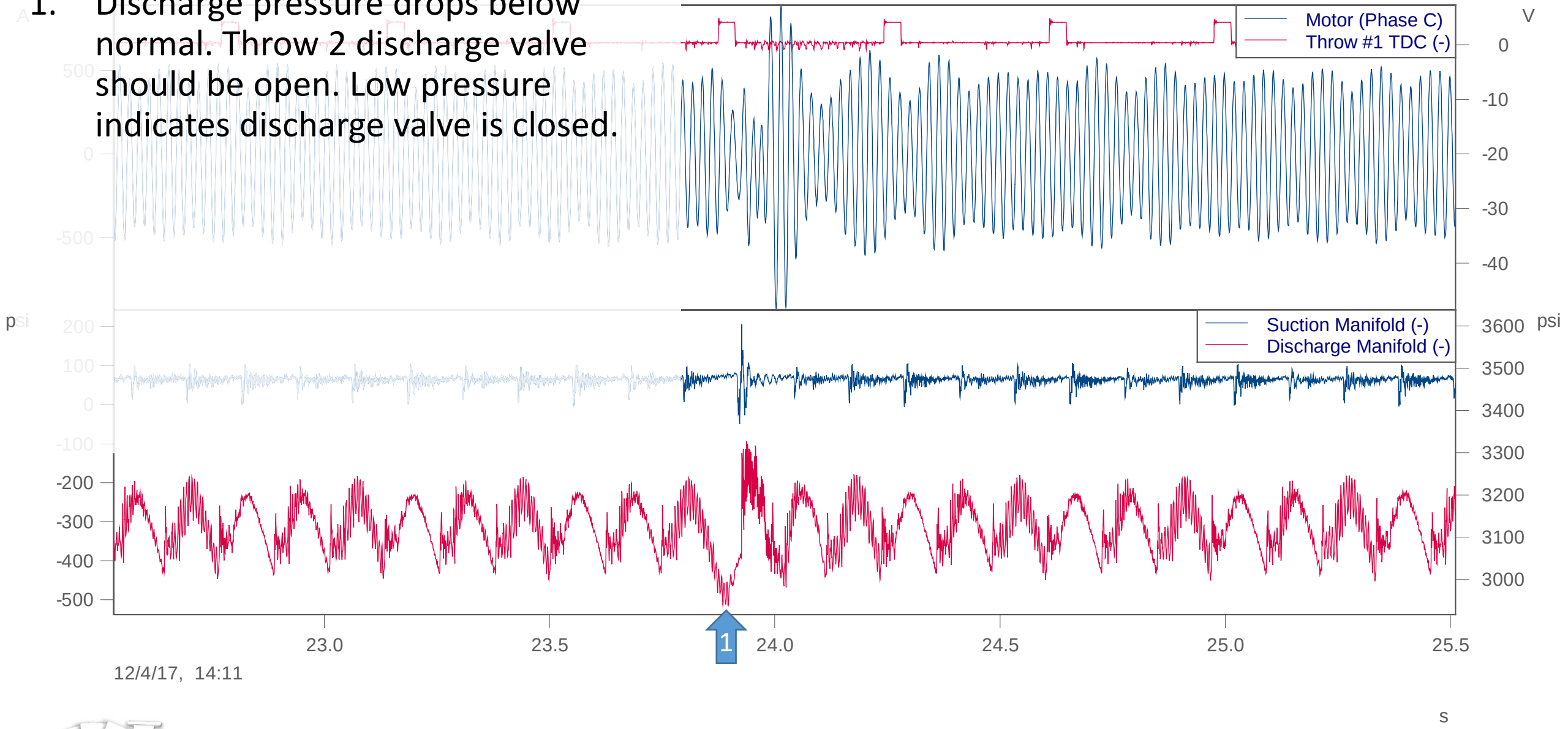



Pump speed (rpm)
Pump shutdown event
Pump shutdown event
Pump TDC marker
Gearbox vibration (g)
Pump motor vibration (in/s)
Manifold pressures (psig)
Motor current – phase C (A)
RPM
Unit Speed (-)
Throw #1 TDC (-)
V
g
Gear Box (A)
Gear Box (H)
in/s
Motor-Non-Drive End (A)
Pump-Throw #1 Fluid End (A)
Pump-Throw #1 Fluid End (H)
psi
Suction Manifold (-)
Discharge Manifold (-)
psi
A
Motor (Phase C)
14:00
14:05
14:10
14:15
14:20
14:25
14:30
14:35
14:40
14:45
14:50
14:55
15:00
12/4/17
h:m

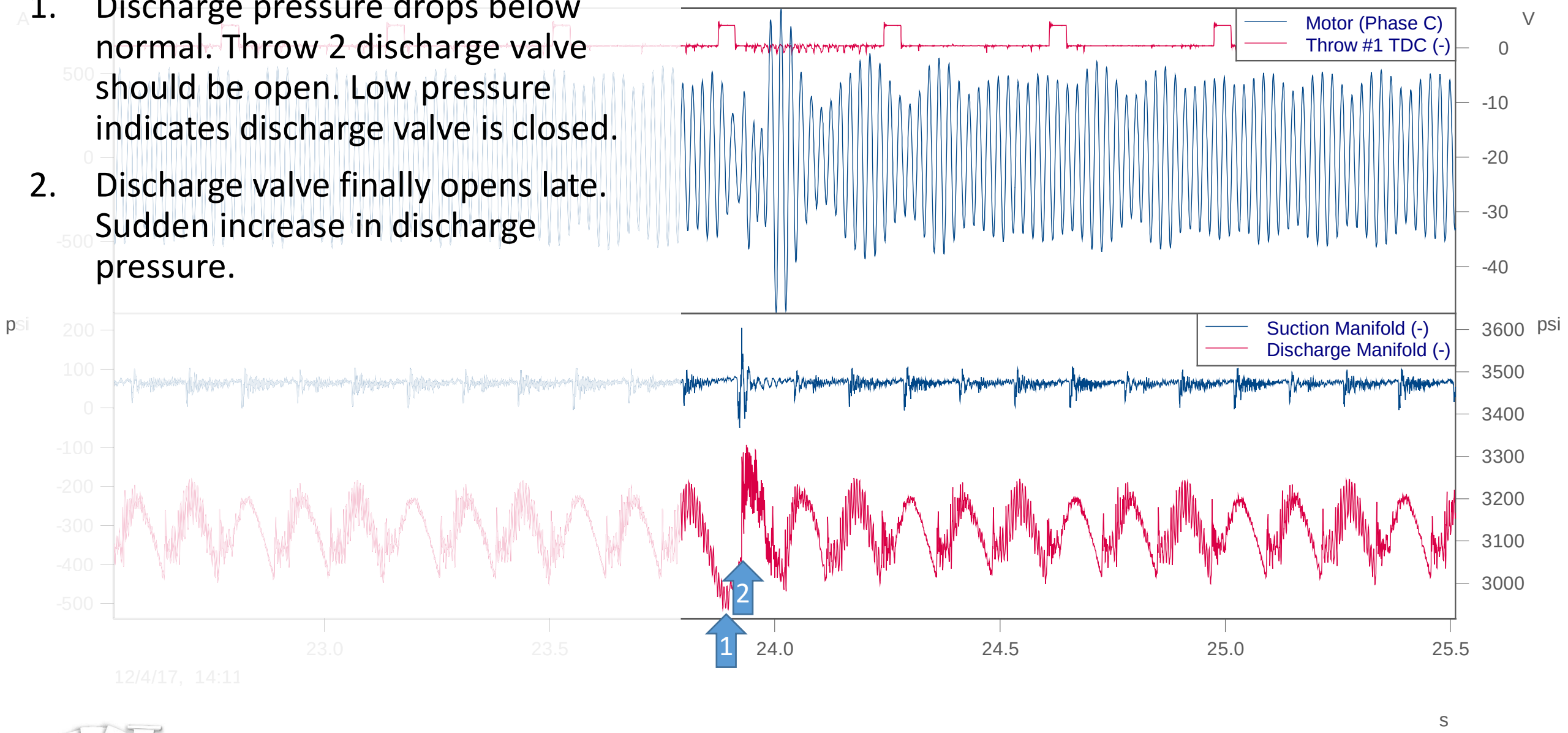

Near-shutdown event
followed by
actual shutdown event
Lets look at it in detail…
RPM
Unit Speed (-)
Throw #1 TDC (-)
V
g
Gear Box (A)
Gear Box (H)
in/s
Motor-Non-Drive End (A)
Pump-Throw #1 Fluid End (A)
Pump-Throw #1 Fluid End (H)
psi
Suction Manifold (-)
Discharge Manifold (-)
psi
A
Motor (Phase C)
14:00
14:05
14:10
14:15
14:20
14:25
14:30
14:35
14:40
14:45
14:50
14:55
15:00
12/4/17
h:m


RPM
Unit Speed (-)
Throw #1 TDC (-)
V
Near-shutdown event
Actual shutdown event
g
Gear Box (A)
Gear Box (H)
in/s
Motor-Non-Drive End (A)
Pump-Throw #1 Fluid End (A)
Pump-Throw #1 Fluid End (H)
Lets look at the near-shutdown event in detail...
psi
Manifold (-)
Manifold (-)
psi
A
Motor (Phase C)
14:11:10
14:11:15
14:11:20
14:11:25
14:11:30
14:11:35
14:11:40
14:11:45
14:11:50
14:11:55
14:12:00
14:12:05
12/4/17
h:m:s

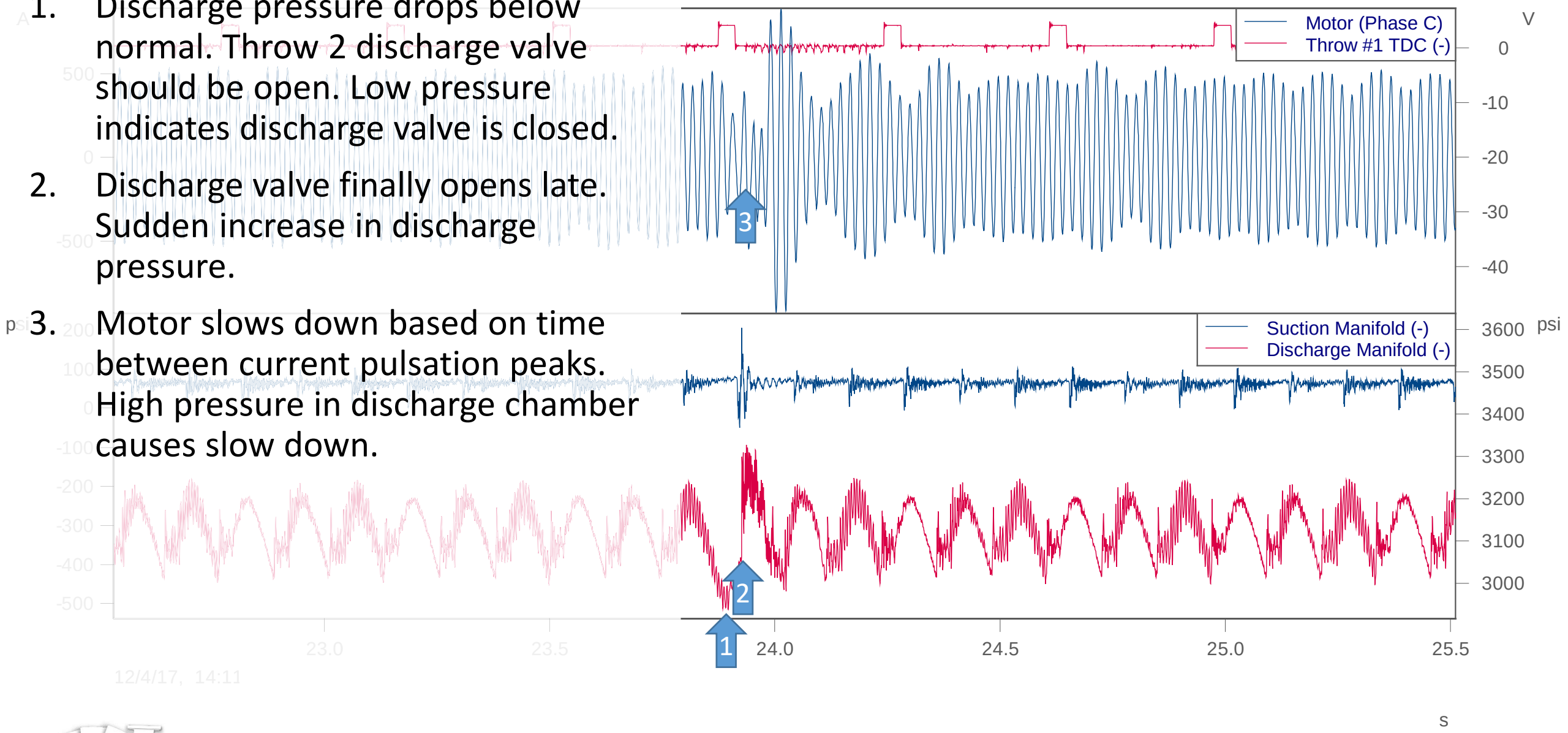
1. Discharge pressure drops below normal. Throw 2 discharge valve should be open. Low pressure indicates discharge valve is closed.



1. Discharge pressure drops below normal. Throw 2 discharge valve should be open. Low pressure indicates discharge valve is closed.
2. Discharge valve finally opens late. Sudden increase in discharge pressure.



1. Discharge pressure drops below normal. Throw 2 discharge valve should be open. Low pressure indicates discharge valve is closed.
2. Discharge valve finally opens late. Sudden increase in discharge pressure.
3. Motor slows down based on time between current pulsation peaks. High pressure in discharge chamber causes slow down.



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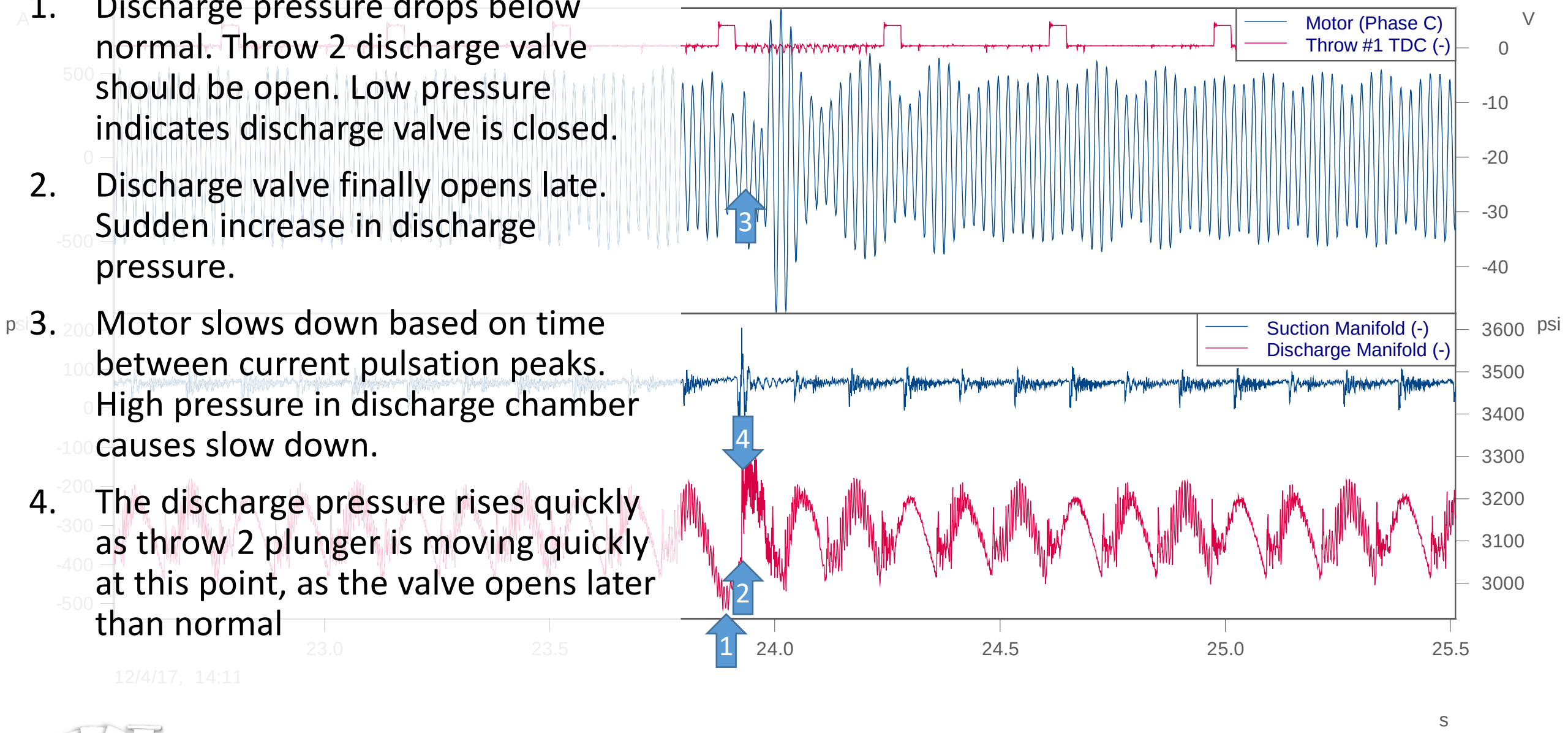
4. The discharge pressure rises quickly as throw 2 plunger is moving quickly at this point, as the valve opens later than normal



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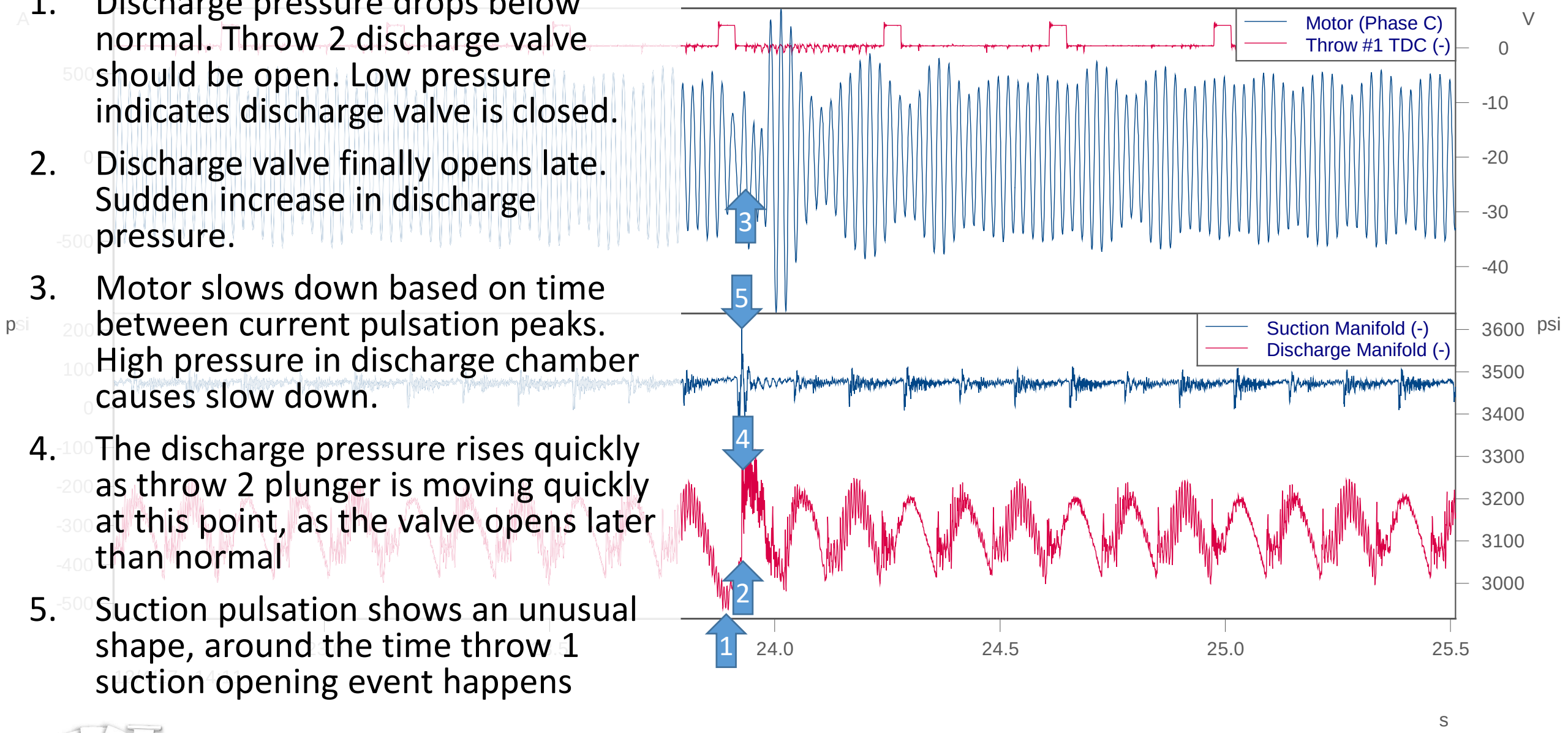
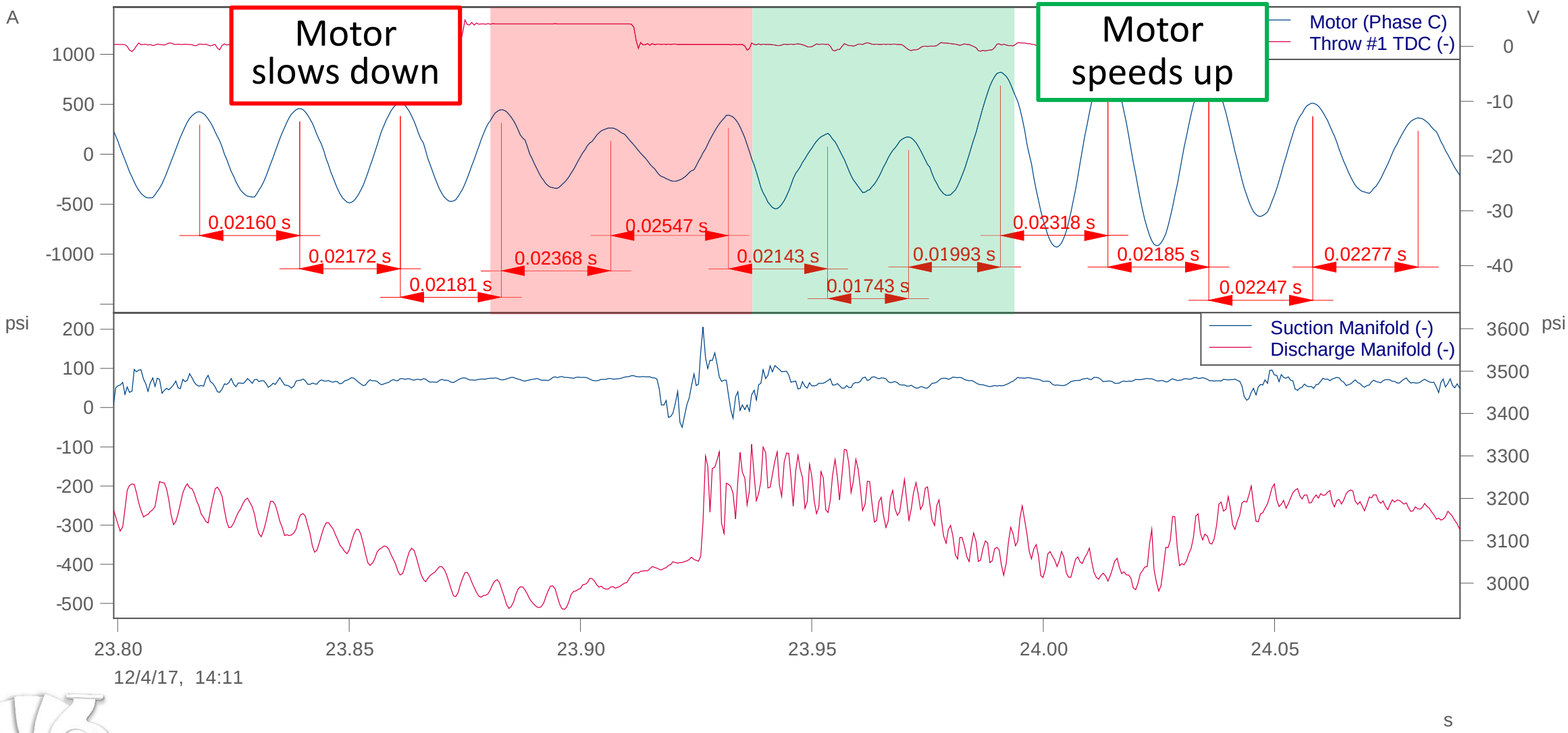
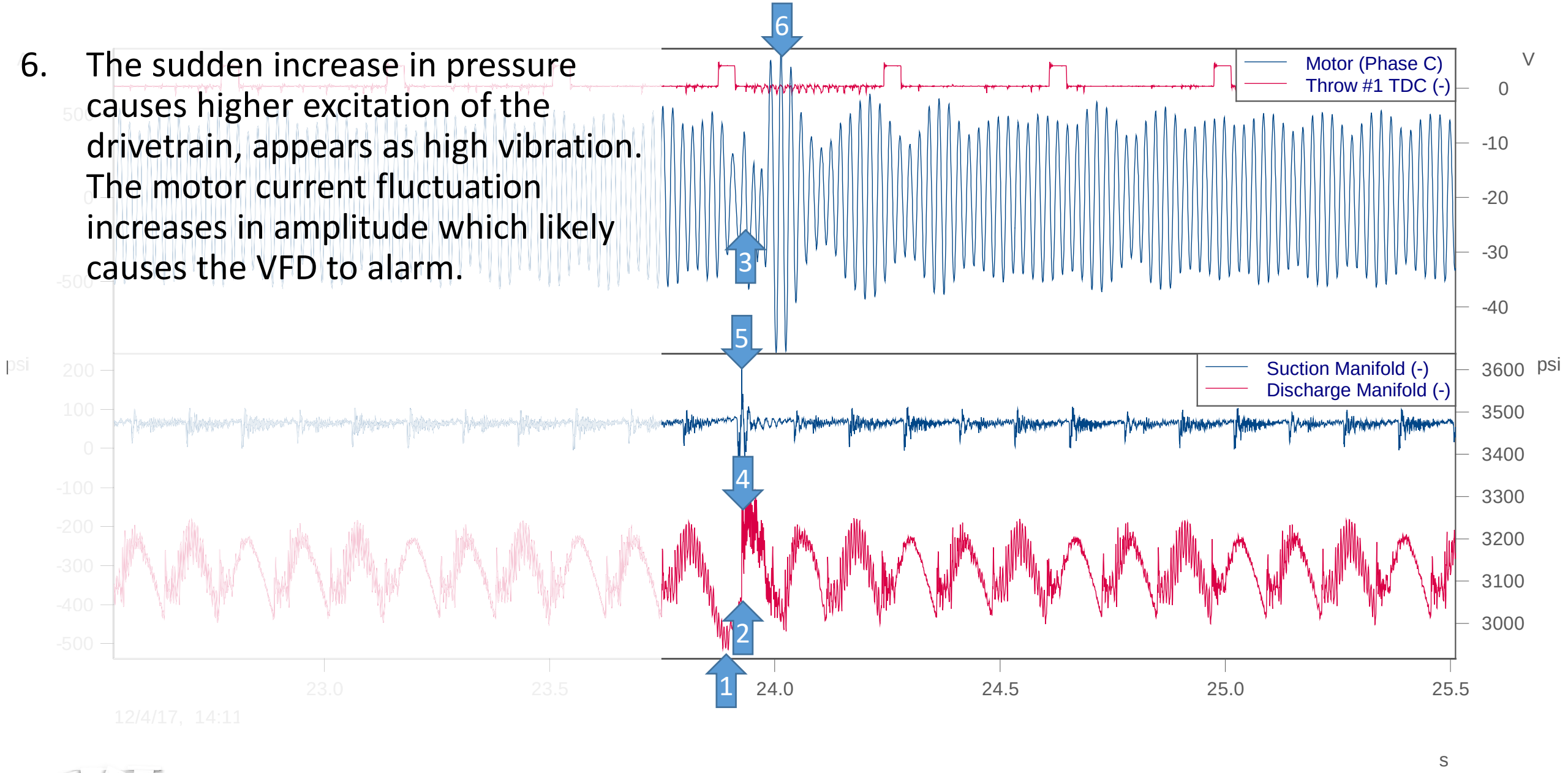
3. Motor slows down based on time between current pulsation peaks. High pressure in discharge chamber causes slow down.
4. The discharge pressure rises quickly as throw 2 plunger is moving quickly at this point, as the valve opens later than normal
5. Suction pulsation shows an unusual shape, around the time throw 1 suction opening event happens



Motor current during near-shutdown event

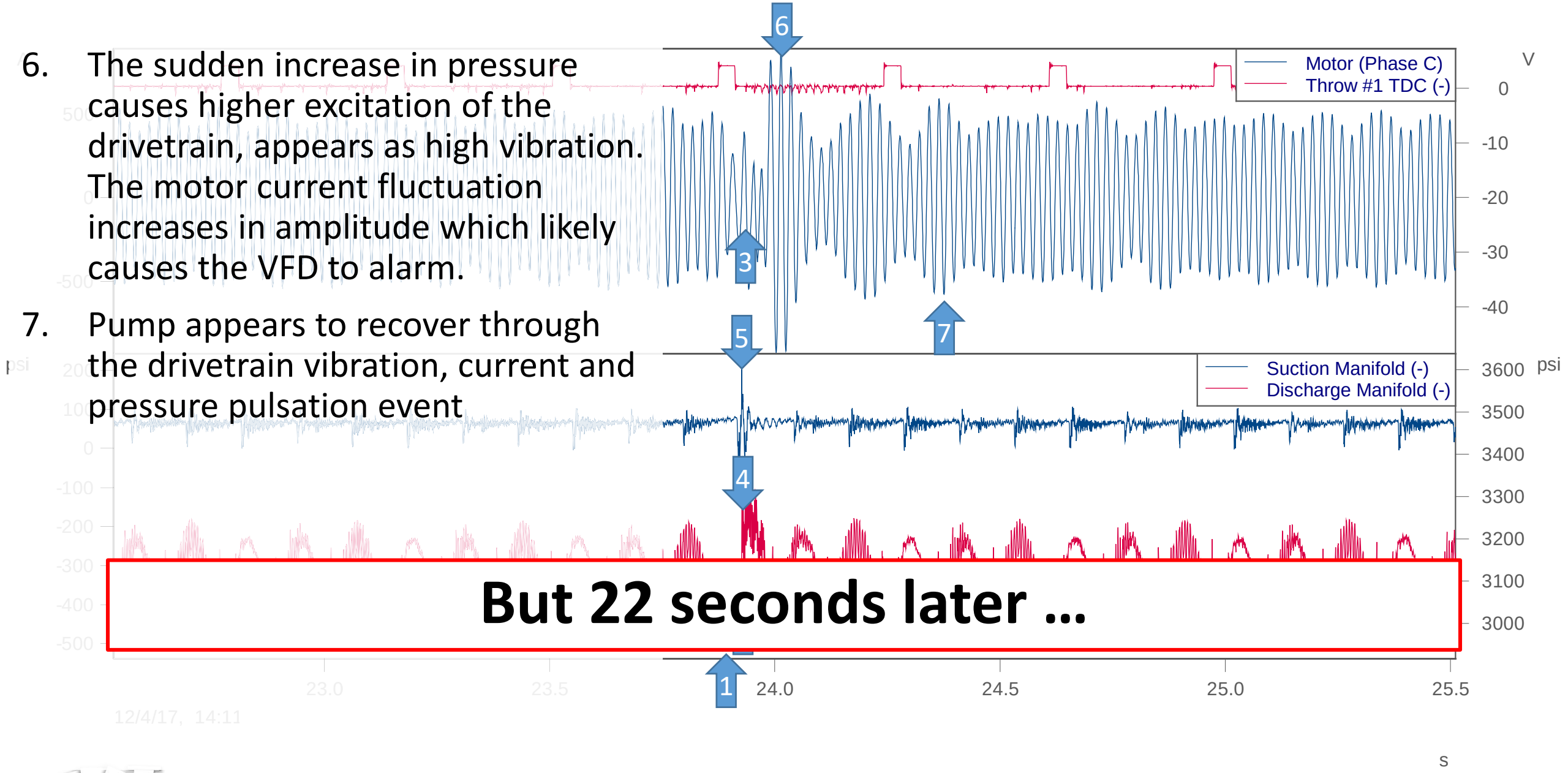


6. The sudden increase in pressure causes higher excitation of the drivetrain, appears as high vibration. The motor current fluctuation increases in amplitude which likely causes the VFD to alarm.



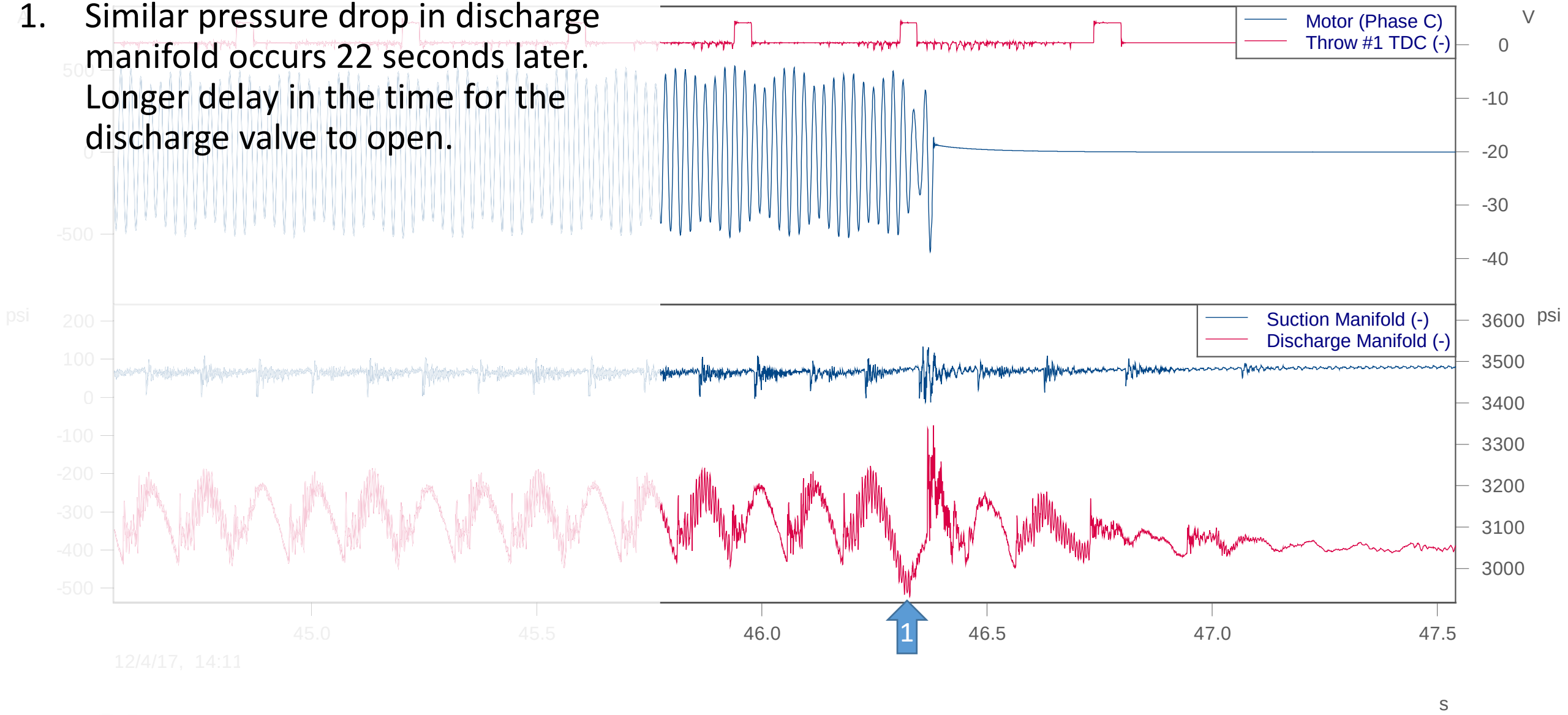
6. The sudden increase in pressure causes higher excitation of the drivetrain, appears as high vibration. The motor current fluctuation increases in amplitude which likely causes the VFD to alarm.

7. Pump appears to recover through the drivetrain vibration, current and pressure pulsation event

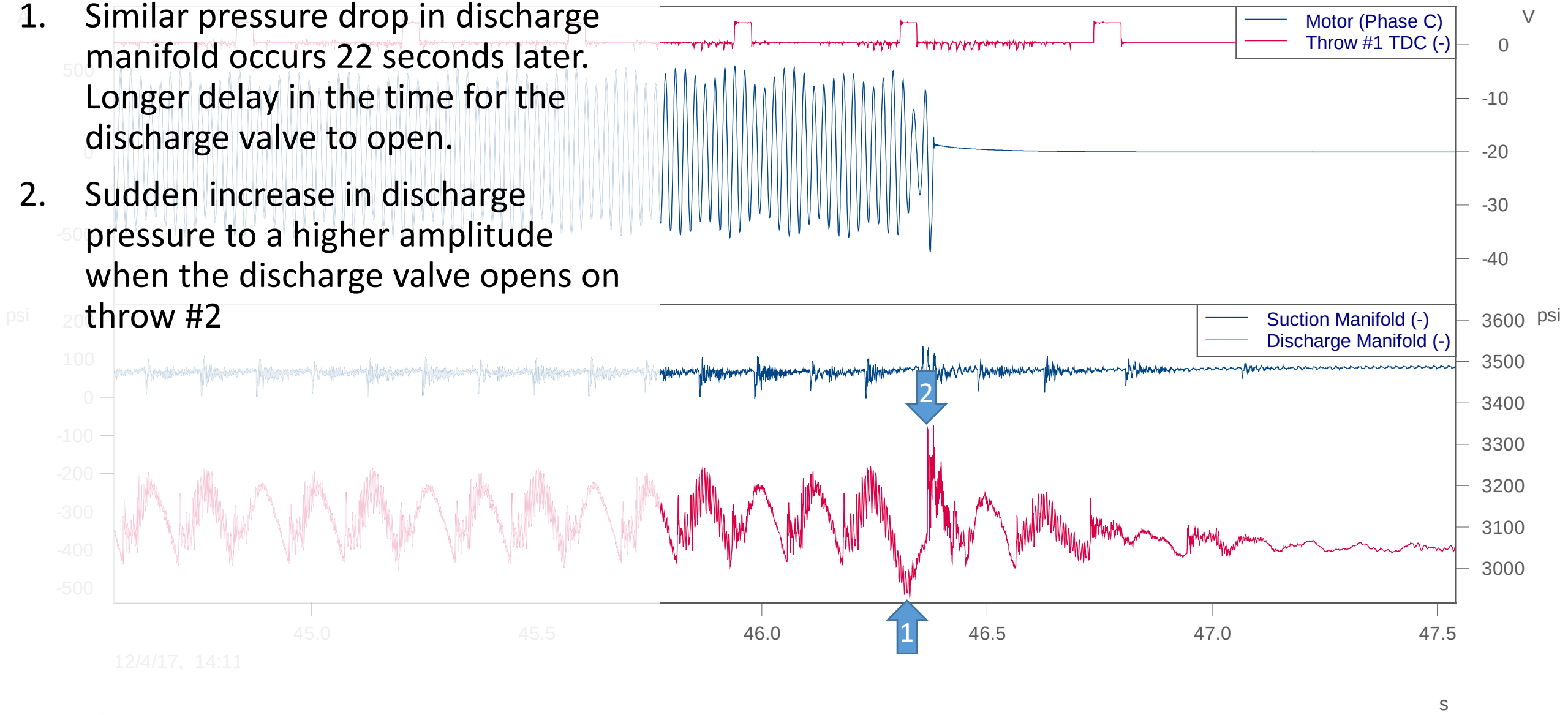


But 22 seconds later …

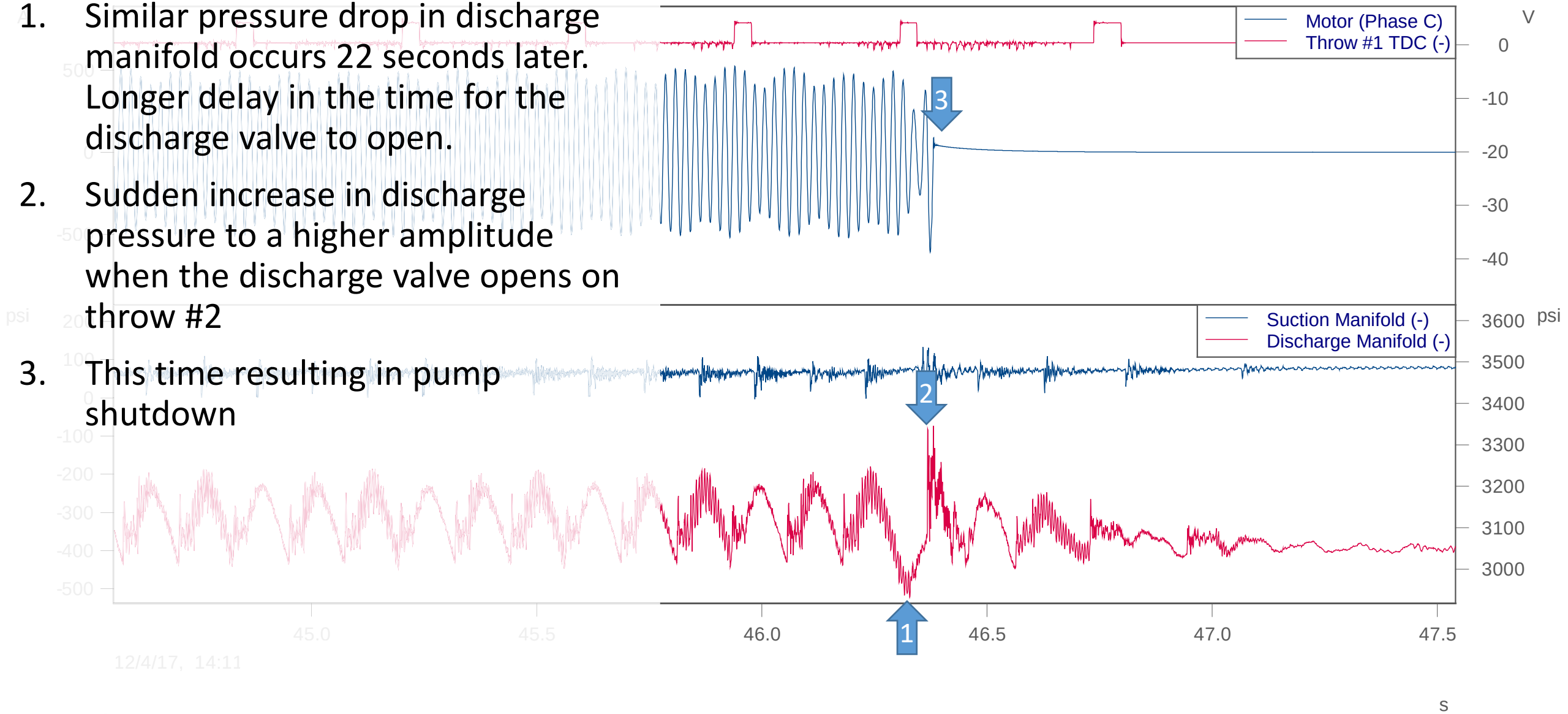
1. Similar pressure drop in discharge manifold occurs 22 seconds later. Longer delay in the time for the discharge valve to open.



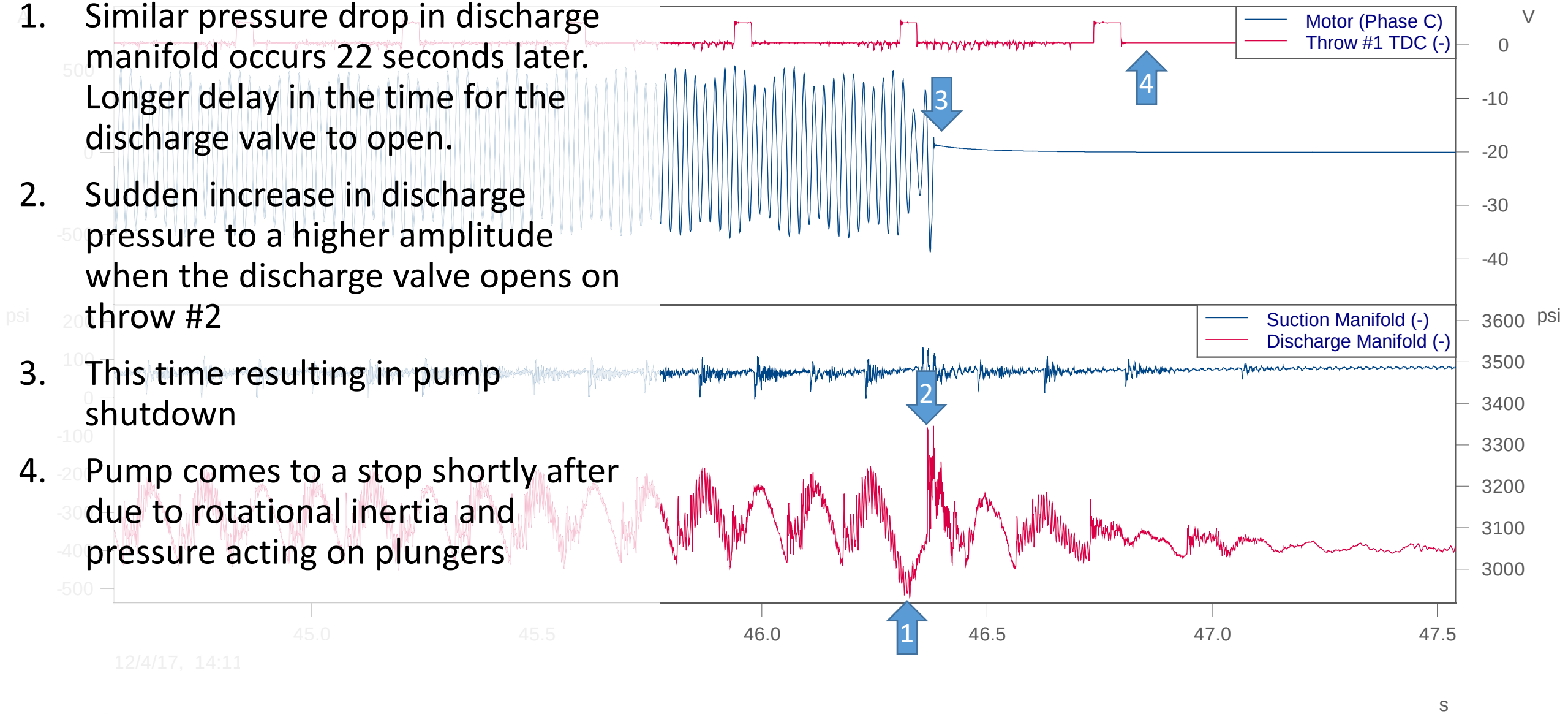
1. Similar pressure drop in discharge manifold occurs 22 seconds later. Longer delay in the time for the discharge valve to open.
2. Sudden increase in discharge pressure to a higher amplitude when the discharge valve opens on throw #2



1. Similar pressure drop in discharge manifold occurs 22 seconds later. Longer delay in the time for the discharge valve to open.
2. Sudden increase in discharge pressure to a higher amplitude when the discharge valve opens on throw #2
3. This time resulting in pump shutdown



1. Similar pressure drop in discharge manifold occurs 22 seconds later. Longer delay in the time for the discharge valve to open.
2. Sudden increase in discharge pressure to a higher amplitude when the discharge valve opens on throw #2
3. This time resulting in pump shutdown
4. Pump comes to a stop shortly after due to rotational inertia and pressure acting on plungers



Cause of the pump shutdown

- Delayed opening of the Throw #2 discharge valve triggers the trip. “Stuck” valve causes pump to momentarily slow down.
- Late and sudden opening of the discharge valve results in a sudden drop in load
- Motor momentarily speeds up which turns the motor into a generator resulting in an over-voltage in the VFD and pump shuts down
- Problems appeared after the stiffer springs were installed. Damage to valves observed.

Action taken

- Change stiffer springs to more flexible springs
- Pumps have operated for several months without tripping with the more flexible springs
- Unsolved mystery: Why did the throw #2 discharge valve stick?
  - Only one of two pumps had problems
  - Problems appeared only on throw #2
  - Stiffer valve springs should have improved the performance
- Additional site testing and simulations proposed to determine root cause
- Pumps running OK with more flexible springs. No further work done.

Conclusions

- Measurement of pump system key indicators allowed to determine the source of trip and recommend corrective action: change valve spring design
- Commercially available equipment, no proprietary equipment required
- Test equipment can:
  - React quickly enough to record fast transients in pump systems
  - Operate continuously, unmanned for days to weeks
  - Can also be setup with event-based recording to reduce data usage
- Avoids trial and error approach to identify pump faults