FIELDWOOD ENERGY

Troubleshooting Subsea Production Systems

Prepared for Texas A&M University (Whoop!) by Michael Kinzel

Agenda

At the end of this presentation:

- Attendees will understand what a trend is.
- Attendees will learn how to combine an understanding of the actual system state vs. inferred system state.
- Attendees will see two examples of applying theory to troubleshoot a failure (or assumed failure) of the Subsea Production System (SPS).

Several slides are marked “For Background Information Only” since there isn’t time to cover everything.

1. Process Monitoring (10 minutes):
   - Any process can breakdown/fail.
   - As subsea systems cannot be easily accessed locally, we rely on remote process monitoring from the host facility to understand what is happening.
2. How valves work (20 minutes):
   - Its important to understand the design and behavior of each type of valve to understand what can go wrong.
   - This presentation only covers a single type of valve, but the most common: Fail Close (FC) gate valve (also called spring return).
   - Attendees will learn how to correlate equipment behavior to the control system “trend”.
3. Case Study:
   - The two examples given in this presentation are not Fail Close (FC) gate valves.
   - Attendees will learn how to use trends to troubleshoot subsea systems.

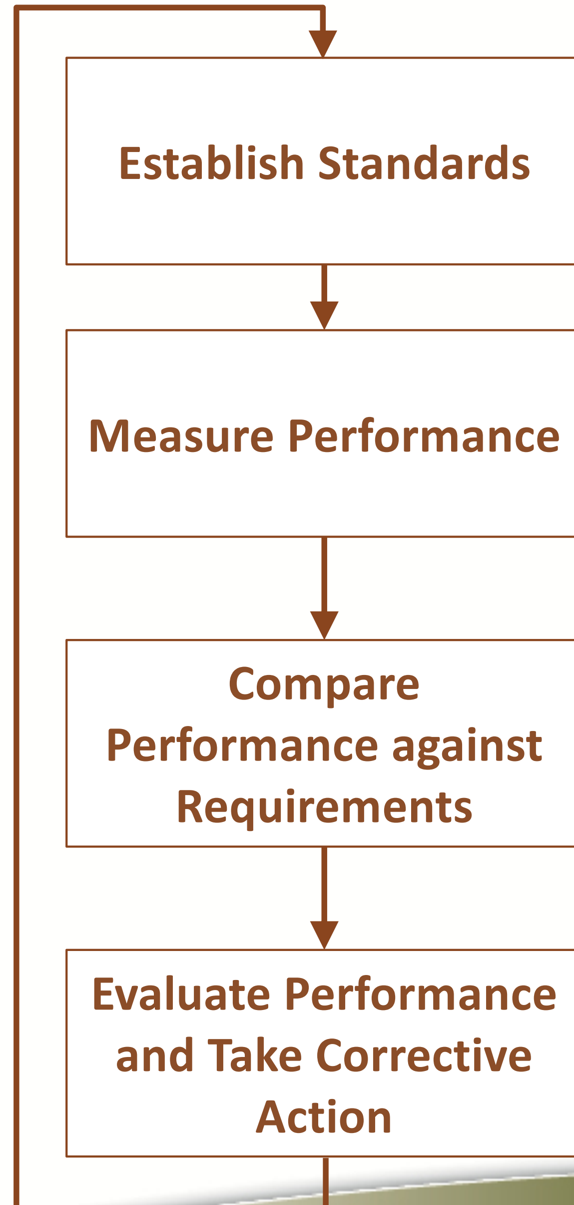
Process Monitoring

(crash course in control theory)

Basic Process Control

- Control systems follow the same process flow as any process management system.

Typical Business Process



- Steps in a control process:
  - Measure the variable.
  - Make a decision.
  - Take action.
- Common variables (i.e., process metrics):
  - Pressure.
  - Temperature.
  - Level.
  - Flow.
- Typical components (key components):
  - Sensor.
  - Transmitter.
  - Controller.
  - Final Control Element (FCE).

Fieldwood Energy

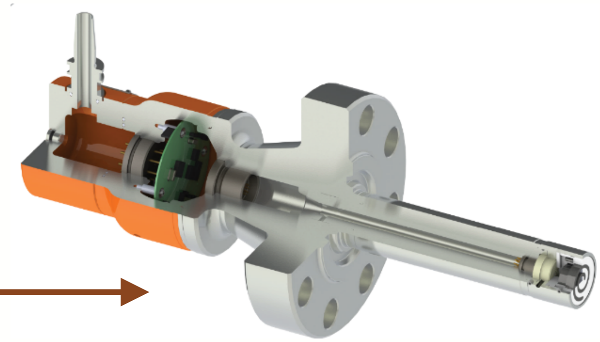
* References in slide notes.

Process Variables: Pressure

<u>Pressure</u>

- Pressure is the amount of force applied by a pressurized fluid on each unit area of its container:
  - Pressure = force of liquid (or gas) / surface area (force per unit area).
  - Changes in force or area cause pressure changes.
  - Force in lb is divided by area in in^2 = pressure in lb per in^2 (psi).

- <u>Seal Gage Pressure</u> (unique to instrumentation):
  - Seal gage pressure is the difference between trapped atmospheric pressure inside the instrument and the system pressure that is being measured.
  - P(g) = P(measured) with respect to P(atm).
  - P(atm) = 14.7 psi; atmospheric pressure.
  - Expressed as psig.



Confusing!

<u>Coincidental Gage Pressure</u>:
  - Coincidental gage pressure is the difference between ambient external pressure and the internal system pressure that is being measured.
  - P(g) = P(i) – P(e).
  - P(i) = internal pressure and P(e) = external pressure.
  - Also expressed as psig!

301.2.1 General

(a) The design pressure of each component in a piping system shall be not less than the pressure at the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service, except as provided in para. 302.2.4.

FIELDWOOD ENERGY

* References in slide notes.

Process Variables: Pressure (continued)

Pressure

- Pressure is the amount of force applied by a pressurized fluid on each unit area of its container:
  - Pressure = force of liquid (or gas) / surface area (force per unit area).
  - Changes in force or area cause pressure changes.
  - Force in lb is divided by area in in^2 = pressure in lb per in^2 (psi).

- Absolute Pressure:
  - Absolute pressure is measured without regard to atmospheric pressure.
  - P(a) = P(g) + P(atm).
  - Expressed as psia.

API 17D defines rated working pressure (RWP) as the maximum internal pressure that the equipment is designed to contain and/or control (see API 17D [2011], 3.1.42). This is an absolute pressure. The API specifications state that the effects of external load, such as external pressure, should be taken into account in the design, but the use of external pressure to increase the equipment RWP is not recommended.

- Differential pressure:
  - Differential pressure is the difference between two pressures that are being measured.
  - DP = P(1) – P(2).
  - Expressed as psid.

FIELDWOOD ENERGY

* References in slide notes.

Process Variables: Level and Density

<u>Level</u>

- Level and volume are directly related quantities.
- Volume is the amount of space occupied by objects or fluid:
  - Capacity of container.
  - Calculated from dimensions of the container.
  - Volume of rectangle = L x W x H.
- Level: Location of interface between two phases of a substance (or two different substances).
- Indicated by:
  - % Fill (e.g.: 50 % full)
  - Height to the variable measured (e.g.: 20 inches).
  - Volume of variable measured (e.g.: 20 gallons)

<u>Density</u>

- Density = mass / volume.
- Liquid type is a factor because hydrostatic head varies with mass, density, and height.
- Different fluids have different densities.
- Fluids are relatively incompressible.
- Gas density varies with pressure and temperature.

<u>Specific Gravity</u>

- A ratio that compares a fluid's density to the density of water.
- SG = density of fluid / density of water (water = 62.4 lb/ft^3 or 1000 kg/m^3).
- SG of water = 1.
- SG of sea water = 1.025.
- SG of oil ranges from about 0.7 – 0.9 depending chemistry: Water Cut (WC) and gas.

For Background Information Only

FIELDWOOD ENERGY

* References in slide notes.

Process Variables: Temperature and Flow

Temperature

- Temperature: The measure of the internal molecular activity of a substance.
- Temperature is measured using the Fahrenheit or Celsius scale.
  - FWE uses °F.
- The temperature scale may not always match absolute process conditions:
  - 0 °F is not a valid reference point for PVT calculations.
  - Example: 0 °F = 459.67 °R.
- Just For Information Only (FIO) as this does not affect basic process monitoring.

Flow

- Flow: The quantity of fluid which moves through pipes and channels in a given unit time.
- Two types of flow measurement:
  - Mass flow rate: Measured in lb/hr.
  - Volumetric flow rate: Measured in gal/min (gpm).
- Differential Pressure (DP or ΔP) measurements are often used to determine flow rate:
  - Flow rate is measured in terms of differential pressure.
  - Flow is directly proportional to the square root of pressure across a fixed restriction (orifice).

$$\Delta p = f_{\mathrm{D}} \cdot \frac{L}{D} \cdot \frac{\rho \langle v \rangle^2}{2} = f \cdot \frac{L}{D} \cdot 2\rho \langle v \rangle^2$$

For Background Information Only

FIELDWOOD ENERGY

* References in slide notes.

Process Variables: Voltage and Current

- Voltage and current are more of a “housekeeping” parameter, but can be used to understand how the system is operating.
- Power (P) = Voltage (V) x Current (I).
- Most subsea electrical components can be abstracted as a constant power load. The amount of current drawn from the power supply is inversely proportional to the supplied voltage.

Voltage:

- Voltage is the portion of the electrical power “pushed” from the control system to the subsea equipment.
- Subsea systems can use Alternating Current (AC) or Direct Current (DC):
  - V_{DC}
  - V_{AC}
- Most power distribution uses AC because its easy to transform (step-up/step-down).
- Most instrumentation, actuators, solenoids, electronics, etc. use DC.
- Most power supplies have a fixed output voltage.

Current:

- Current is the portion of the electrical power “pulled” from the subsea equipment, given adequate voltage from the host facility.
- Measured in Amps (A) or milliamps (mA).

- 0 A = open circuit or no load.
- ∞ A = short circuit.
- A short circuit far from the power source will not be infinite, but depend on the amount of wire between the power supply and short (V = IR).

For Background Information Only

FIELDWOOD ENERGY

* References in slide notes.

Measuring Process Variables

Sensors

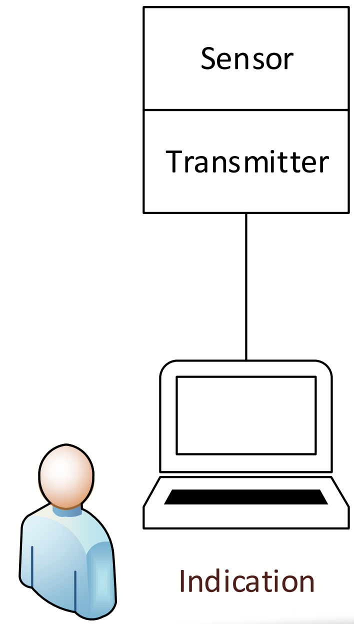
- Response time: Time it takes to respond to a change in a controlled variable.
  - Sensor response.
  - Controller response.
  - Both affect the response of the entire loop.
- Accuracy vs. Precision:
  - Accuracy: How closely a sensor reflects the controlled variable.
  - Precision: How consistently the sensor indicates the same input value over time.
  - Sensors should be both accurate and precise.

Transmitters

- Convert the signal:
  - Sensors may produce mechanical movement, millivolts, or capacitance.
  - Transmitters convert sensor signal into instrument signal.
- Transmission methods:
  - Transmission signals are electrical, pneumatic, or electronic/digital.
  - Sensors measure changes and relay to transmitters.
  - Transmission signals are sent to a controller.
- Performance of the feedback control loop depends on the proper operation of sensors and transmitters.
- Transmission signals represent the value of the controlled variable.

Indicators

- Actual representation of the process:
  - Panel mounted.
  - Digital displays.
  - Human Machine Interface (HMI).



For Background Information Only

FIELDWOOD ENERGY

* References in slide notes.

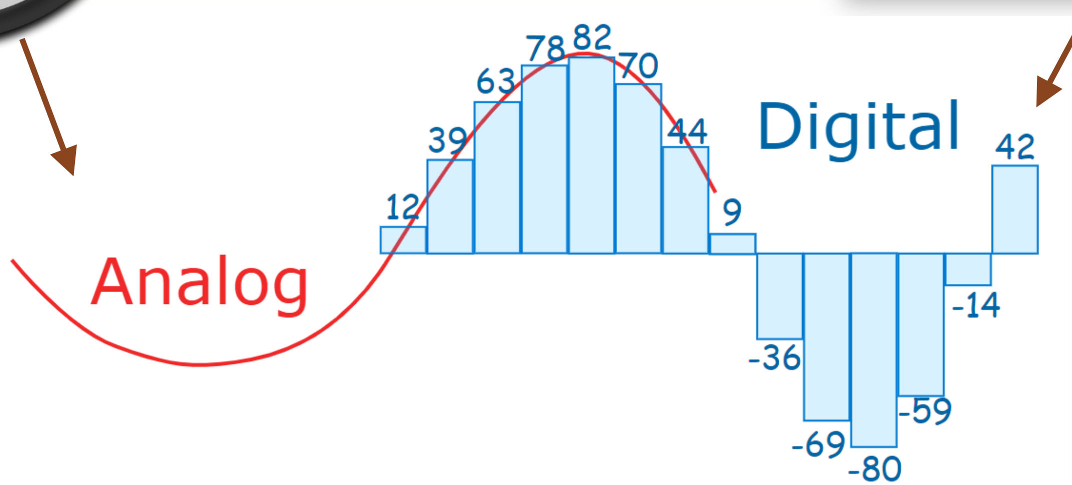
Types of Values

Analog:

- Continuous change.
- Infinite possibilities.
- Can be any number.

Digital:

- Finite possibilities.
- It can only be a certain number.
- Discrete (ON/OFF, True/False, 1/0, etc.).



FIELDWOOD ENERGY

* References in slide notes.

Types of Errors

- Definition of Instrument Error:
  - Difference between the actual process value and the value indicated by the instrument.
  - Amount of acceptable error depends on the process system demands.

- Can result from conversion:
  - Digital Input (DI) to Analog Output (AO).
  - Analog Input (AI) to Digital Output (DO).

- Errors can result from instrument readings that do not reflect the process conditions:
  - Hysteresis,
  - Zero Shift,
  - Linearity,
  - Deadband,
  - Span Error, and
  - Repeatability.

- Different instruments can be polled / interrogated differently:
  - Only when the process value changes.
  - Only at certain time intervals.
  - Only when pre-configured setpoints are exceeded.
  - Etc.

- Timestamps may not be accurate.

- Data historians may display different types of data differently.
  - Some historians report actual process values.
  - Some historians interpolate between timestamped values.
  - Etc.

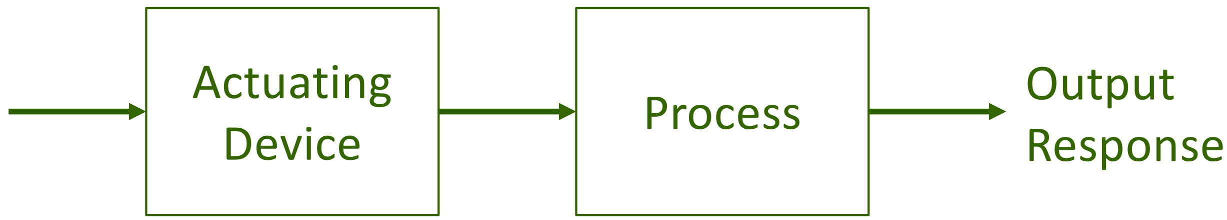
- What you infer may not reflect the actual condition!

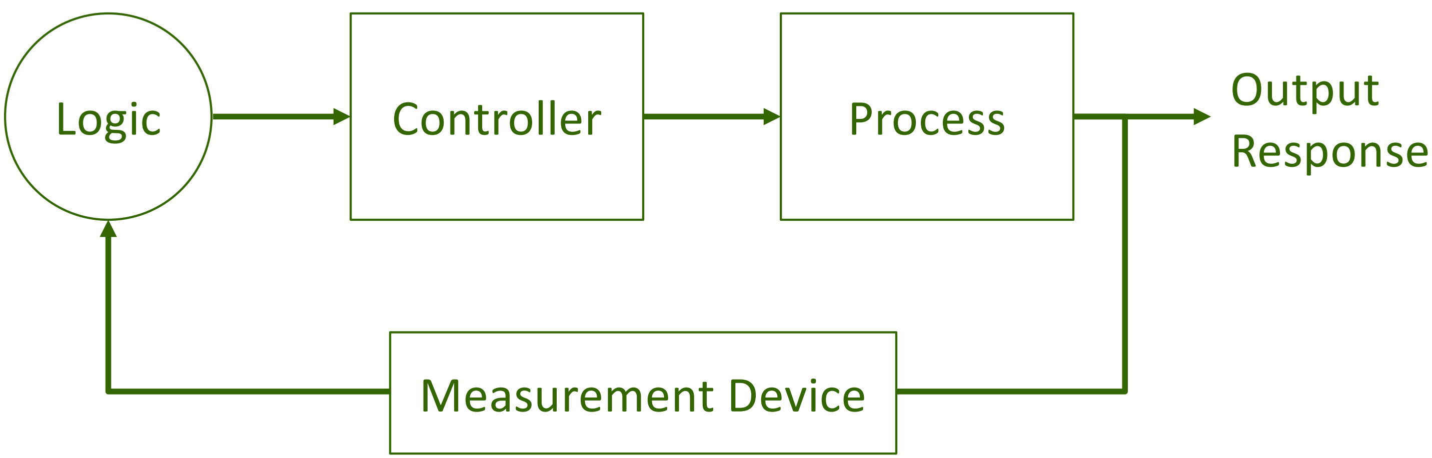
FIELDWOOD ENERGY

* References in slide notes.

Open vs. Closed Control Loops

- Open Loop: The process variable is not compared, and action is not taken in response to a deviation from the set point.
- E.G.: Water Faucet.





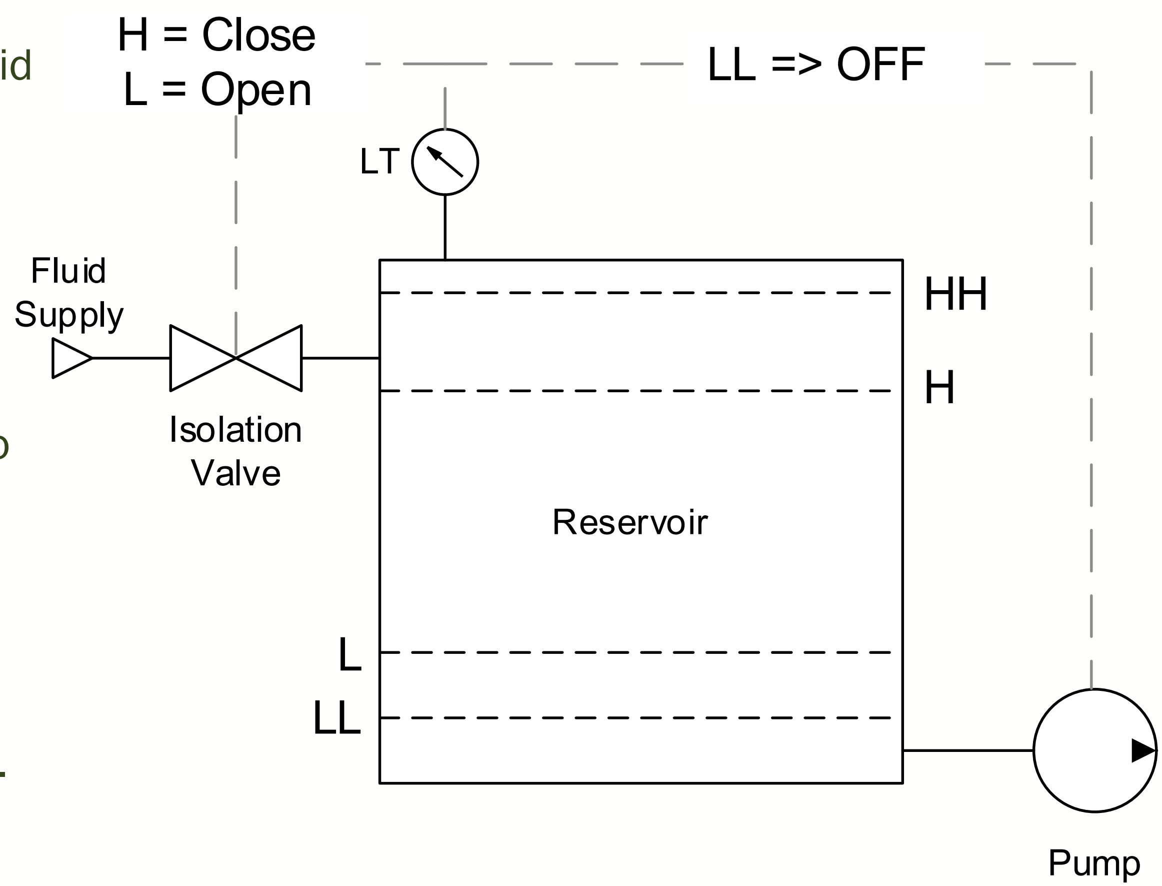
- Closed Loop: The process variable is measured, compared to a set point, and action is taken to correct any deviation from the set point.
- E.G.: Air Conditioning.

* References in slide notes.

Process Control Example: Level

Level:

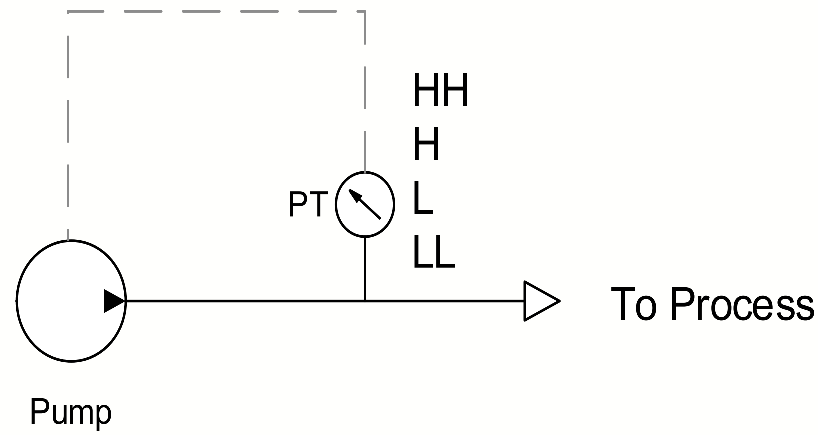
- A fluid reservoir provides hydraulic fluid to a pump.
- An ON/OFF isolation valves controls fluid fill.
- **The normal or desired level is between the Low (L) and High (H) levels.**
- **A Level Transmitter (LT) continuously monitors the fill level of the reservoir.**
- At a High (H) threshold, the controller automatically closes the supply valve to prevent overflow.
- At a Low (L) threshold, the controller automatically opens the supply valve.
- At a LowLow (LL) threshold, the controller automatically turns off the pump (prevents pulling air into system). **This is a Trip/interlock.**
- At a HighHigh (HH) threshold, the controller signals an alarm as this is an abnormal condition. The valve should have already been closed.



Process Control Example: Pressure

Pressure:

- A pump provides fluid power to a process.
- **A Pressure Transmitter (PT) continuously monitors the process.**
- A controller turns the pump ON or OFF depending on the indicated **pressure.**
- The normal or desired pressure is between the Low (L) and High (H) pressure thresholds.
- At a High (H) threshold, the controller automatically turns the pump OFF to **prevent overpressure.**
- At a Low (L) threshold, the controller automatically turns the pump ON to **ensure adequate system pressure.**
- At a LowLow (LL) threshold, the controller automatically turns the pump off (indication of a leak). **This is a TRIP/Interlock.**
- At a HighHigh (HH) threshold, the controller automatically turns the pump off, but latches it OFF. **This is a TRIP/Interlock.**



FIELDWOOD ENERGY

Broken Process: Why is all of this important?

- What if the process doesn't work:
  - Process conditions change.
  - Process control can fail.
- What if the actual system state is different than the virtual (inferred) state?
- What if something is broken?
- What if the system state is indeterminate?

- We can never "know" the state of subsea systems without direct observation.
- However, we can "infer" the system state through monitoring of the process variables.

Fieldwood Energy

Valve Operation

(Fail Close Gate Valve is the staple of subsea applications)

FIELDWOOD ENERGY

Hydraulically Actuated Valves: Overview

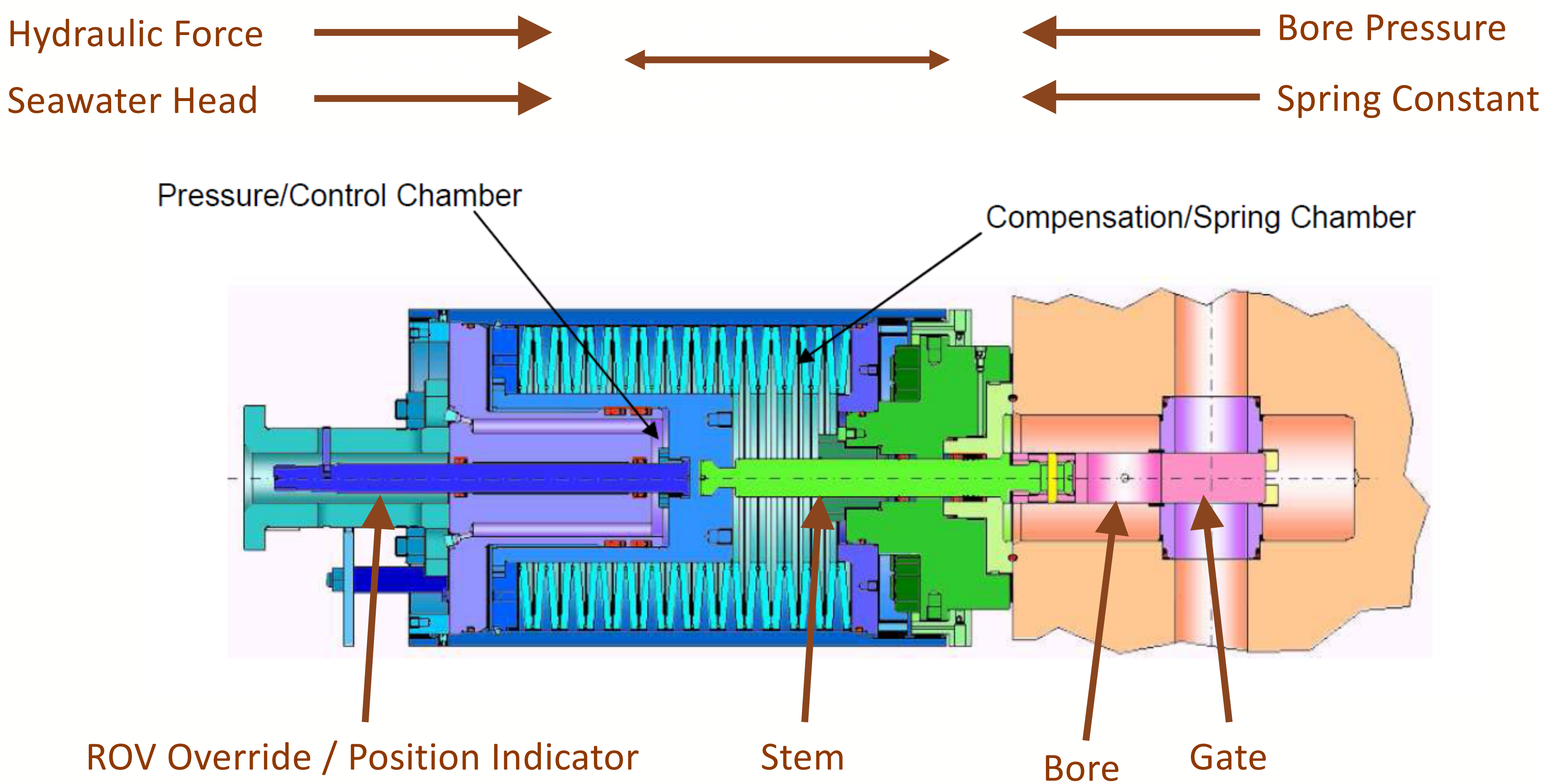
- Key Points:

  - Subsea process valves work on the principle of differential pressure applied across a piston.
    - Both sides of the piston are wetted with hydraulic fluid, such that the hydraulic motive force is always coincidental to the ambient subsea hydrostatic pressure (g = coincidental, not 1 ATM) with minimal back pressure.
    - Single acting valves include a compensated return.
    - Subsea Gate Valves have a Remote Operated Vehicle (ROV) override stem that wants to open the valve proportional to water depth.

  - Subsea Valves have a small signal and solenoid time latency.
    - Signal latency is not in the software configurable travel time.
    - Solenoid (DCV) shift time is included in the software configurable travel time.

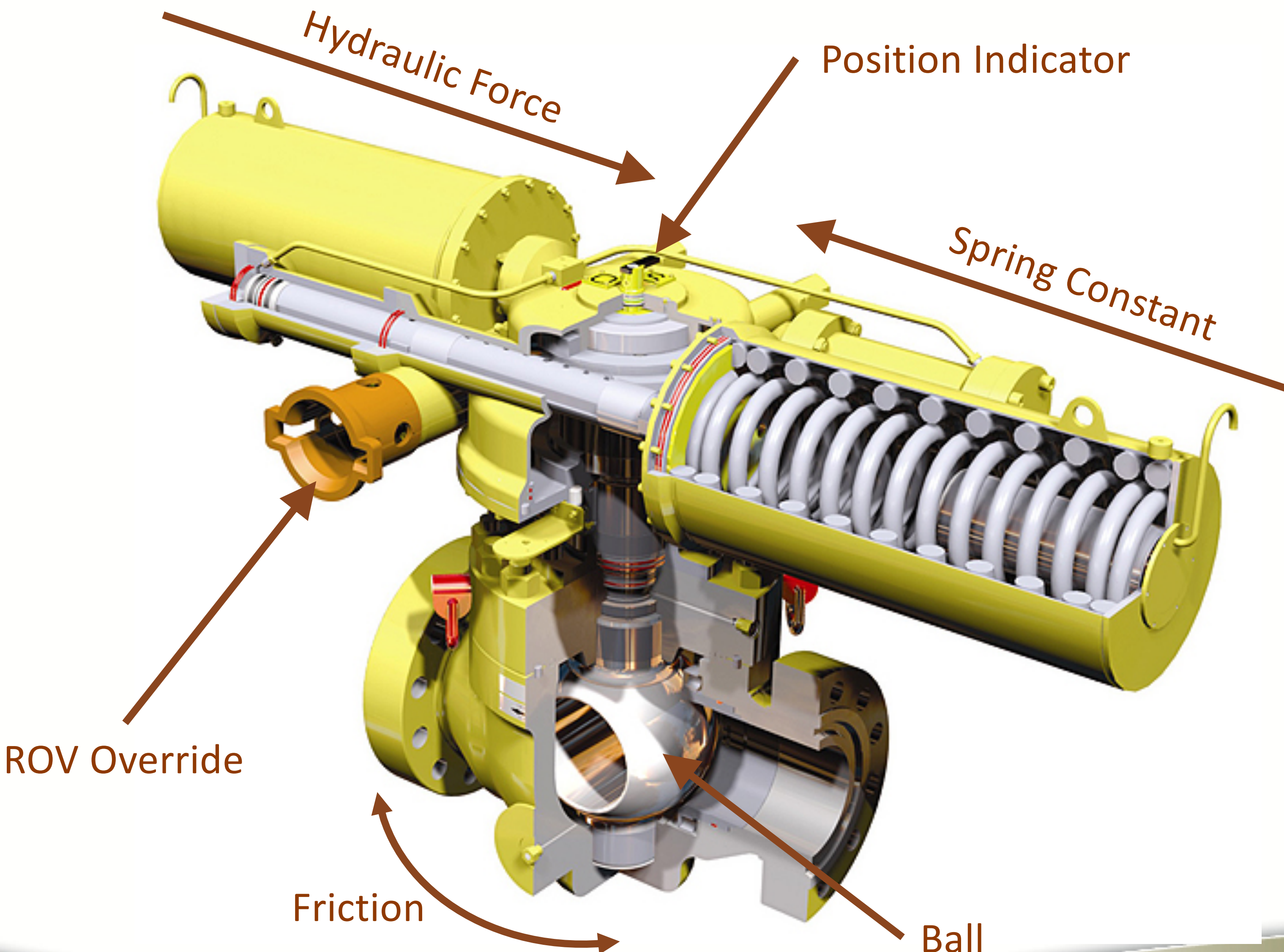
* References in slide notes.

Hydraulically Actuated Valves: FC Gate Valve



* Cross section from TechnipFMC

Hydraulically Actuated Valves: FC Ball Valve

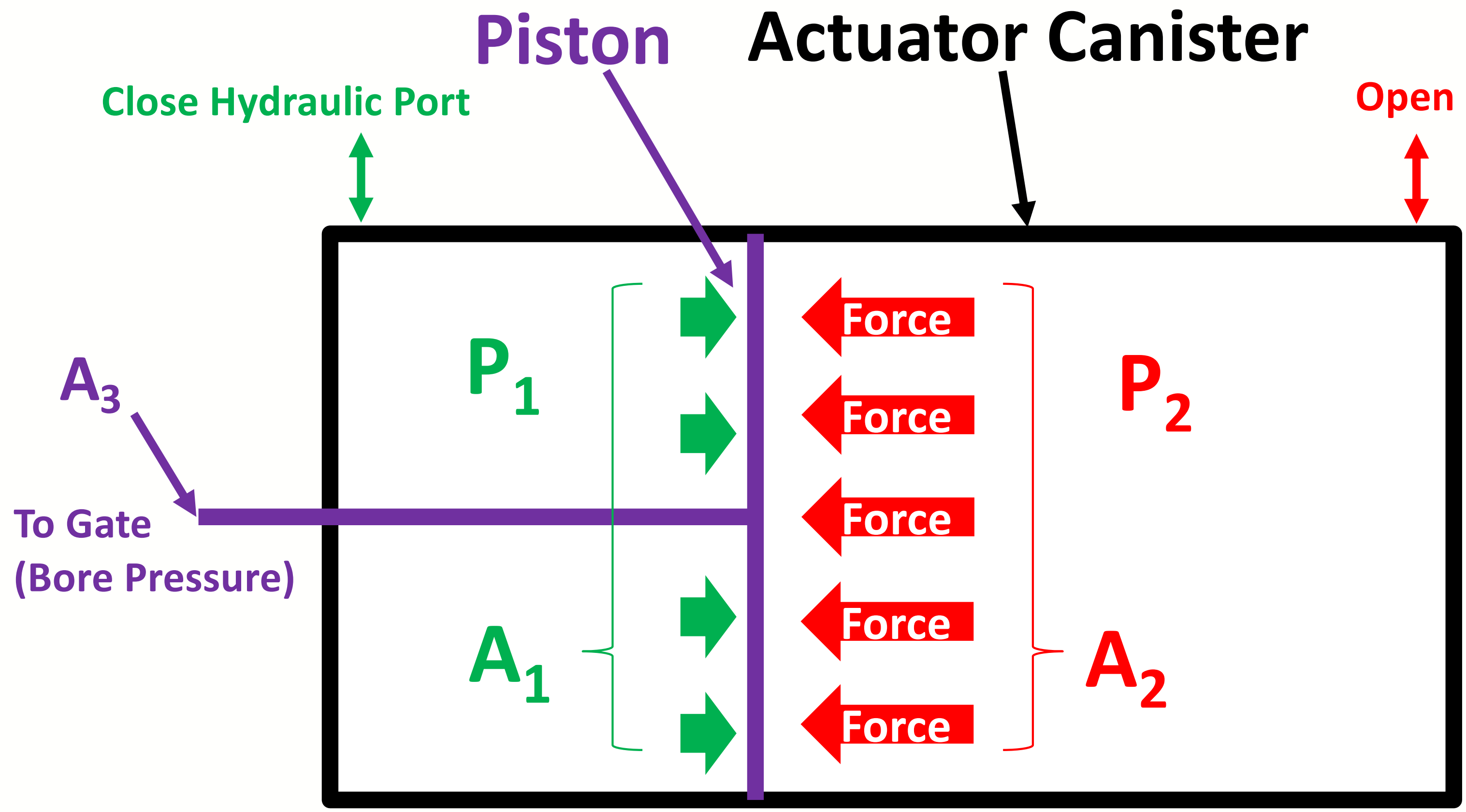


For Background Information Only

FIELDWOOD ENERGY

* References in slide notes.

Hydraulically Actuated Valves: Valve Actuator



Resultant force on the piston (F) = hydraulic pressure (P) x piston area (A)

Actuator Motive Force = $(P_1 A_1 + \text{Bore} \times A_3) - (P_2 A_2)$

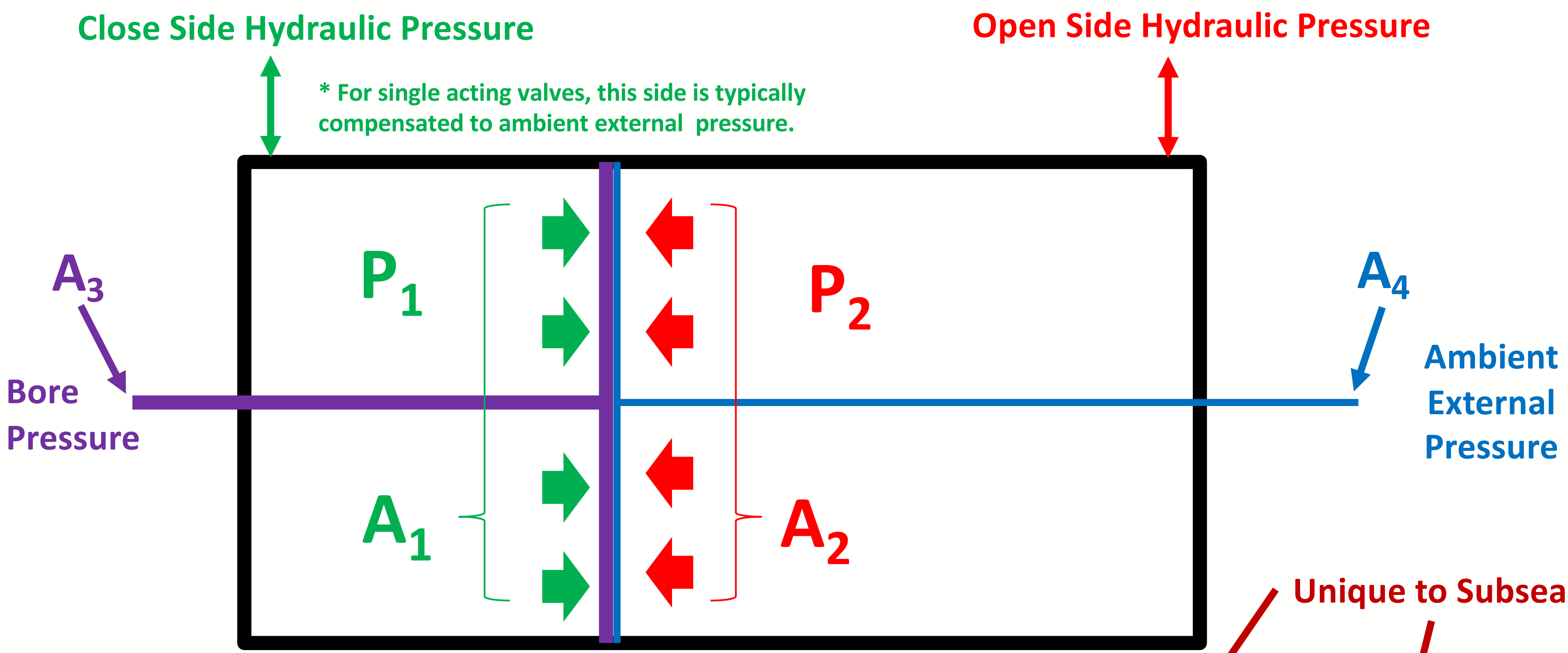
Actuator Motive Force (Neglecting Bore Pressure) = DP between P_1 and P_2

Processes end in a tank, so air is negligible.

FIELDWOOD ENERGY

* References in slide notes.

Hydraulically Actuated Valves: Valve Actuator



Actuator Motive Force = (P_1 A_1 + Bore x A_3) – (P_2 A_2 + Seawater Head x A_4)

Actuator Motive Force (Neglecting Bore Pressure) = Still DP between P_1 and P_2, but the ambient subsea pressure is additive to P_2.
Bore pressure "wants" to close the valve but ambient hydrostatic pressure "wants" to open the valve.
Opposing side must be compensated to account for depth and depth variation.

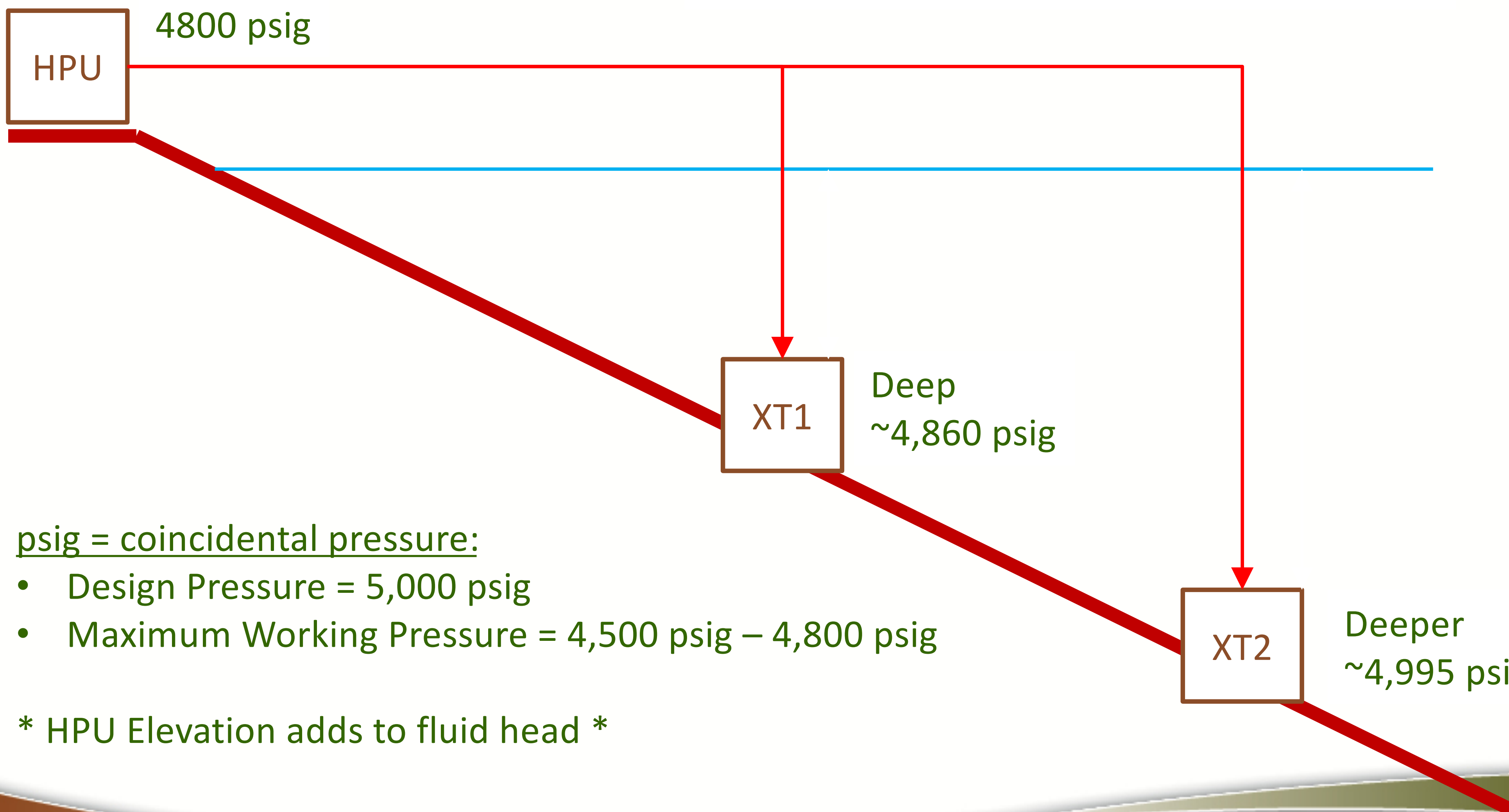
FIELDWOOD ENERGY

* References in slide notes.

Hydraulically Actuated Valves: Depth Variation

<u>Differences in API / ASME:</u>

- Older systems can operate at ~5,000 psig.
- Newer systems operate at ~4,500 psig.



<u>psig = coincidental pressure:</u>

- Design Pressure = 5,000 psig
- Maximum Working Pressure = 4,500 psig – 4,800 psig

* HPU Elevation adds to fluid head *

FIELDWOOD ENERGY

* References in slide notes.

Hydraulically Actuated Valves: 3280 ft (1000 m) WD

<u>Abstract away all other factors</u>:

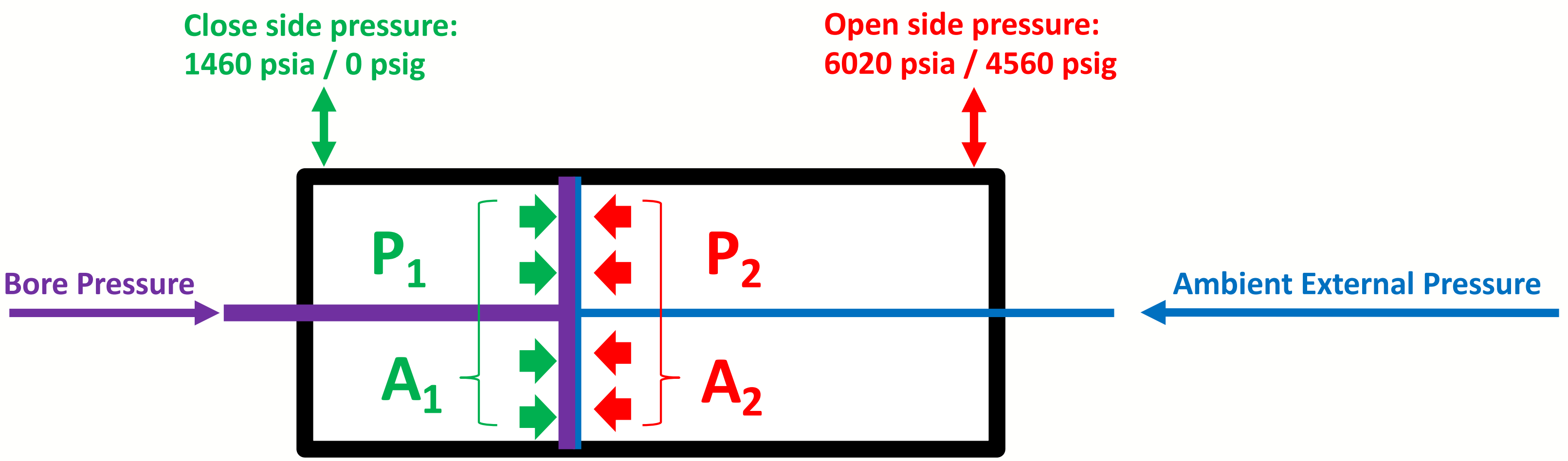
Subsea Head = 1,460 psi

Hydraulic Head = 1,520 psi

Supply Pressure = 4,500 psi

Motive Force = (4,500 psi + 1,520 psi) – 1,460 psi

Motive Force = 4,560 psi



Key takeaways:

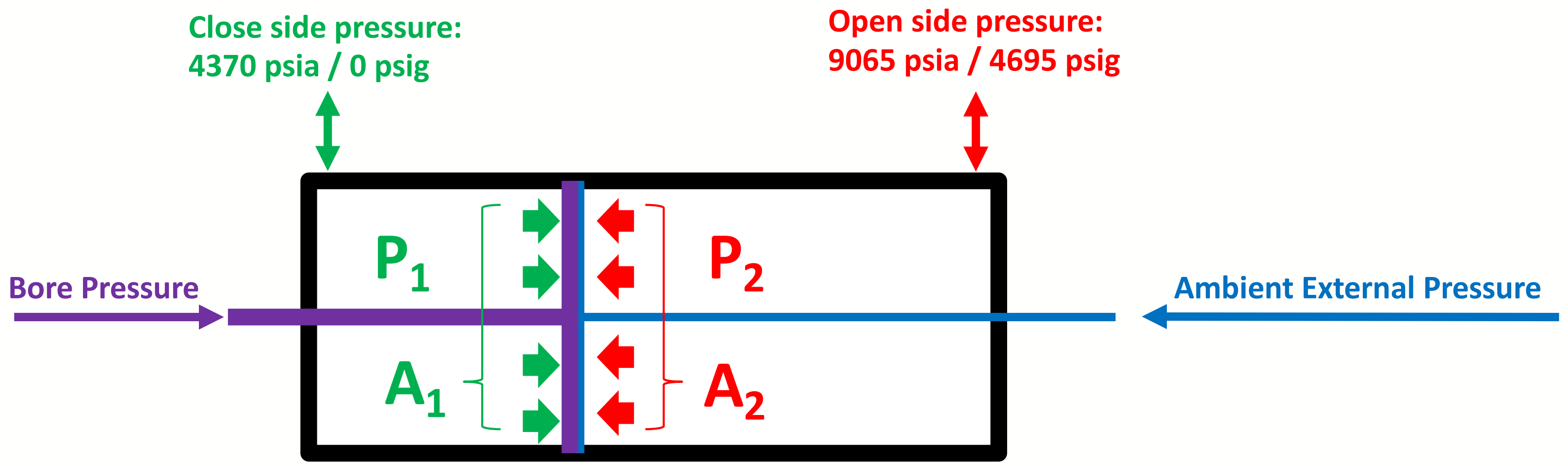
1. Depth adds to the hydraulic motive force.
2. Hydraulic pressures are truly "coincidental."

FIELDWOOD ENERGY

* References in slide notes.

Hydraulically Actuated Valves: 9840 ft (3000 m) WD

Abstract away all other factors:
Subsea Head = 4,370 psi
Hydraulic Head = 4,565 psi
Supply Pressure = 4,500 psi
Motive Force = (4,500 psi + 4,565 psi) – 4,370 psi
Motive Force = 4,695 psi



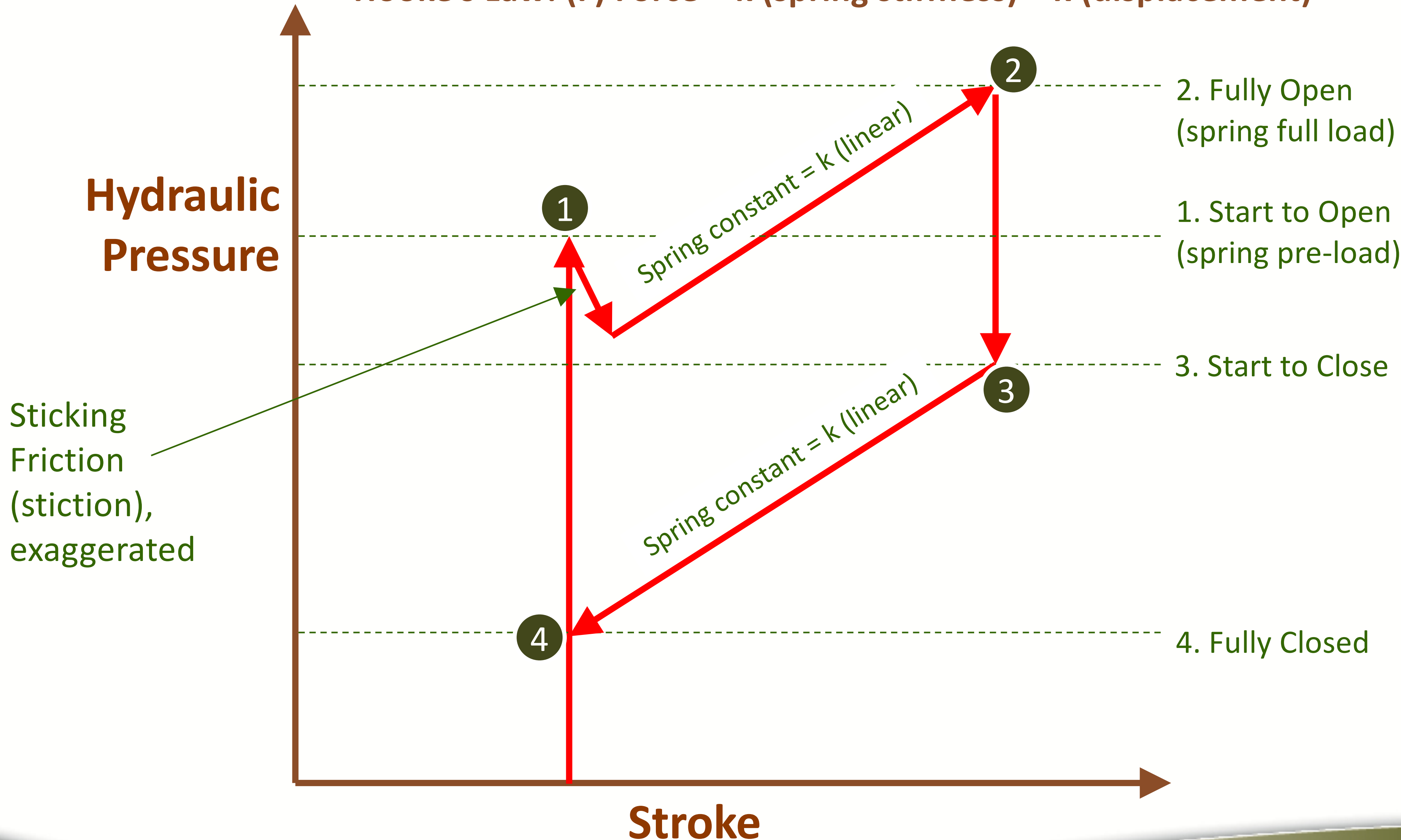
Key takeaways:
1. Depth adds to the hydraulic motive force.
2. Hydraulic pressures are truly "coincidental."

Fieldwood Energy

* References in slide notes.

Hydraulically Actuated Valves: Pressure vs. Stroke

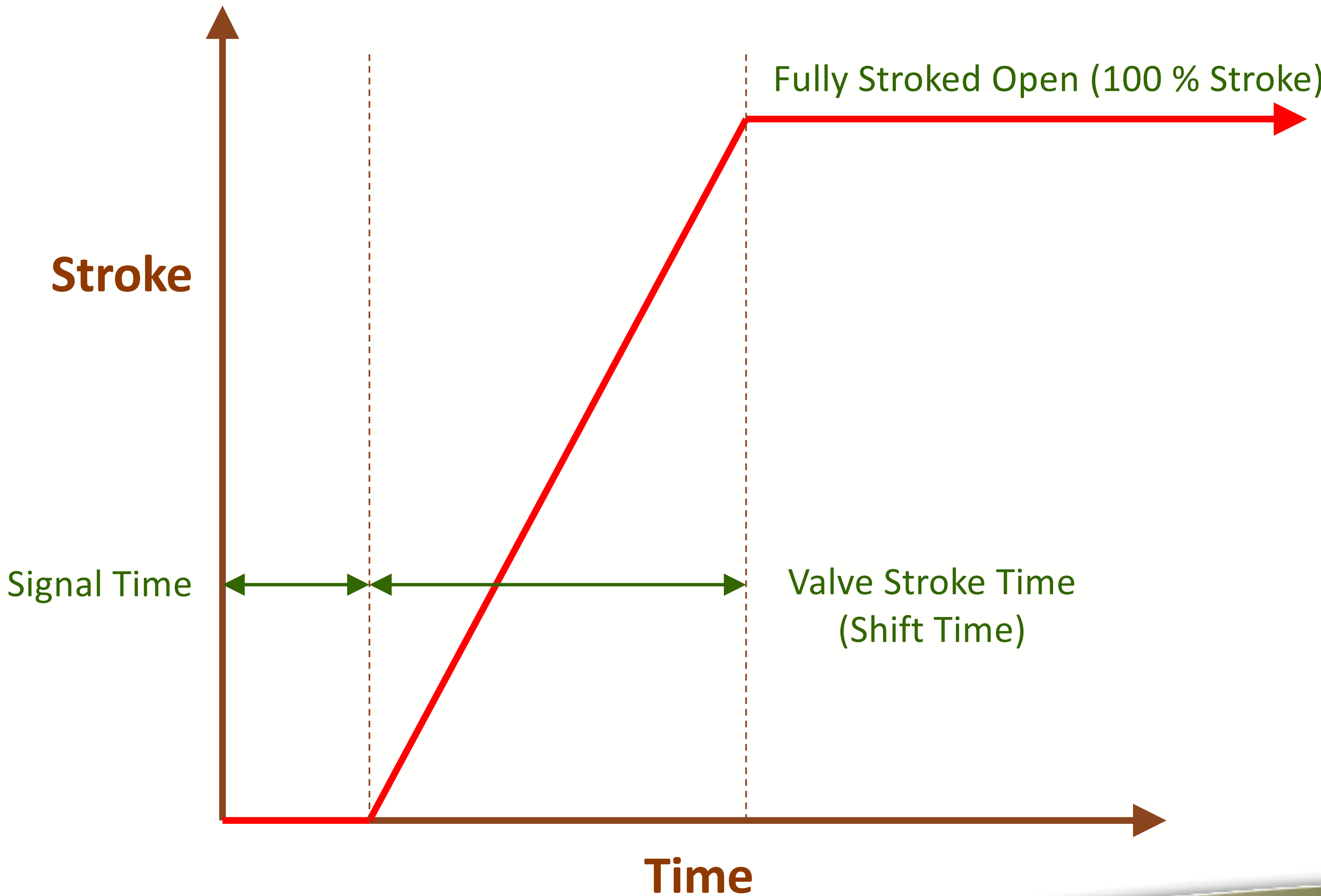
Hooke's Law: (F) Force = k (spring stiffness) * x (displacement)



FIELDWOOD ENERGY

* References in slide notes.

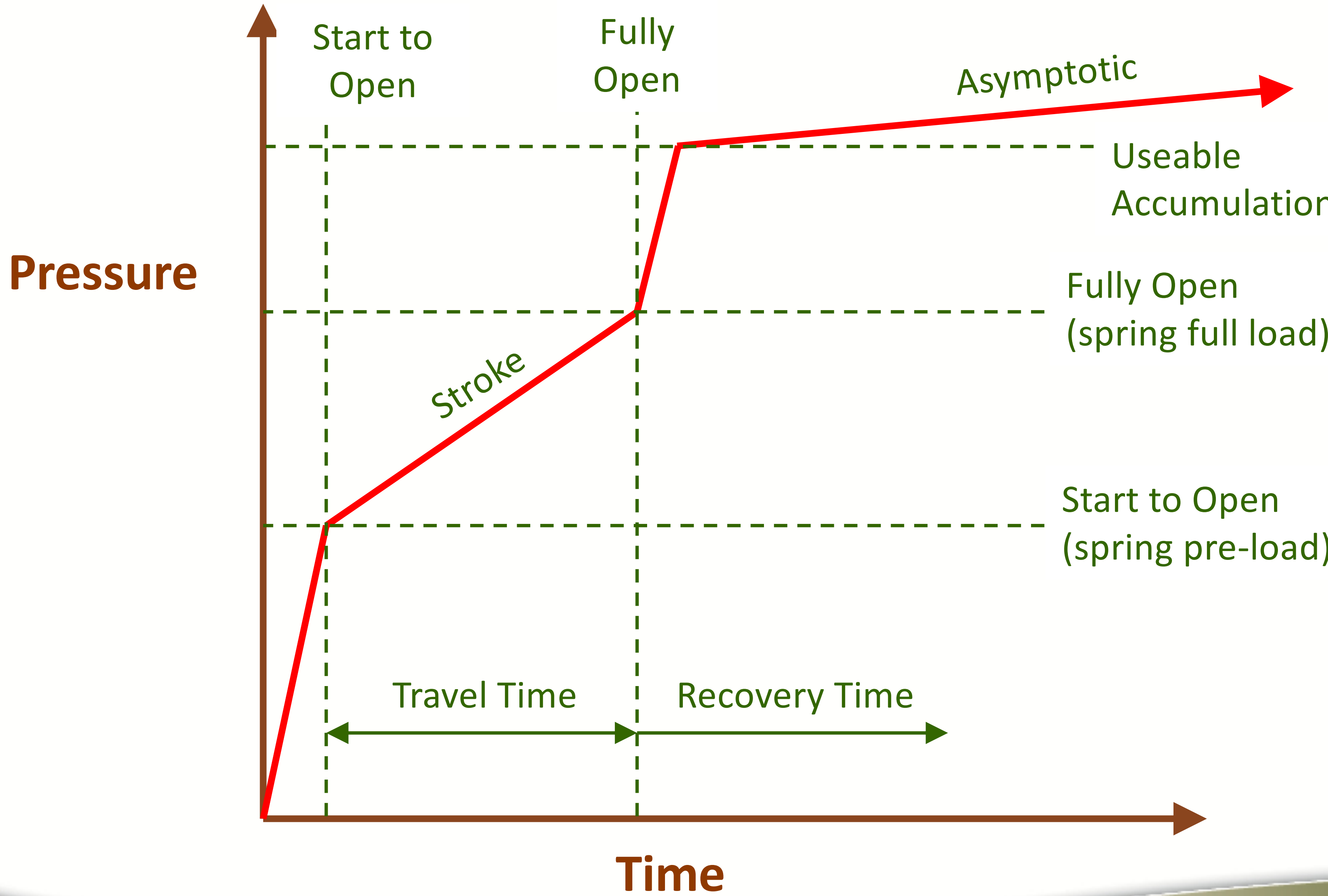
Hydraulically Actuated Valves: Abstract Response



Fieldwood Energy

* References in slide notes.

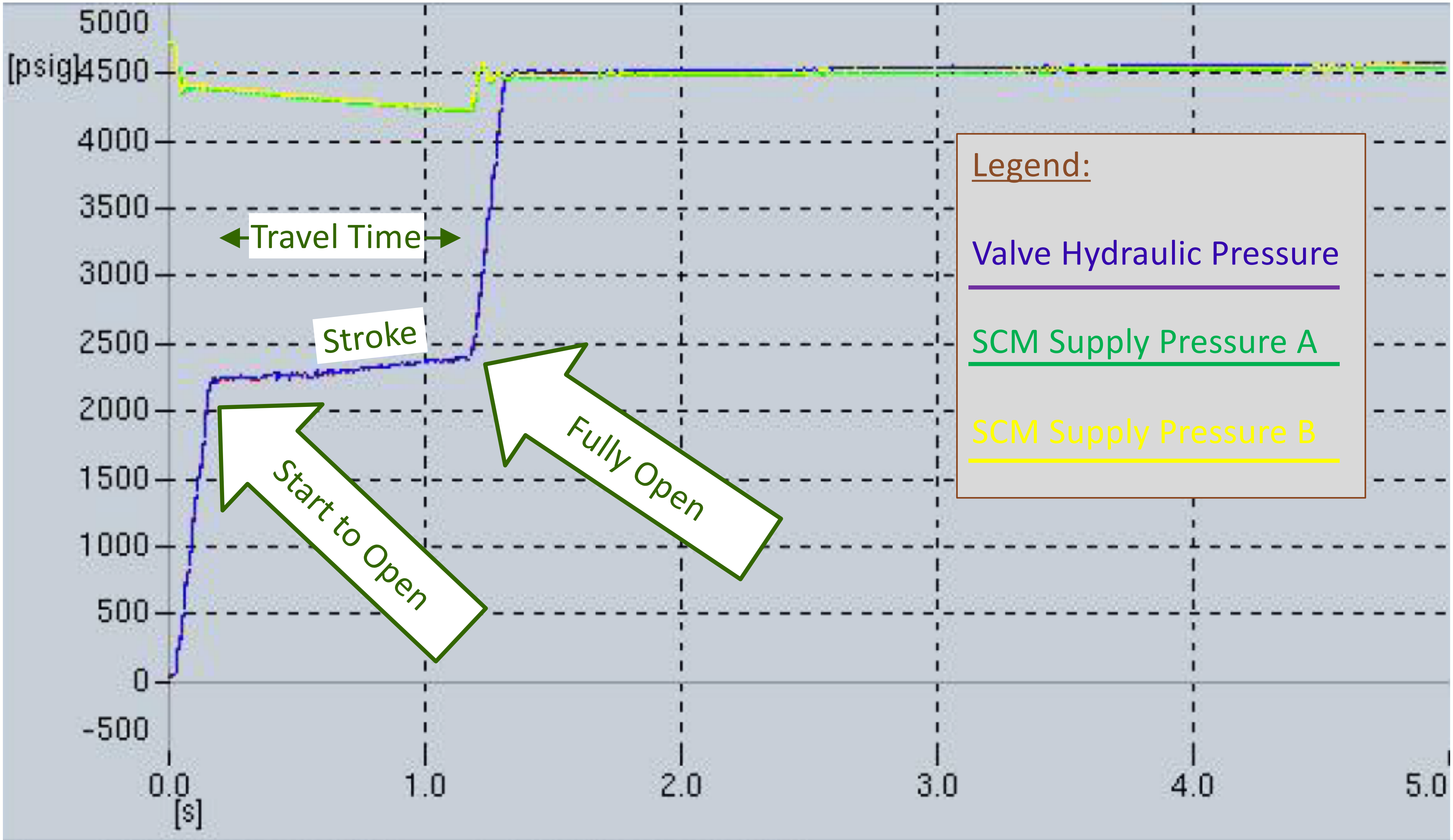
Hydraulically Actuated Valves: Open Response



FIELDWOOD ENERGY

* References in slide notes.

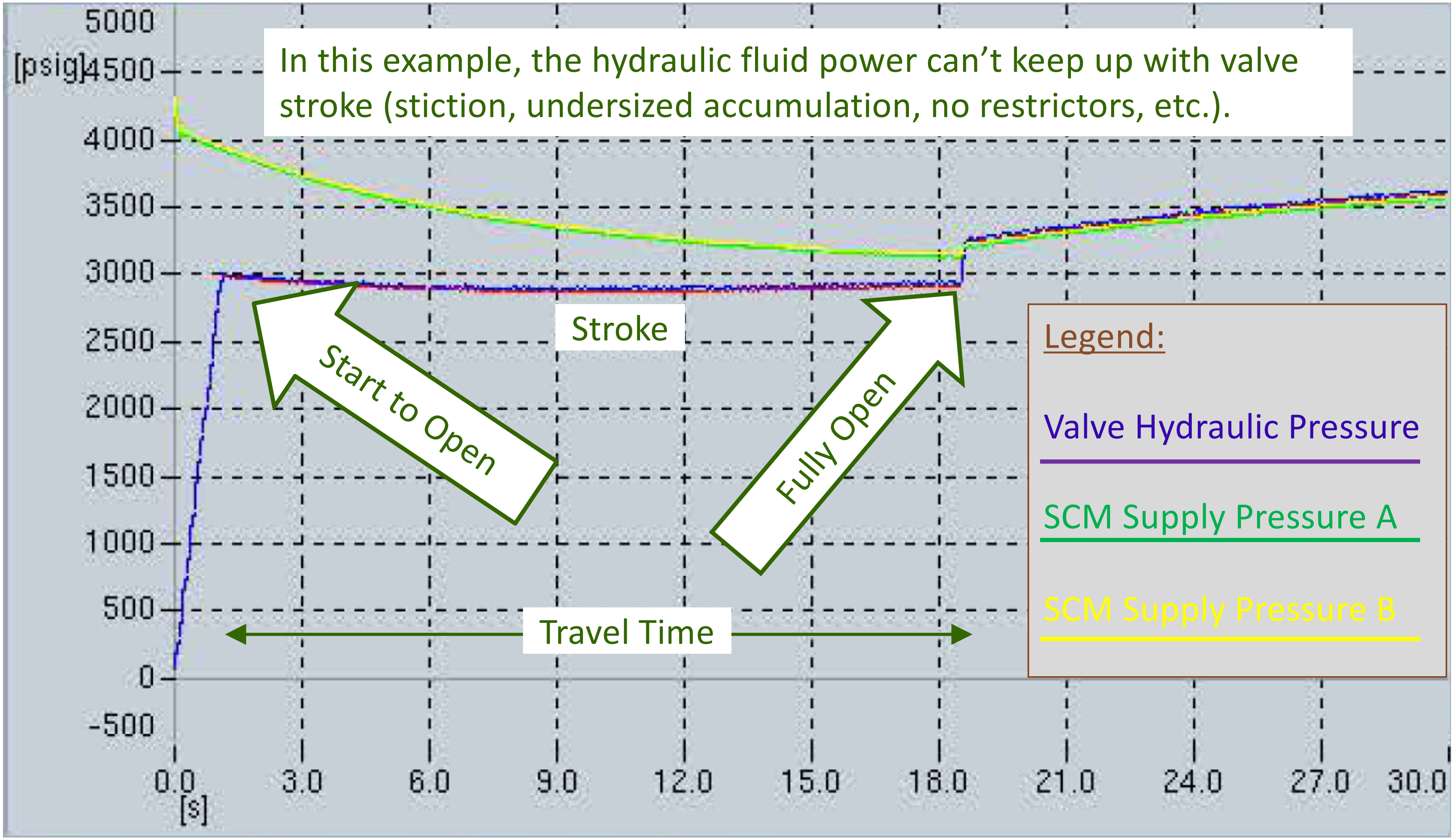
Hydraulically Actuated Valves: Open Profile



Fieldwood Energy

* References in slide notes.

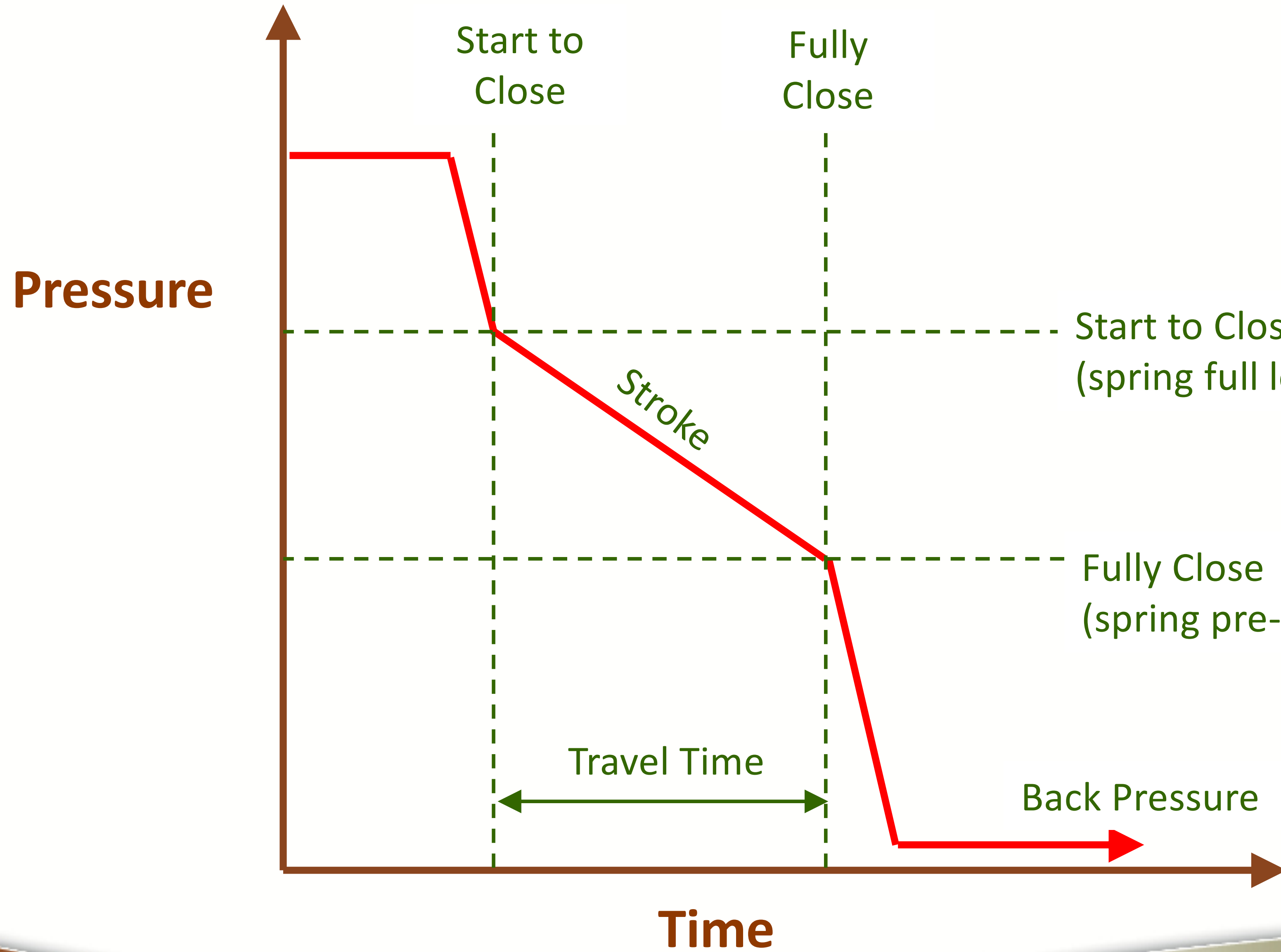
Hydraulically Actuated Valves: Open Profile



FIELDWOOD ENERGY

* References in slide notes.

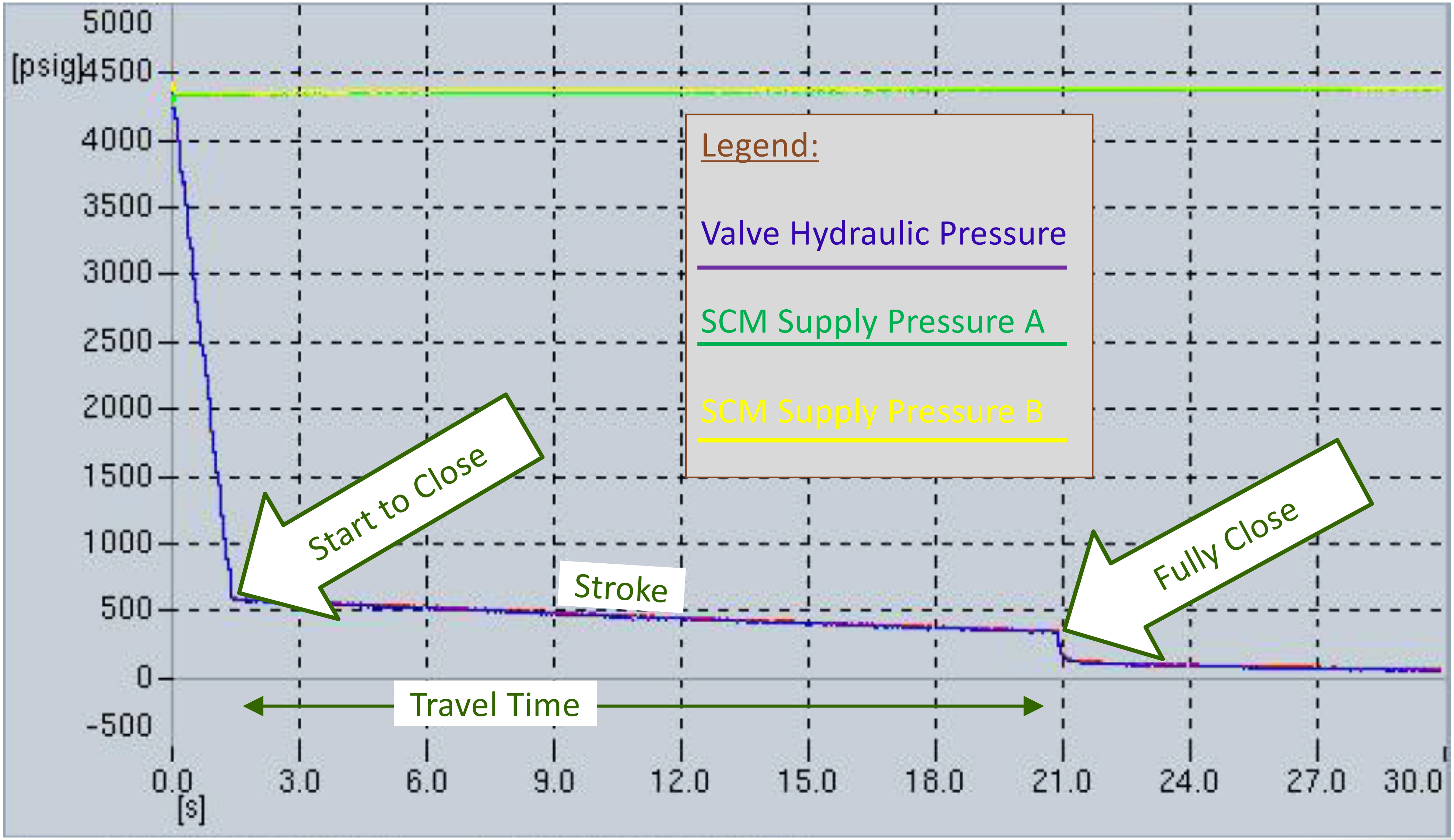
Hydraulically Actuated Valves: Close Profile



FIELDWOOD ENERGY

* References in slide notes.

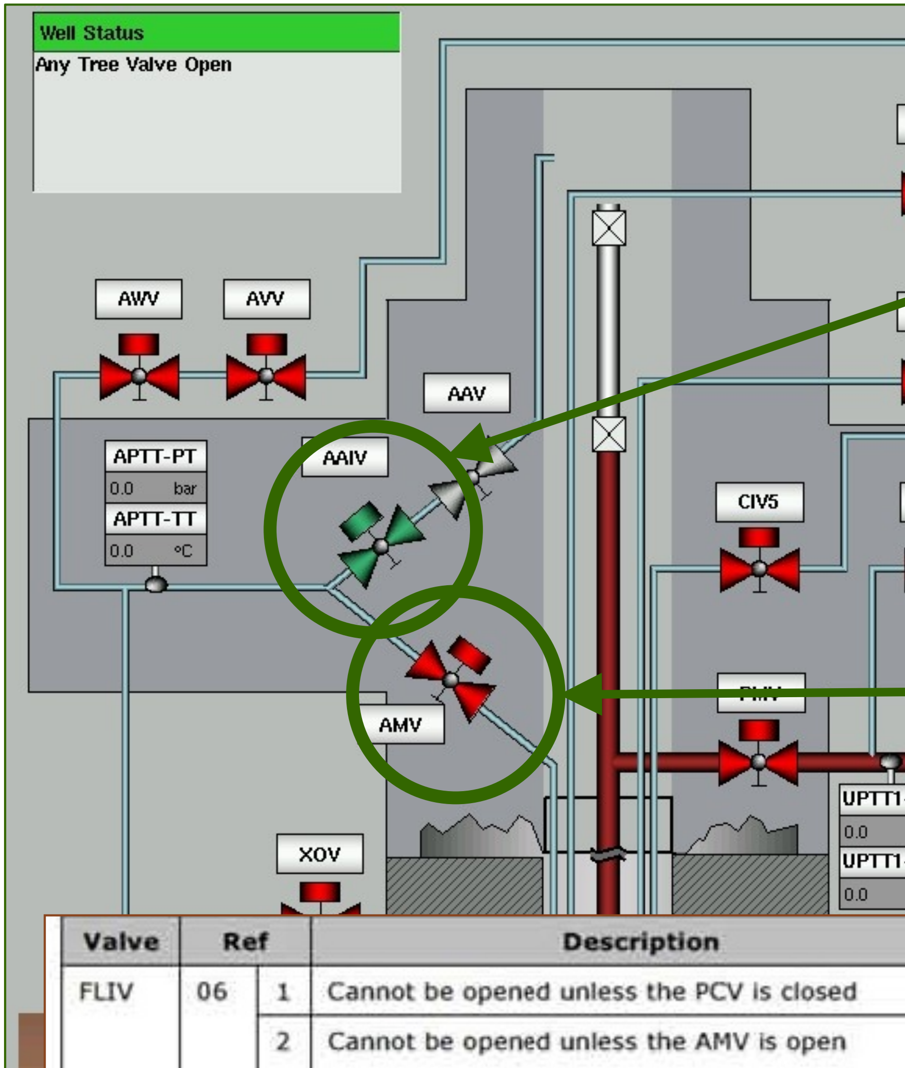
Hydraulically Actuated Valves: Close Profile



FIELDWOOD ENERGY

* References in slide notes.

Hydraulically Actuated Valves: Inferred Valve Position



Mimic of OPEN valve

Mimic of CLOSED valve

Used for Interlocks

For Background Information Only

Valve	Ref		Description	Message		Comment
FLIV	06	1	Cannot be opened unless the PCV is closed	Interlock	PCV is open	
		2	Cannot be opened unless the AMV is open	Interlock	AMV is closed	The AMV must be open prior to opening the FLIV to monitor annulus pressure

* References in slide notes.

Valve Discrepancies – Inferred vs. Actual Position

- Why is this important?
  - What if the valve positon is not known?
  - What if the inferred valve position is contradictory to the actual valve position?
  - What if the valve is broken?
- What if operations does not attempt to intervene when they should?
- What if operations attempts to intervene when they shouldn’t?

FIELDWOOD ENERGY

Subsea Troubleshooting: Subsea Production Choke Valve (PCV)

FIELDWOOD ENERGY

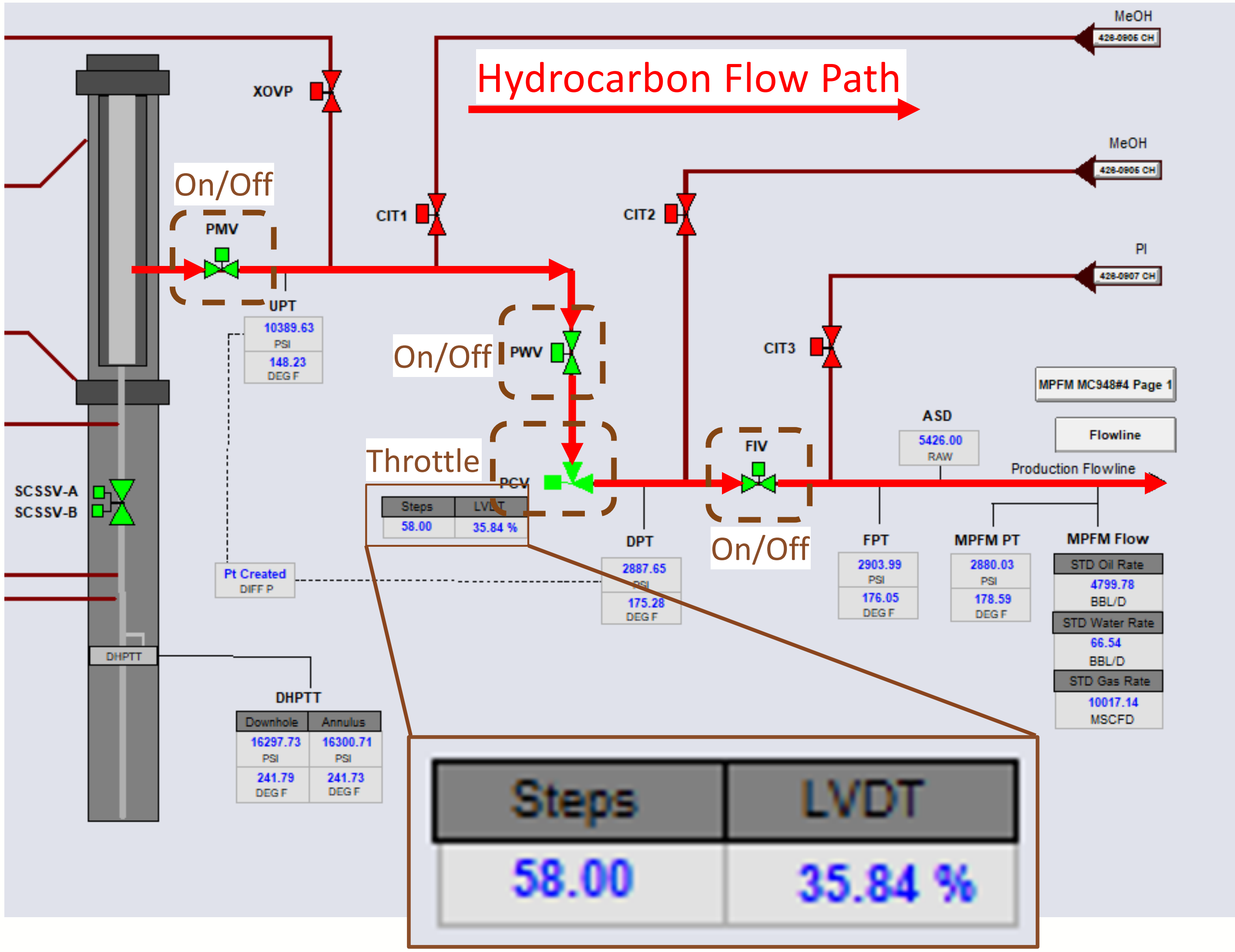
Instrumentation of Interest

- The Production Choke Valve (PCV) is a throttled valve (continuous) used for well ramp-up and controlled shut-in.
- Valve position is inferred in two ways:
  - Linear Variable Differential Transformer (LVDT): 4-20 mA instrument.
  - Calculated Position:

    Last value + commanded value = new value.

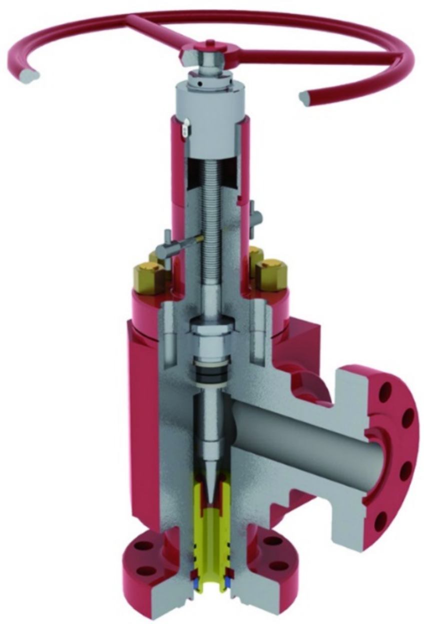
    Total travel = 160 Steps.

    Each step = 0.625 % travel.

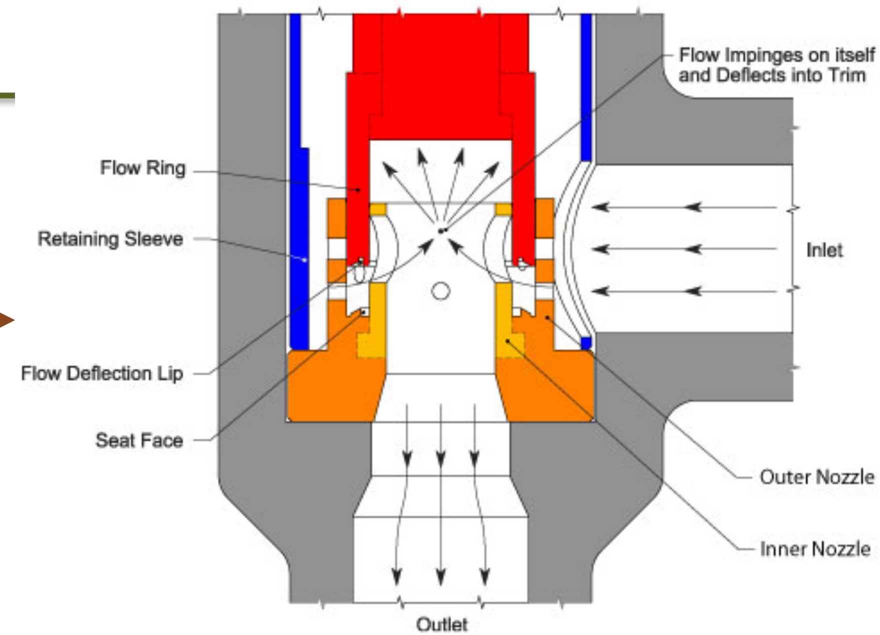


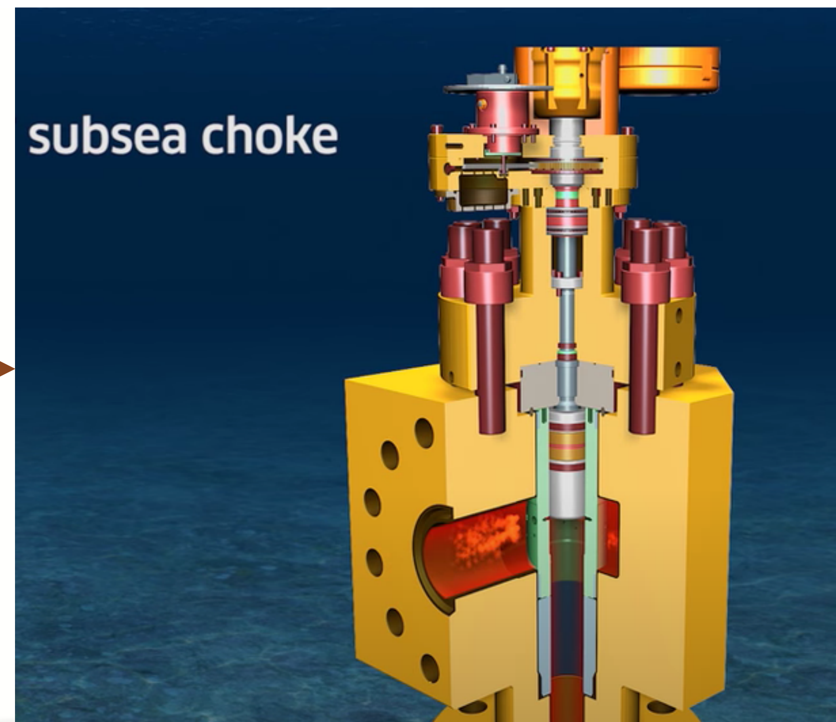
Choke (PCV) Illustration

Topside chokes are a simple needle valve design.



Subsea chokes use a plug and cage design.

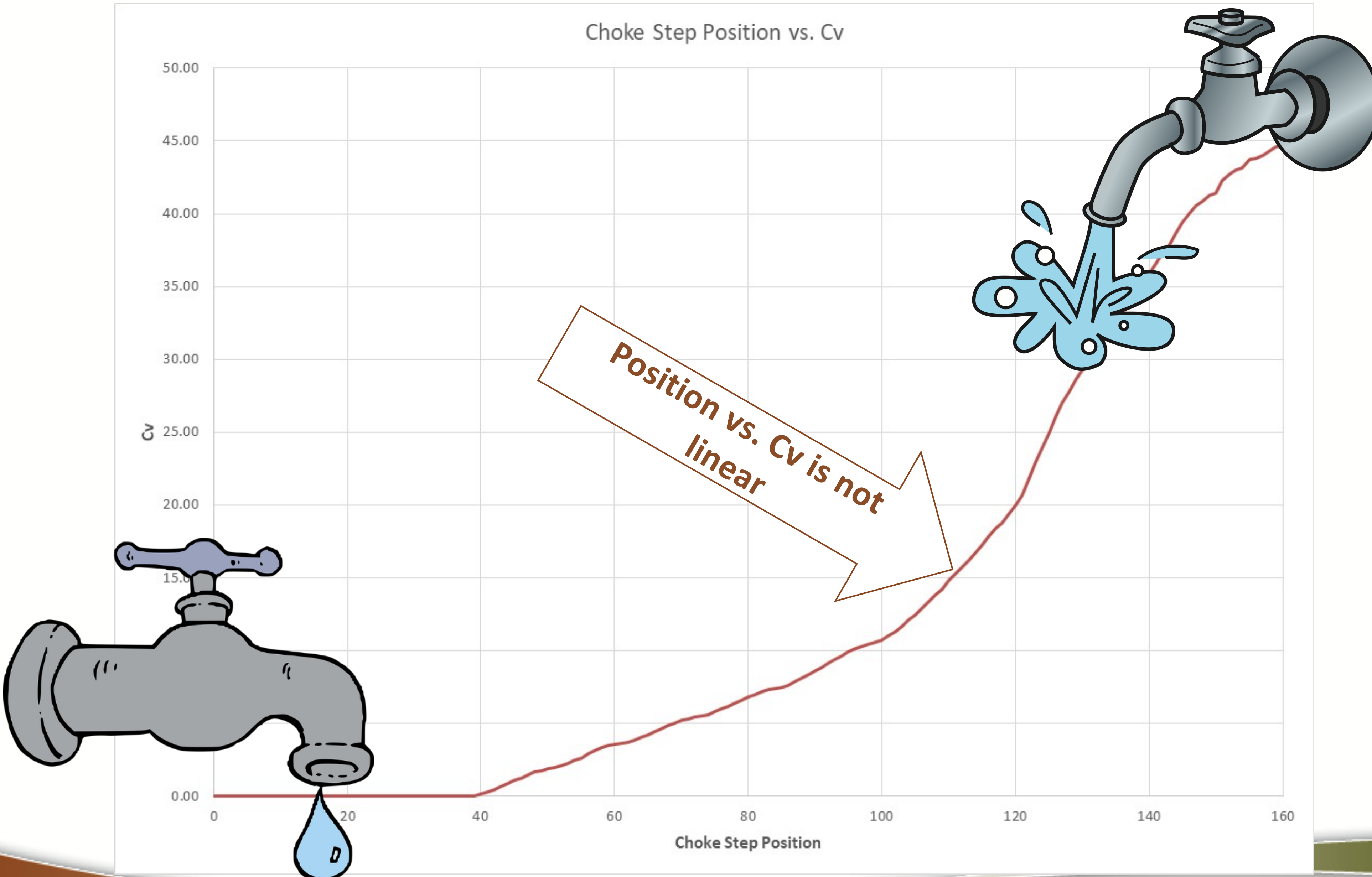




FIELDWOOD ENERGY

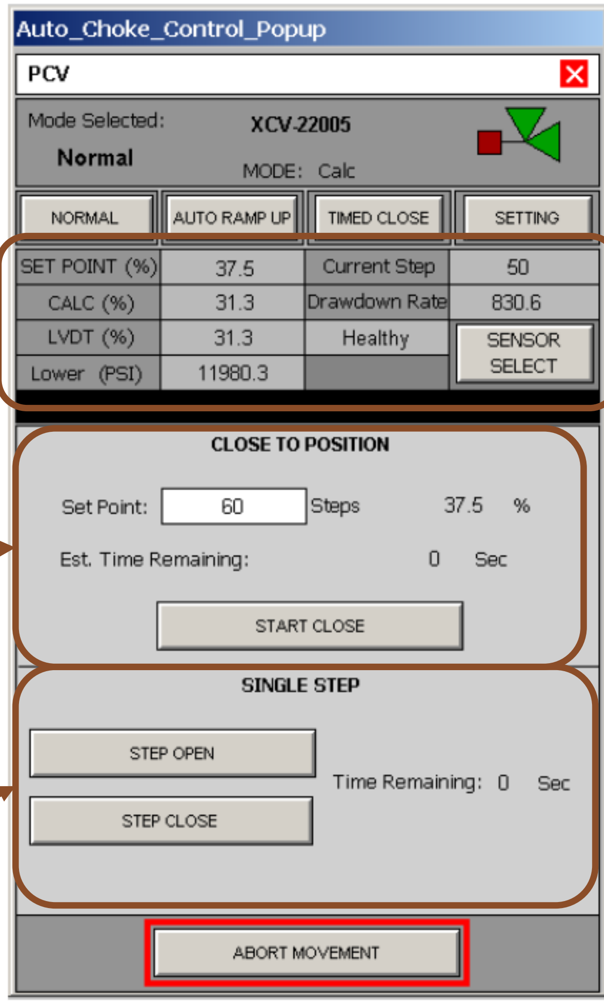
* References in slide notes.

Positon vs. Cv: PCV is Continuous, Not ON/OFF



PCV Position Surveillance and Control

PCV Control Pop-Up

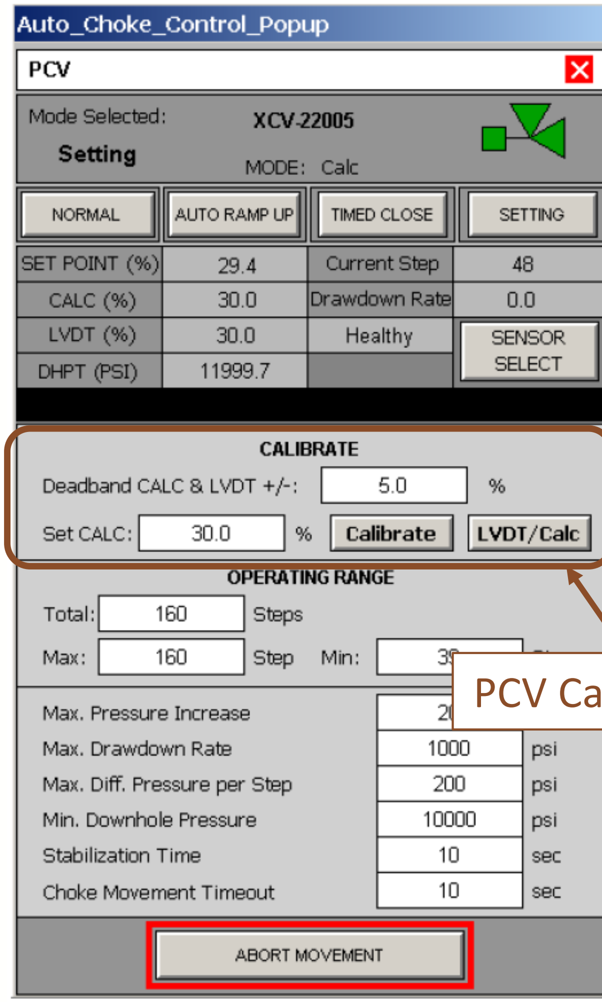


Inferred and actual PCV position

Command PCV to specified step

Command PCV to increment/ decrement 1 step

PCV Config Pop-Up



PCV Calibration

Observation Summary

- The Production Choke Valve (PCV) continuously experiences un-commanded valve movement:

Case	Total Drift (%)	Total Drift (Step)	Start to Drift ΔP (psi)	Finish Drift ΔP (psi)
1	0.856 %	1.37 Steps	1695 psi (min)	1892 psi (min)
2	0.877 %	1.40 Steps	1838 psi	2010 psi
3	0.879 %	1.406 Steps	2103 psi	2285 psi
4	No Drift	No Drift	No Drift	No Drift
5	0.887 %	1.42 Steps	2142 psi	2335 psi
6	0.803 % (min)	1.28 Steps (min)	2030 psi	2182 psi
7	0.865 %	1.384 Steps	2503 psi (max)	2539 psi
8	0.928 % (max)	1.485 Steps (max)	1882 psi	1940 psi
9	0.91 %	1.456 Steps	2327 psi	2412 psi
10	0.848 %	1.357 Steps	2372 psi	2562 psi (max)

- Important: Data polls at different rates and historians may interpolate data between timestamps!

Fieldwood Energy

Case 1: 17-Feb-17

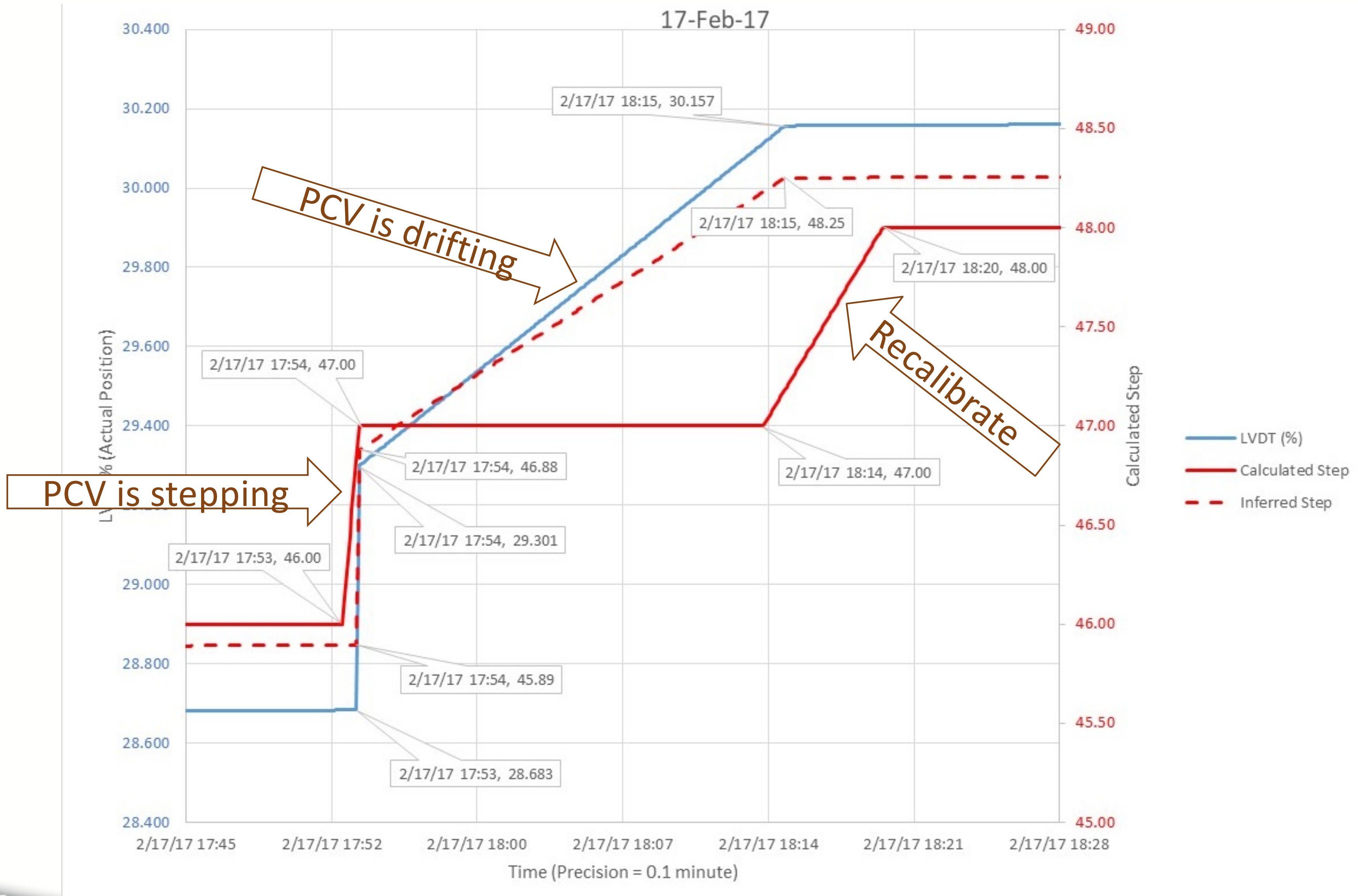
- Observation:
  - 6:00 PM: Well #4 made a step from 46 to 47 steps. The LVDT drifted 2%, from 28% to 30%. Flowing Bottom Hole Pressure (FBHP) went from 17,018 psia to 16,778 psia. Draw Down was 240 psi in 30 minutes. Recalibrated the choke and it went from 47 step to 48 steps.

- Analysis:
  - 17:53, Commanded the PCV to step 1 step (assumed to be from 46 to 47).
  - 17:53, PCV stepped 1 step from 46 to 47 (approximate).
  - 17:54 – 18:15, PCV drifted from 47 to 48 steps.
  - 18:14, Recalibrate PCV to Step = LVDT.

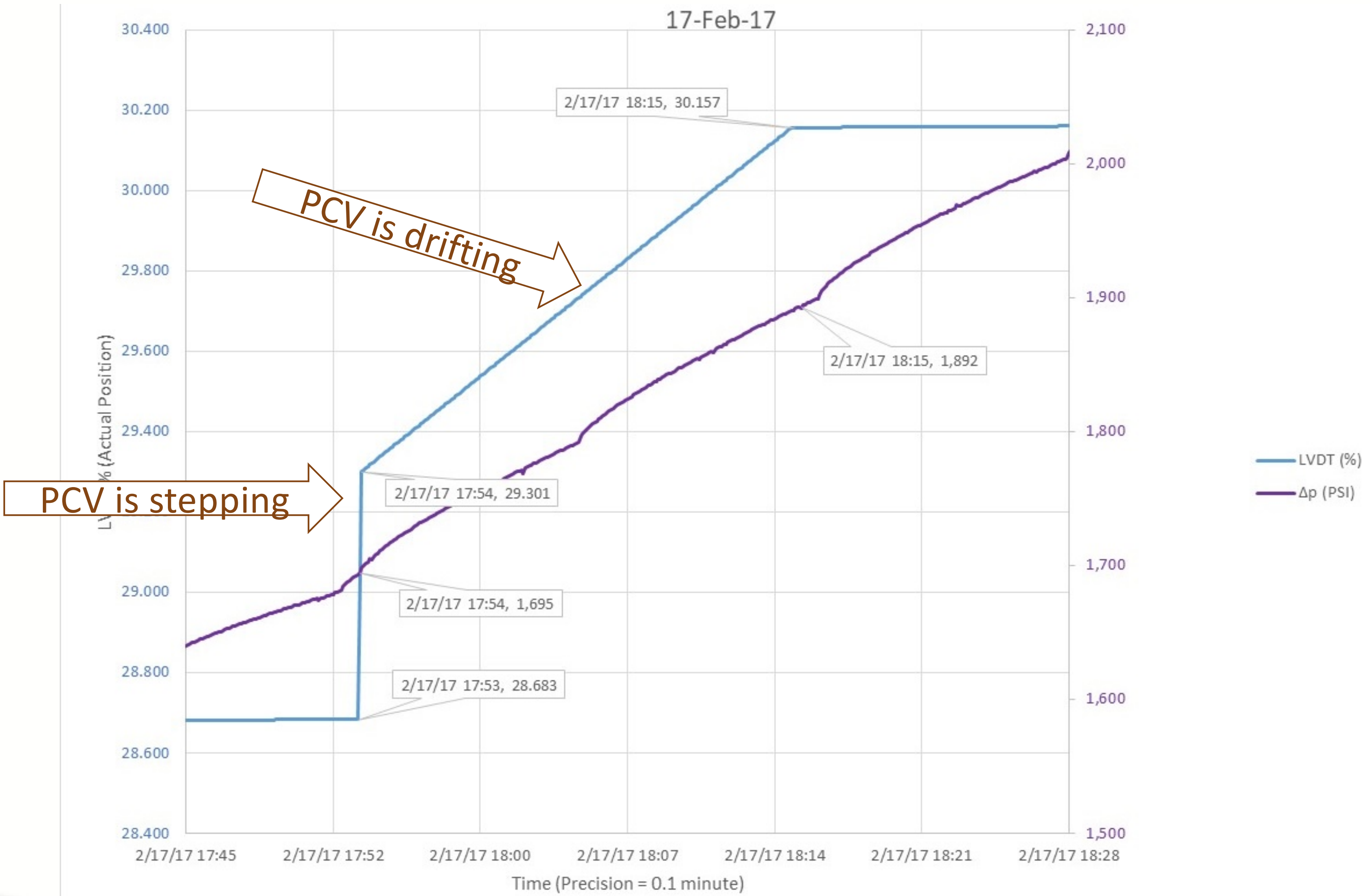
- Drift based on Slope:
  - Total Drift (LVDT): 29.301 % – 30.157 % = 0.856 %.
  - Total Drift (LVDT): 0.856 % / 0.625 % per Step = 1.37 Steps.

- Drift based on total movement:
  - Total movement (LVDT): 30.157 % – 28.683 % = 1.474 %.
  - Total movement (LVDT): 1.474 % / 0.625 % per Step = 2.358 Steps.
  - Total Drift (Step) = 2.358 – 1 = 1.36 Steps.

Case 1: 17-Feb-17 (Supporting Data, Controls)



Case 1: 17-Feb-17 (Supporting Data, Pressure)



FIELDWOOD ENERGY

Case 2: 20-Feb-17

- Observation:
  - 12:30 PM: Well #4 made a step from 42 to 43 steps. The LVDT drifted almost 3% from 26.2% to 27.7%. FBHP went from 17,571 psia to 17,286 psia. Draw Down was 285 psi in 30 minutes. Recalibrated the choke and it went from 43 step to 44 steps.

- Analysis:
  - 12:34, Commanded the PCV to step 1 step (assumed to be from 42 to 43).
  - 12:38, PCV stepped 1 step from 42 to 43 (approximate).
  - 12:38 – 13:06, PCV drifted from 43 to 44 steps.
  - 12:48, Recalibrate PCV to Step = LVDT.

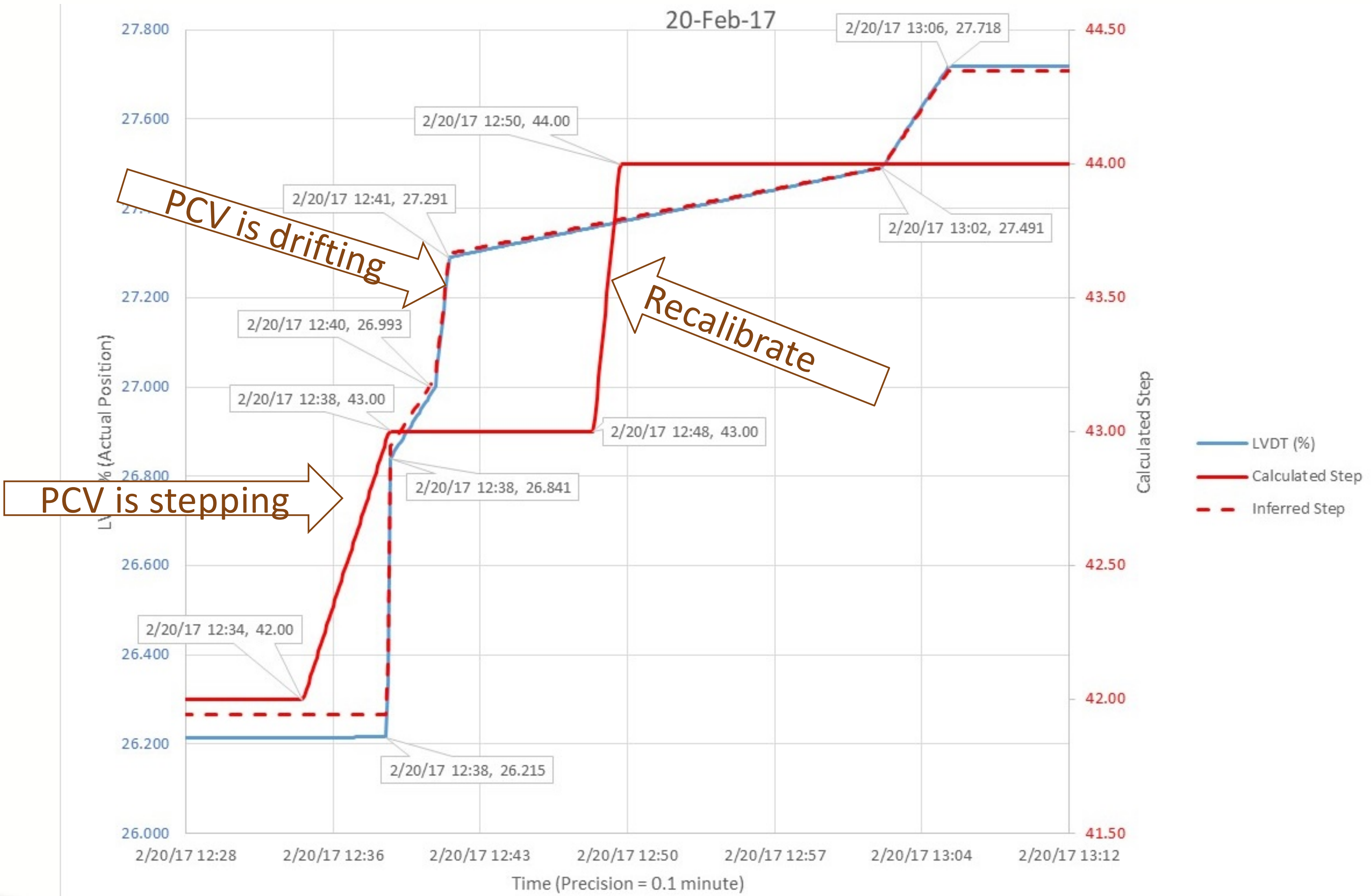
- Drift based on slope:
  - Total Drift (LVDT): 26.841 % – 27.718 % = 0.877 %.
  - Total Drift (LVDT): 0.877 % / 0.625 % per Step = 1.4 Steps.

- Drift based on total movement:
  - Total movement (LVDT): 27.718 % – 26.215 % = 1.503 %.
  - Total movement (LVDT): 1.503 % / 0.625 % per Step = 2.405 Steps.
  - Total Drift (Step) = 2.405 – 1 = 1.4 Steps.

For Background Information Only

FIELDWOOD ENERGY

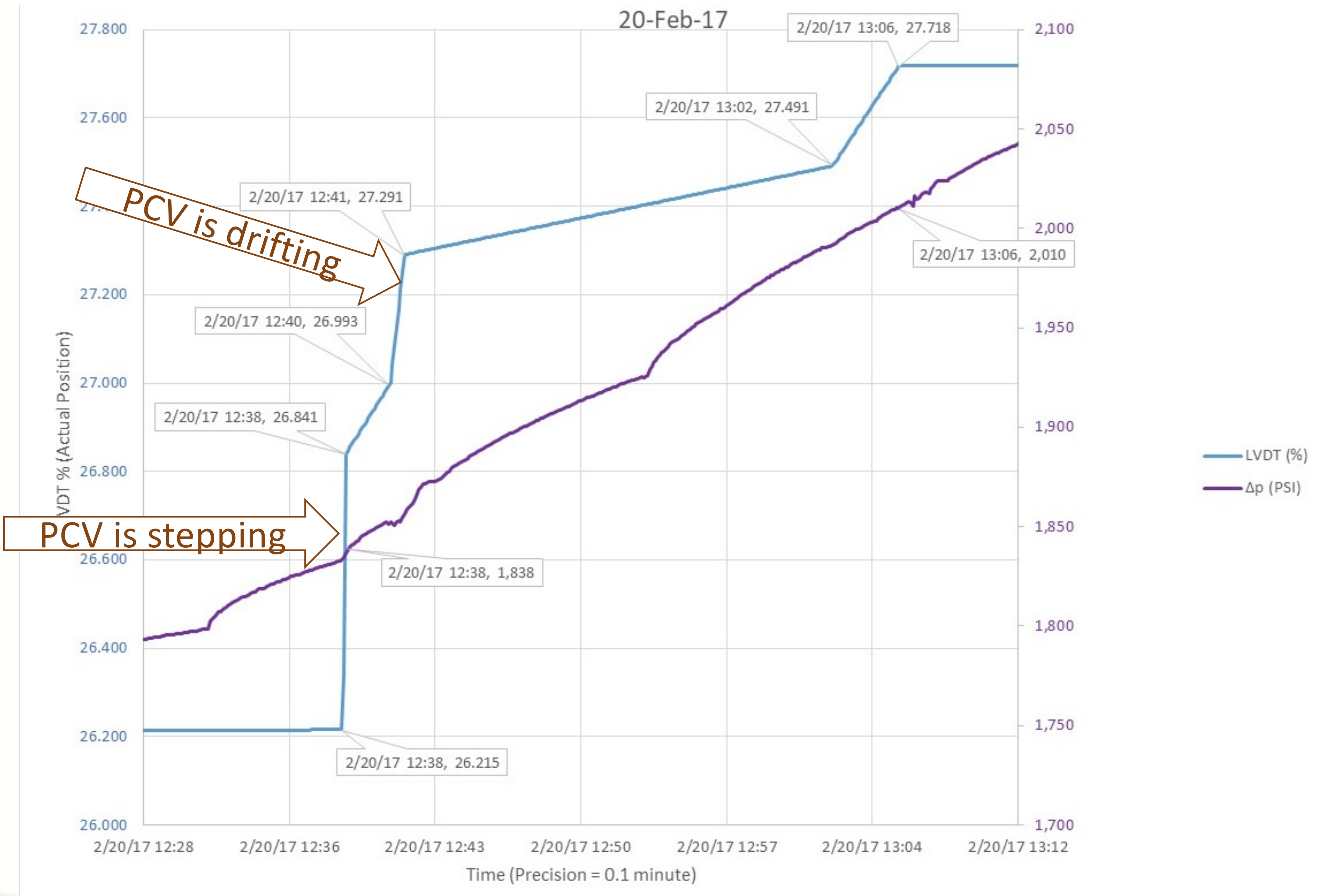
Case 2: 20-Feb-17 (Supporting Data, Controls)



For Background Information Only

FIELDWOOD ENERGY

Case 2: 20-Feb-17 (Supporting Data, Pressure)



For Background Information Only

FIELDWOOD ENERGY

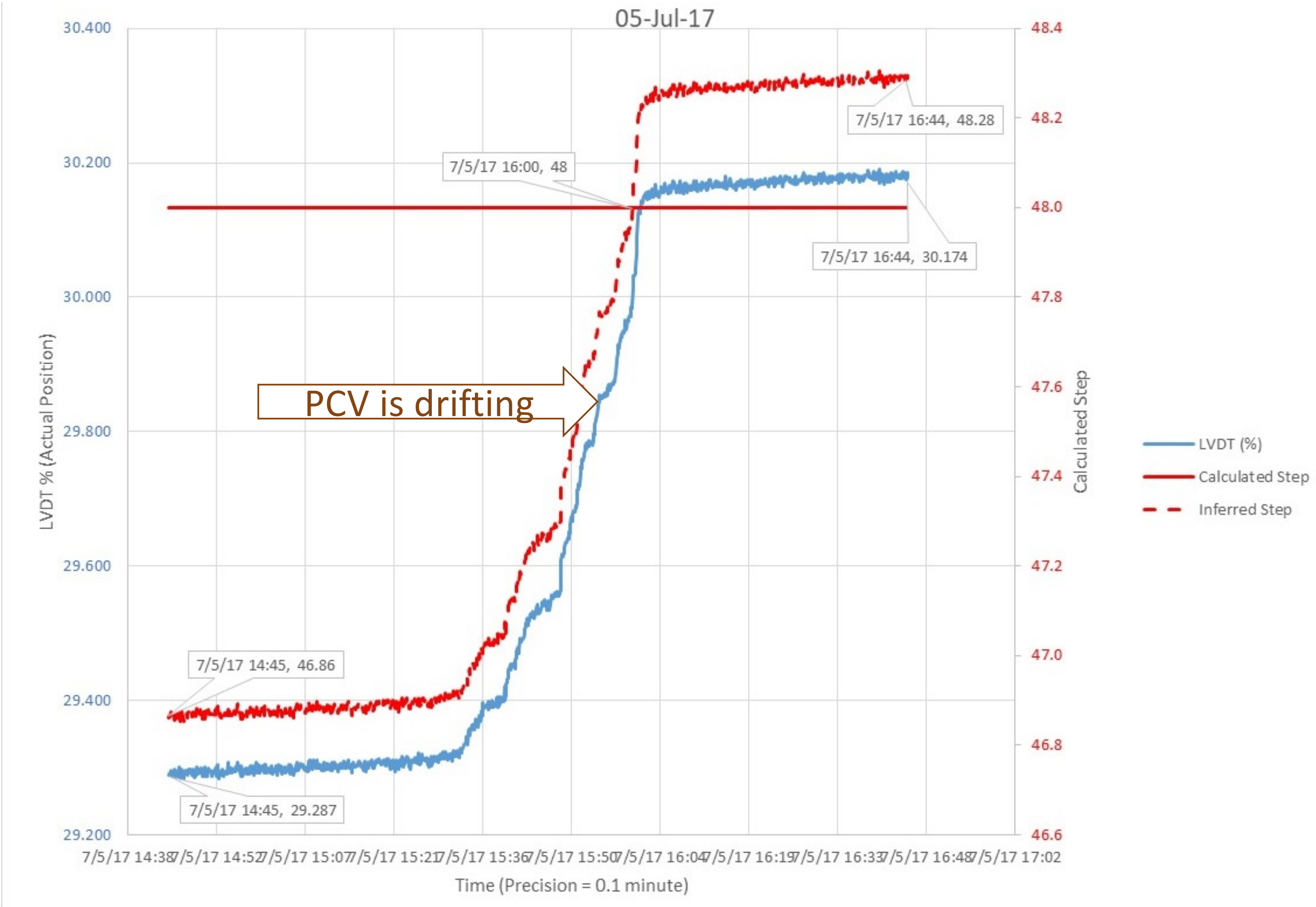
Case 5: 5-Jul-17

- Observation:
  - 3:00 PM: Observed un-commanded movement of the #4 Well Choke LVDT. It went from 29.3% to 30.1% in 31 minutes. Caused FBHP to drift another 145 psi.

- Analysis:
  - 14:45, PCV begins to drift.
  - 15:33, PCV drift is steep.

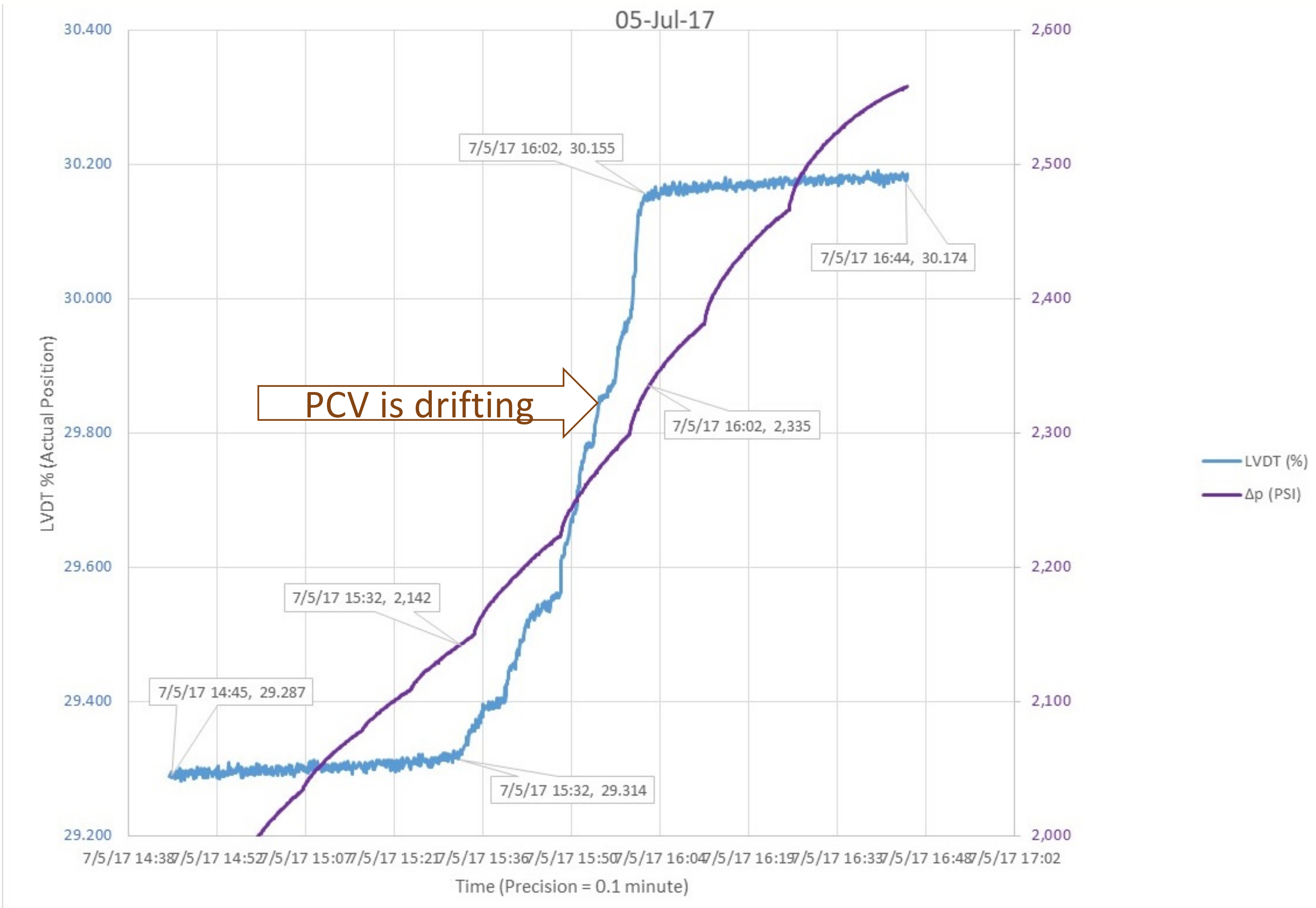
- Drift based on slope:
  - Total Drift (LVDT): 29.287 % – 30.174 % = 0.887 %.
  - Total Drift (LVDT): 0.887 % / 0.625 % per Step = 1.42 Steps.

Case 5: 05-Jul-17 (Supporting Data, Controls)



FIELDWOOD ENERGY

Case 5: 05-Jul-17 (Supporting Data, Pressure)



FIELDWOOD ENERGY

Case 6: 02-Oct-17

- Observation:
  - 8:52 AM: Well #4 made a step from 46 to 47. The LVDT went from 28.1% to 28.7% then drifted to 29.5%. FBHP dropped 355 psi in 20 minutes from 16,683 psia to 16,328 psia. Held Well for 3.75 hours.

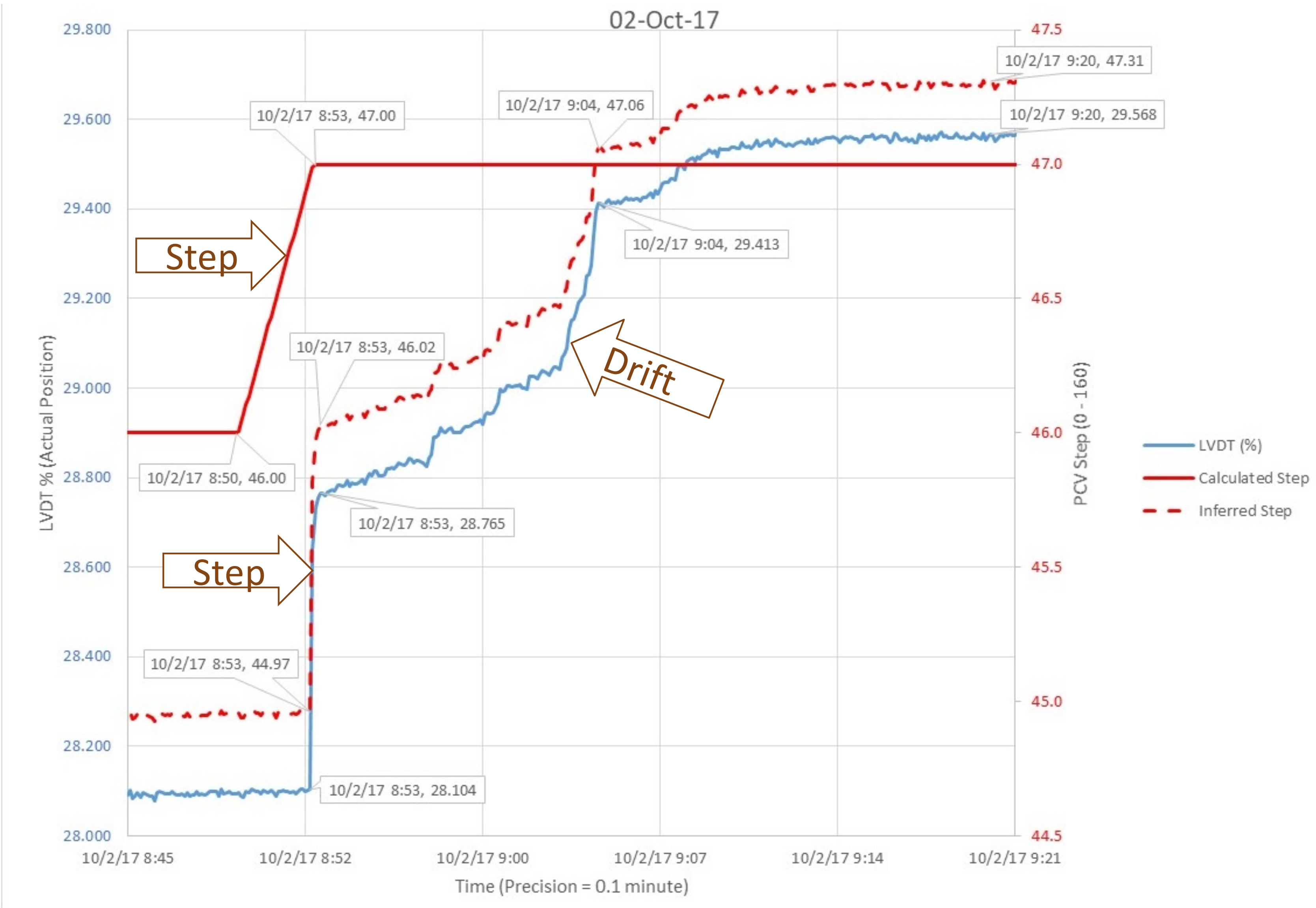
- Analysis:
  - 08:50, Commanded the PCV to step 1 step (assumed to be from 46 to 47).
  - 08:53, PCV stepped 1 step from 45 to 46 (approximate).
  - 08:53 – 09:20, PCV drifted from 46 to 47.3 steps.

- Drift based on Slope:
  - Total Drift (LVDT): 29.568 % – 28.765 % = 0.803 %.
  - Total Drift (LVDT): 0.803 % / 0.625 % per Step = 1.28 Steps.

- Drift based on total movement:
  - Total movement (LVDT): 29.568 % – 28.104 % = 1.464 %.
  - Total movement (LVDT): 1.464 % / 0.625 % per Step = 2.34 Steps.
  - Total Drift (Step) = 2.34 – 1 = 1.34 Steps.

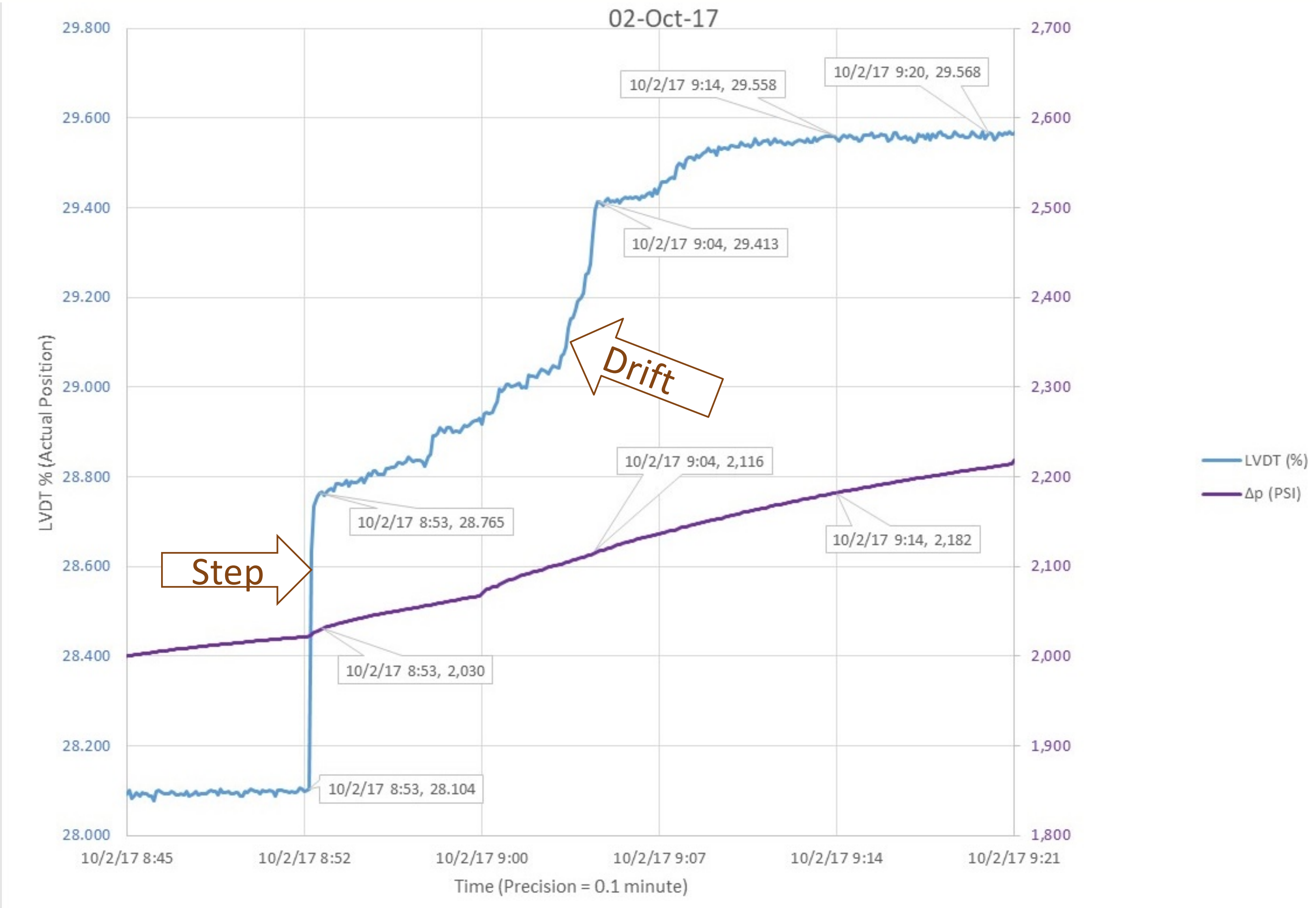
FIELDWOOD ENERGY

Case 6: 02-Oct-17 (Supporting Data, Controls)



FIELDWOOD ENERGY

Case 6: 02-Oct-17 (Supporting Data, Pressure)



FIELDWOOD ENERGY

Case 7: 28-Oct-17

- Observation:
  - 8:00 AM: Noticed un-commanded movement of Well #4 choke. LVDT went from 33.7% to 34.6%. The steps stayed at 55 steps.

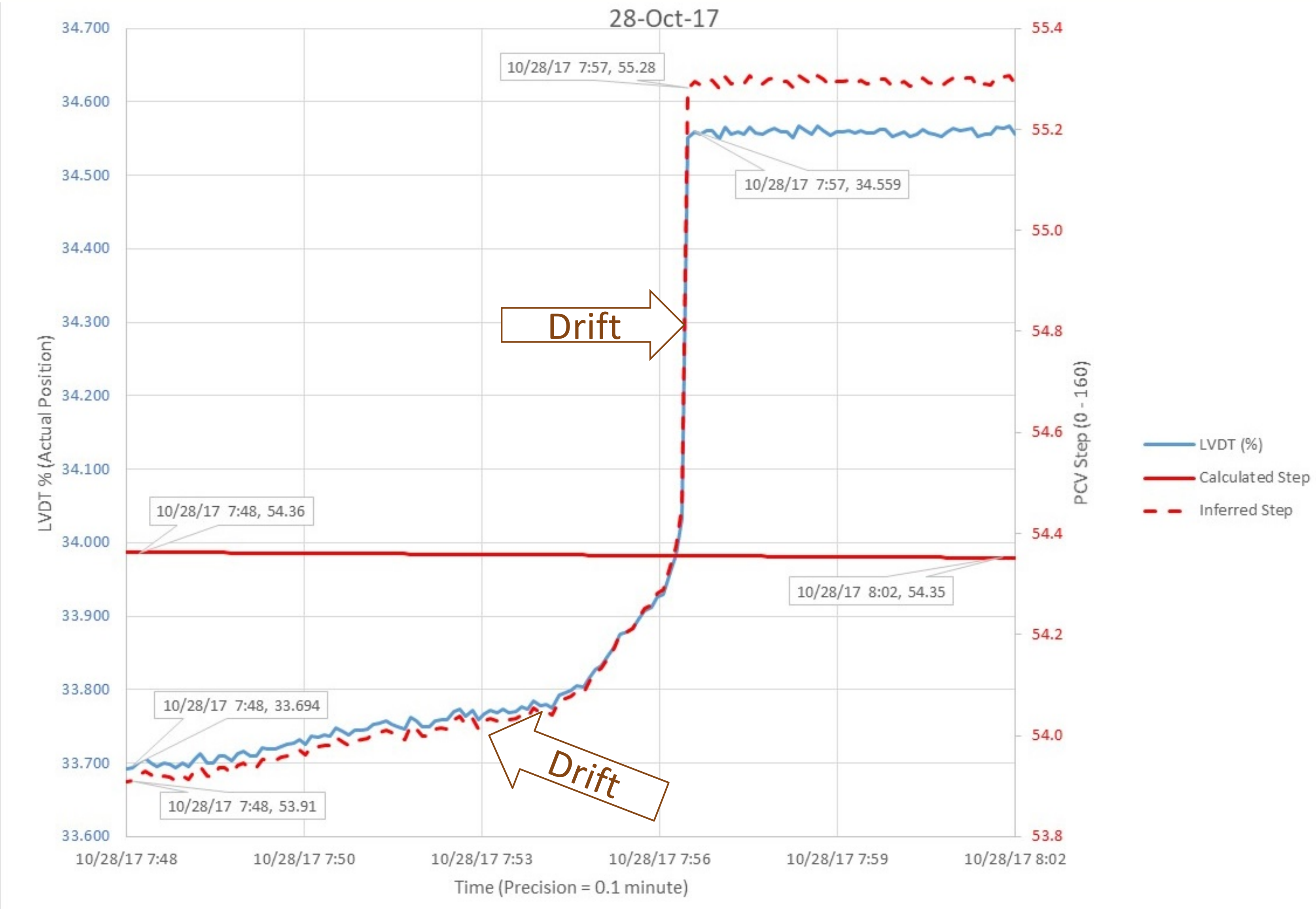
- Analysis:
  - 07:48, PCV begins to drift.
  - 07:55, PCV drift is steep.
  - 07:57, PCV stops drifting.

- Drift based on slope:
  - Total Drift (LVDT): 34.559 % – 33.694 % = 0.865 %.
  - Total Drift (LVDT): 0.865 % / 0.625 % per Step = 1.384 Steps.

For Background Information Only

Fieldwood Energy

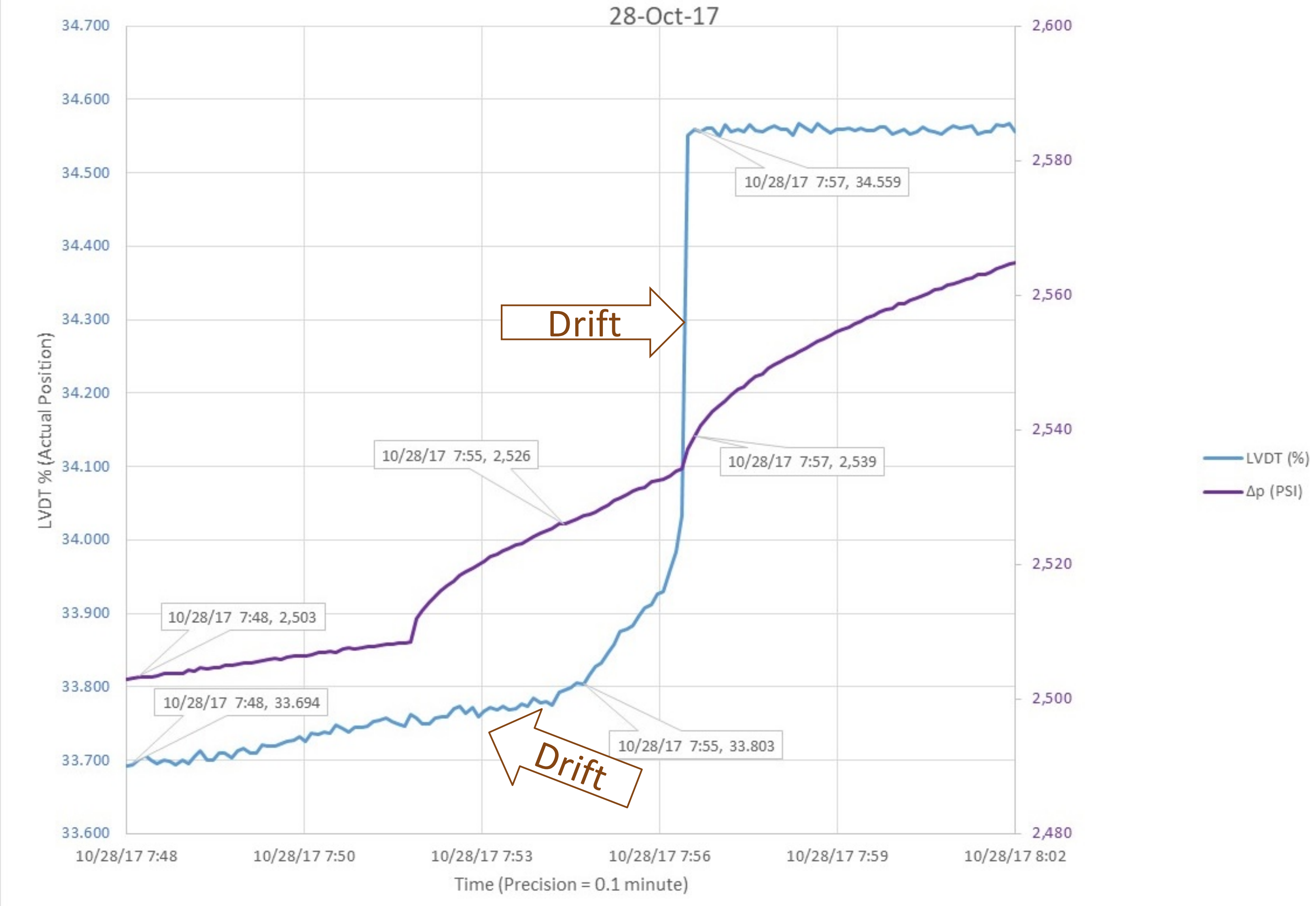
Case 7: 28-Oct-17 (Supporting Data, Controls)



For Background Information Only

FIELDWOOD ENERGY

Case 7: 28-Oct-17 (Supporting Data, Pressure)



For Background Information Only

Case 9: 04-Apr-18

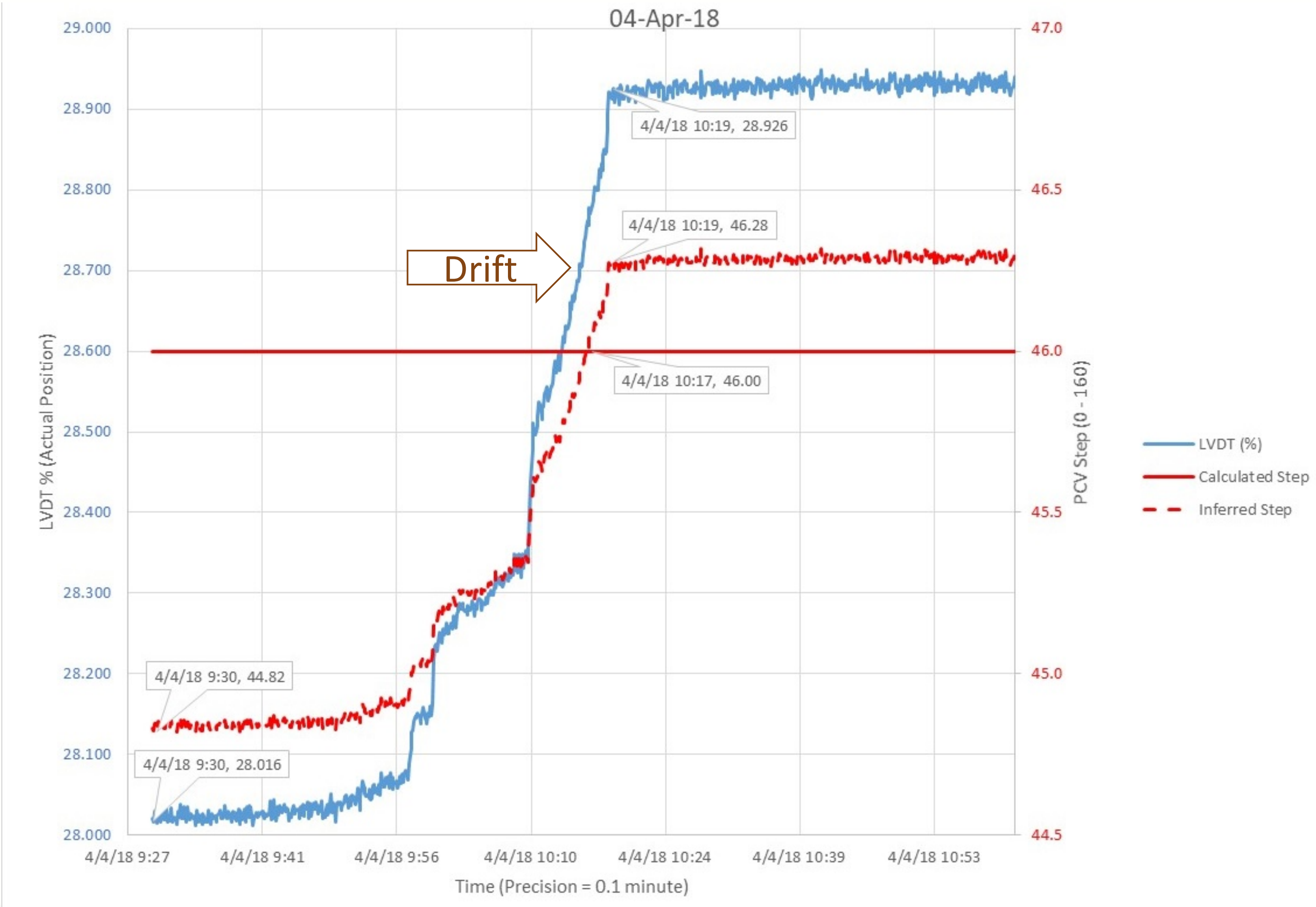
- Observation:
  - 9:50 AM: Well #4 choke started drifting from LVDT 28% to 28.9%. FBHP fell an additional 272 psi in 1 hour from 16,472 psia to 16,200 psia. Held Well for 3 hours.

- Analysis:
  - 09:30, PCV begins to drift.
  - 09:57, PCV drift begins to accelerate.
  - 10:19, PCV stops drifting.

- Drift based on slope:
  - Total Drift (LVDT): 28.926 % – 28.016 % = 0.91 %.
  - Total Drift (LVDT): 0.91 % / 0.625 % per Step = 1.456 Steps.

For Background Information Only

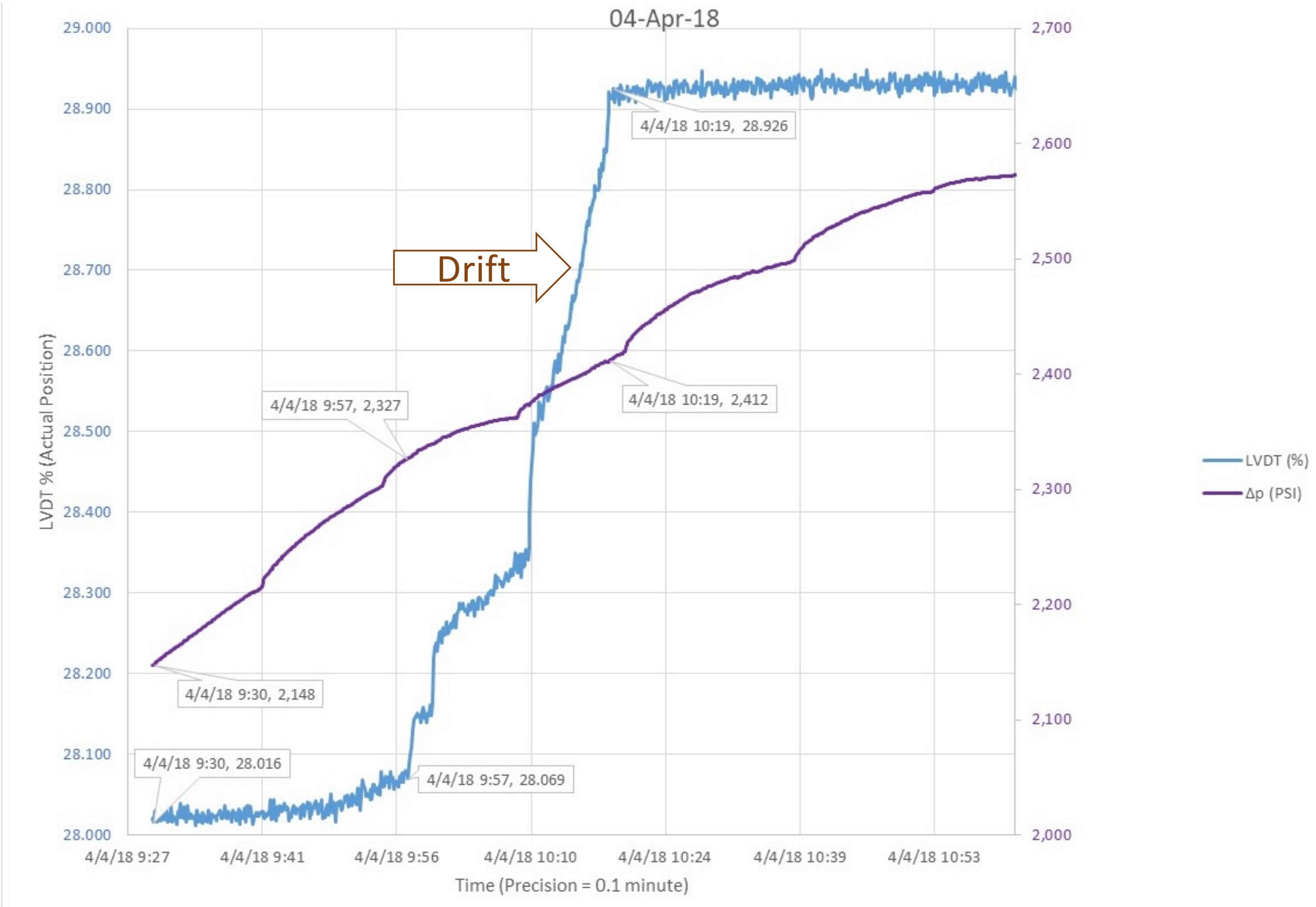
Case 9: 04-Apr-18 (Supporting Data, Controls)



For Background Information Only

FIELDWOOD ENERGY

Case 9: 04-Apr-18 (Supporting Data, Pressure)



For Background Information Only

Case 10: 30-Apr-18

- Observation:
  - 7:28 AM: Well #4 choke started drifting un-commanded from LVDT 26.8% to 27.6%. FBHP fell 264 psi in 32 minutes from 16,822 psia to 16,558 psia. Held Well for 2.5 hours.

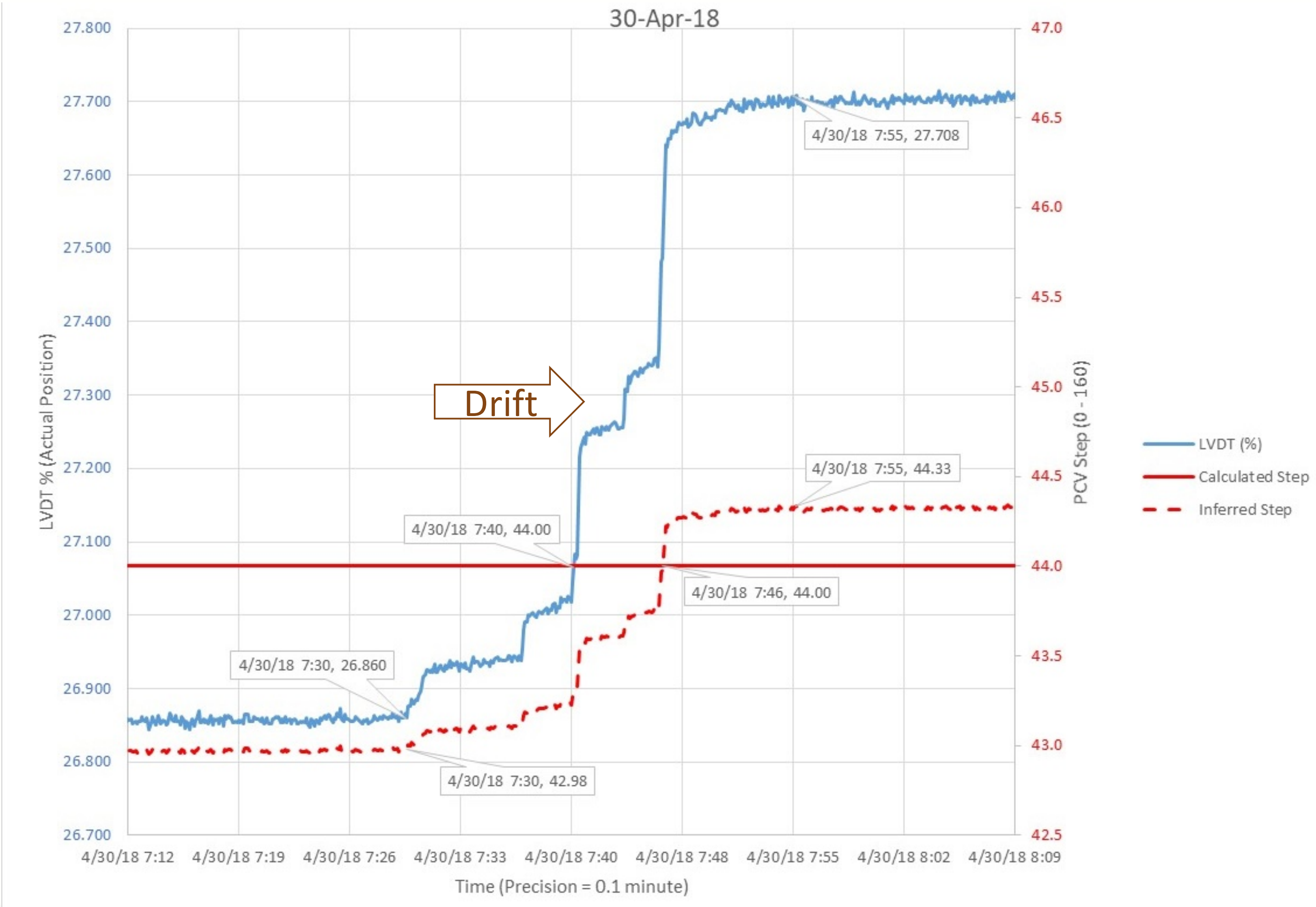
- Analysis:
  - 07:30, PCV begins to drift.
  - 07:48, PCV stops drifting.

- Drift based on slope:
  - Total Drift (LVDT): 27.708 % – 26.860 % = 0.848 %.
  - Total Drift (LVDT): 0.848 % / 0.625 % per Step = 1.357 Steps.

For Background Information Only

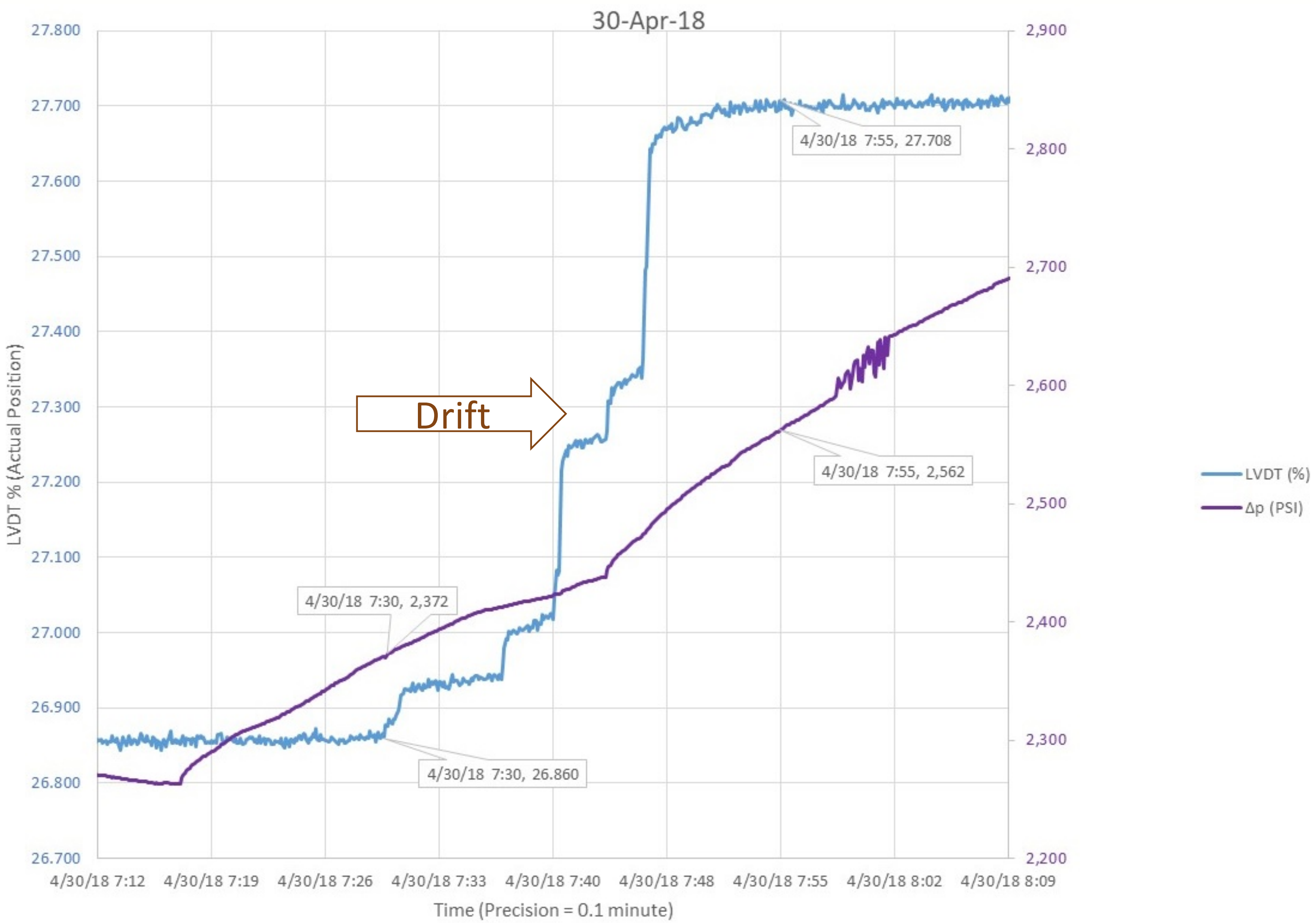
Fieldwood Energy

Case 10: 30-Apr-18 (Supporting Data, Controls)



For Background Information Only

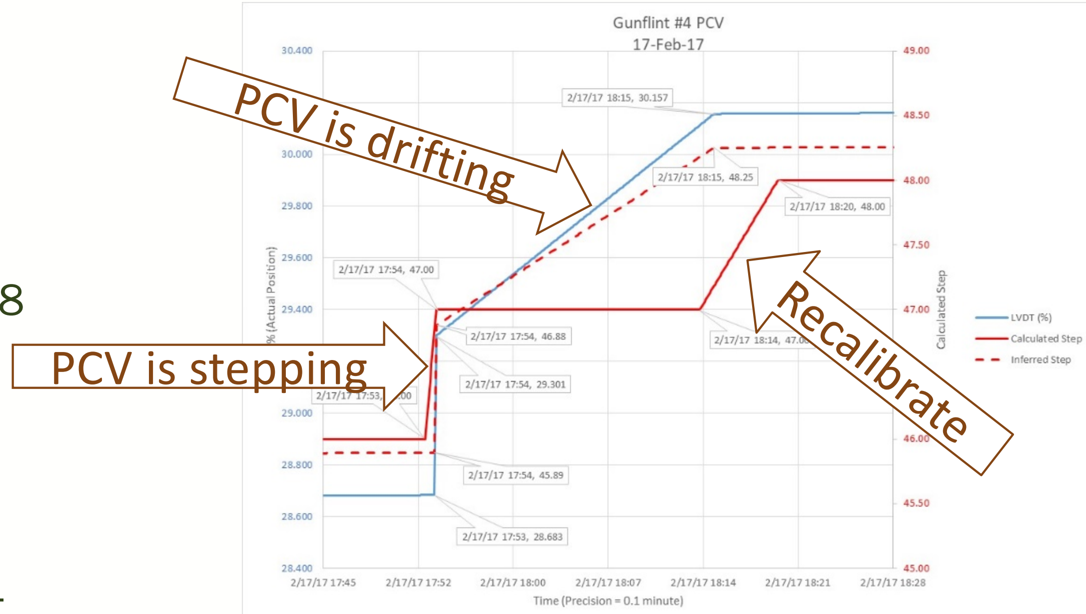
Case 10: 30-Apr-18 (Supporting Data, Pressure)

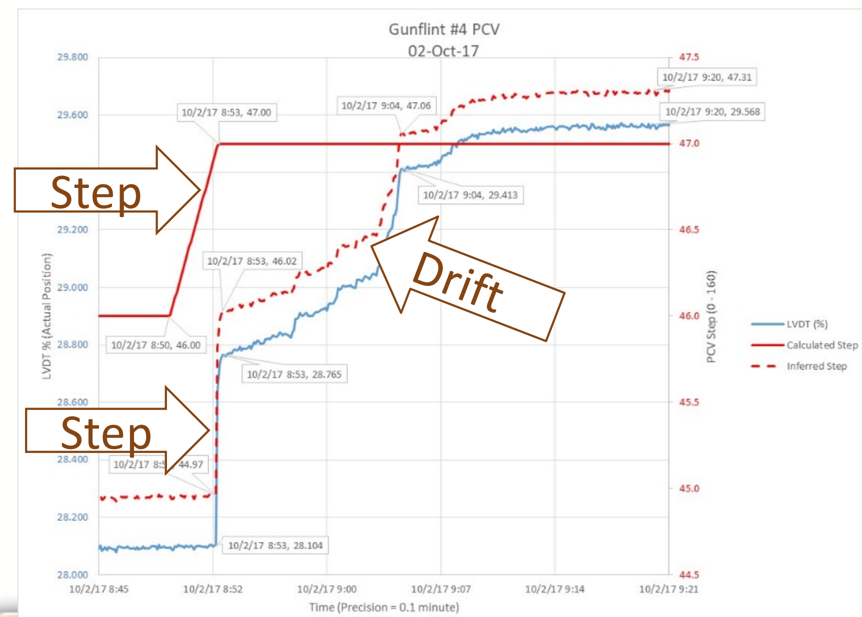


For Background Information Only

Field Observations and Analysis

- The Production Choke Valve (PCV) has 23 reported cases of drift:
  - Earliest reported drift occurred on 17-Feb-17.
  - Reported drift approached 3 % (4.8 steps).
- Drift occurred both in both static and dynamic states:
  - Drift occurred when no valve command was initiated, hence un-commanded valve movement in steady state.
  - Drift also occurred after the PCV was commanded to step, hence valve overstepped commanded position.
- Further investigation revealed maximum drift approached 1.5 steps (0.9375 %).



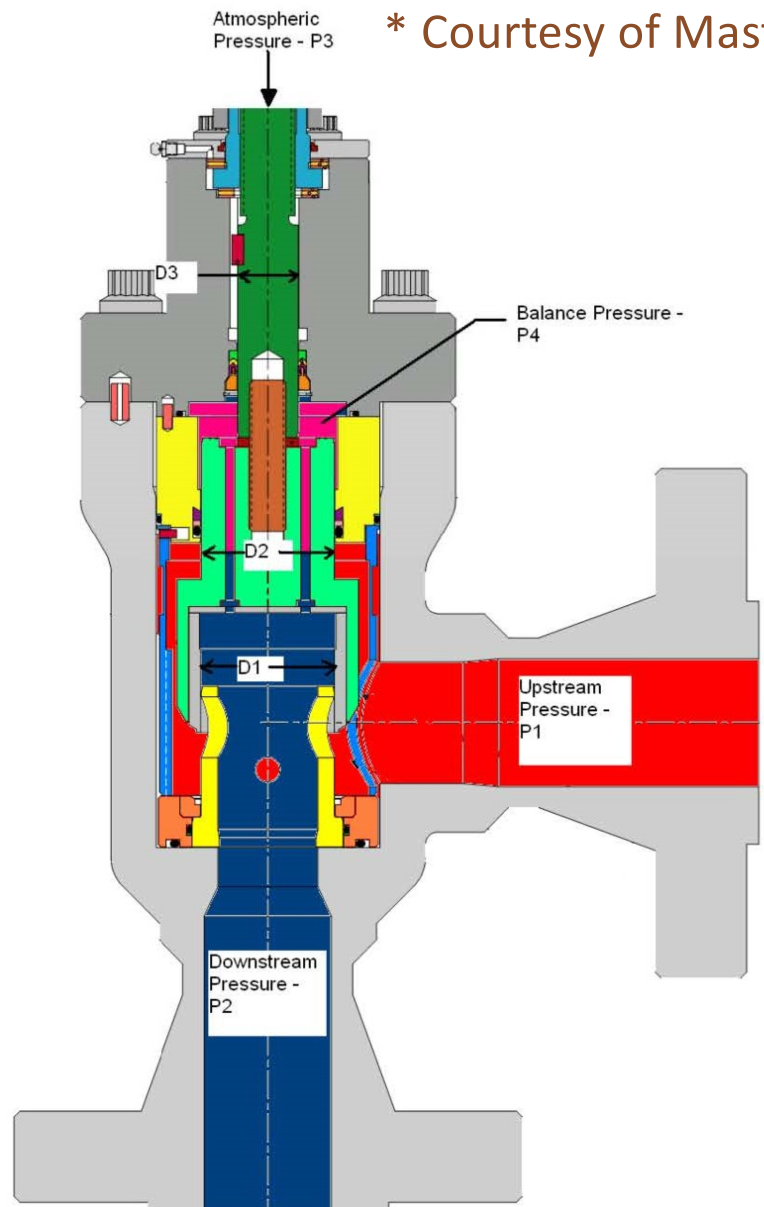


FIELDWOOD ENERGY

PCV Drift Due to Manufacturing Tolerances

- This is not a failure!
- Drift is attributed to tolerances between the thrust washers and actuator housing ring groove.
- Drift is also due to the threaded interface between the stem and stem nut (drive screw).
- All subsea Production Choke Valves (PCV) have tolerance stack-ups resulting in drift, or un-commanded movement.
- Drift can be reduced by proprietary means (only one OEM has a solution to this problem).
- Maximum "design" drift in this PCV is 2.6 steps or 1.625%.

* Courtesy of MasterFlo



Fieldwood Energy

So What?

- Maximum drift in this PCV is 2.6 steps or 1.625%.
- Drift occurs when back pressure and ambient hydrostatic head are between 1695 – 2562 psi apart.
  - Ambient hydrostatic head cannot be changed.
  - The back-pressure can be changed by modifying the topside PCV.

- Most important: Operations should not “freak out” when this happens, its per design intent.
  - The un-commanded PCV movement is not the result of equipment failure.

- Also important: If the un-commanded drawn down could cause well damage:
  - Aborting the movement won’t result in a PCV step-change.
  - Stepping close will not result in any valve movement.
  - The closure of the valve must include additional steps for valve movement, because it will “float” again in the other direction if no changes to back-pressure occur.
  - Depending on where the un-commanded movement occurs during well start-up, operations can either increase or decrease the back pressure on the PCV to move the un-commanded float to a different time during the start-up procedure.
    - However, the PCV will “float” no matter what.
    - The choice is “When do you want it to happen?”

Subsea Troubleshooting: Surface Controlled Subsurface Safety Valve (SCSSV)

FIELDWOOD ENERGY

Background

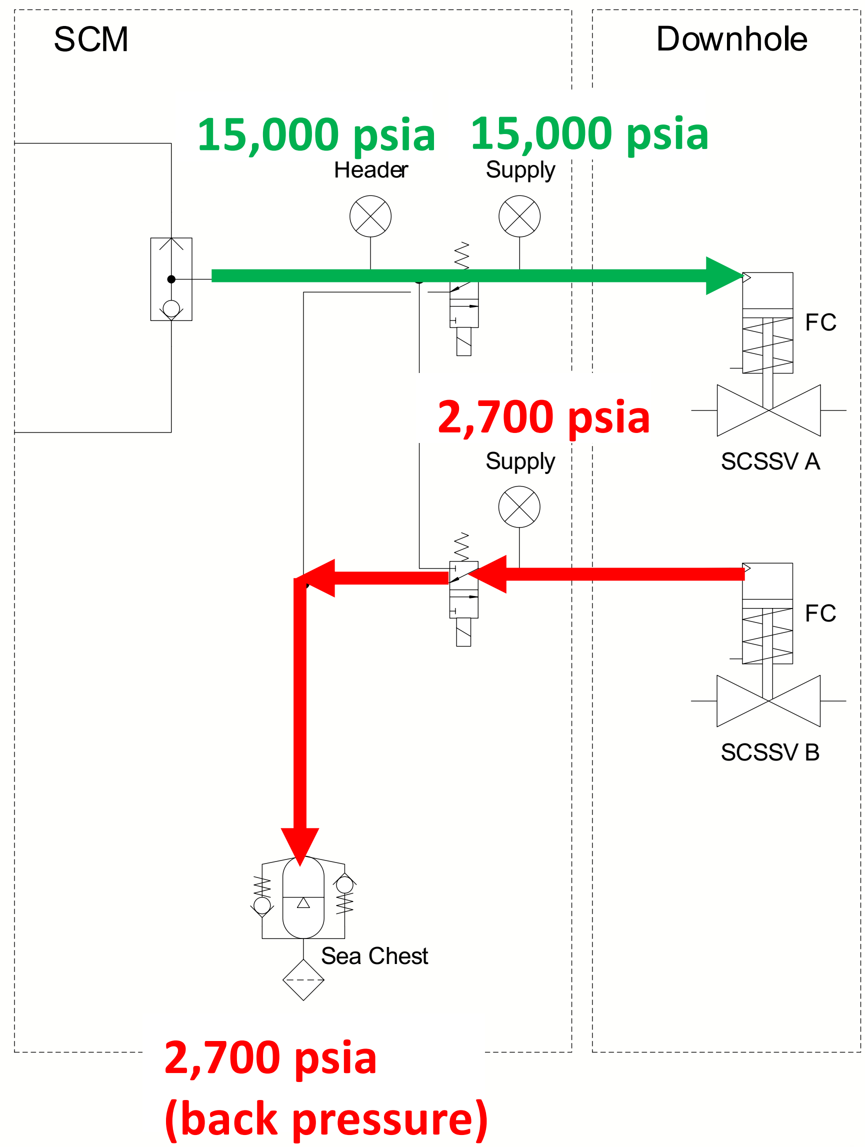
- The Surface Controlled Subsurface Safety Valve (SCSSV) or "Safety Valve" is a discrete On/Off valve installed in the completion, downhole, below the mudline.
  - Its sole purpose is to shut-in the well.
  - It "wants" to close.
  - Like most subsea devices, its dual/redundant. Only one has to be able to work.
  - Unlike the Production Choke Valve (PCV), the SCSSV is either fully open or closed.

- The platform was evacuated due to tropical storm Cristobal in Q2 2020.

- Upon re-manning the facility and restarting the subsea system, the SCSSV initialized in an error state.
  - BOTH #2 SCSSV-A and SCSSV-B closed (vented) pressure increased to about 3,030 psi, which is greater than the CLOSE threshold of 3,000 psia. This means the computer thought the valve tried to stroke, but couldn't stroke all the way open.
  - When closed, the SCSSV-A and SCSSV-B pressure should be at 2700 psia, as these circuits are compensated/vented to sea.
  - This indicates physical failure in the subsea system.
- Since mid-June, we have not been able to pressurize the SCSSV-A circuit.
  - We were able to pressurize the SCSSV-B circuit until 06-Jul-20.
- At about 06-Jul-20, both SCSSV-A and SCSSV-B pressures increased to about 9,000 psia.
- After this behavior, we reduced the tubing pressure and observed that the SCSSV-B pressure tracked the tubing pressure.

Pressures Tell the Story

- The SCSSV can be abstracted as two separate valves:
- Header ~ 15,000 psia. This works.
- Sea chest = vents the "return" hydraulic fluid to sea. Back pressure = 2,700 psia.
- Supply pressure "A" should read:
  - 15,000 psia when open.
  - 2,700 psia when closed.
- Supply pressure "B" should read:
  - 15,000 psia when open.
  - 2,700 psia when closed.
- There are no "in between" states.

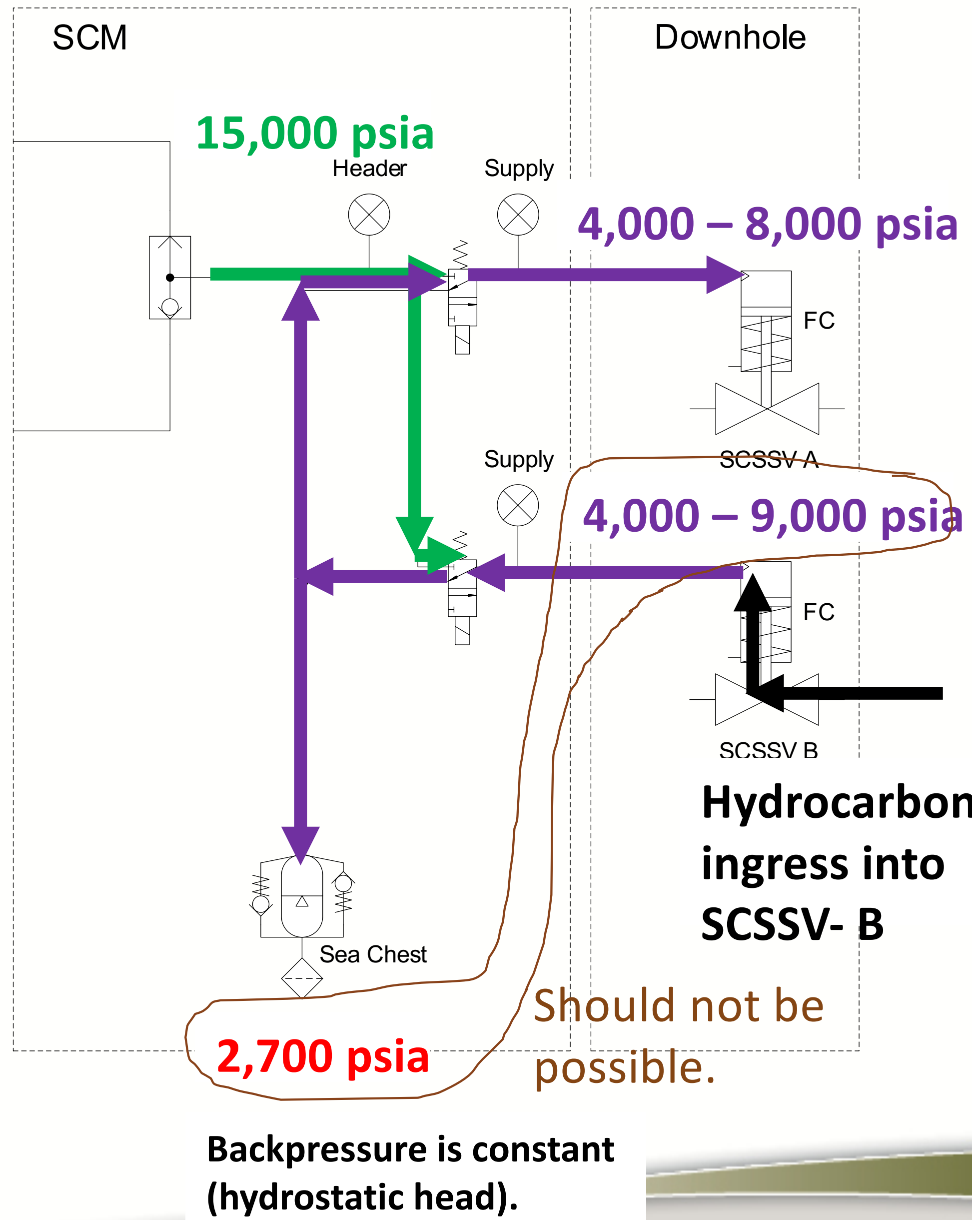


FIELDWOOD ENERGY

Pressure Observations

- Supply pressure “A” reads:
  - 4,000 – 8,000 psia, at random.
  - PT failure (not likely) or DCV failure (likely).
- Supply pressure “B” reads:
  - 3,000 – 9,000 psia, follows tubing pressure. This is bad.
  - DCV failure likely caused by production ingress into circuit.

- The vented or closed side of SCSSV-A and SCSSV-B are communicating (hydraulically contiguous).

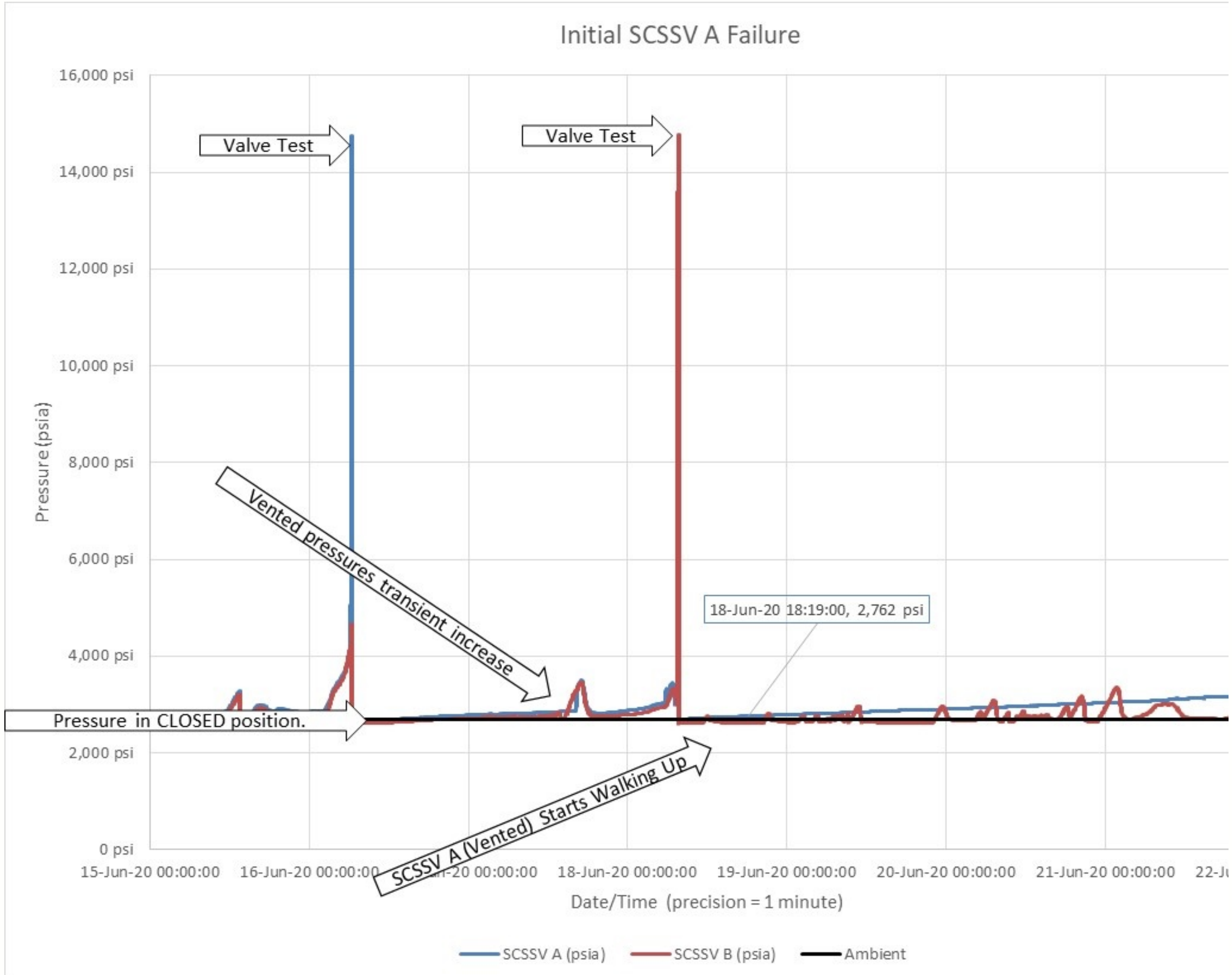


FIELDWOOD ENERGY

Chronological History - Re-manned Platform

- Upon re-manning the platform, the SCSSV-A and SCSSV-B were cycled to clear alarms.
- SCSSV-A (blue line)/SCSSV-B (red line) starts walking up at about 18-Jun-20.
- Suspect restrictions at SCM as early as 18-Jun-20.

Key observation: Both the blue and red lines increased above 2700 psia.



Initial Troubleshooting

Observation 1:

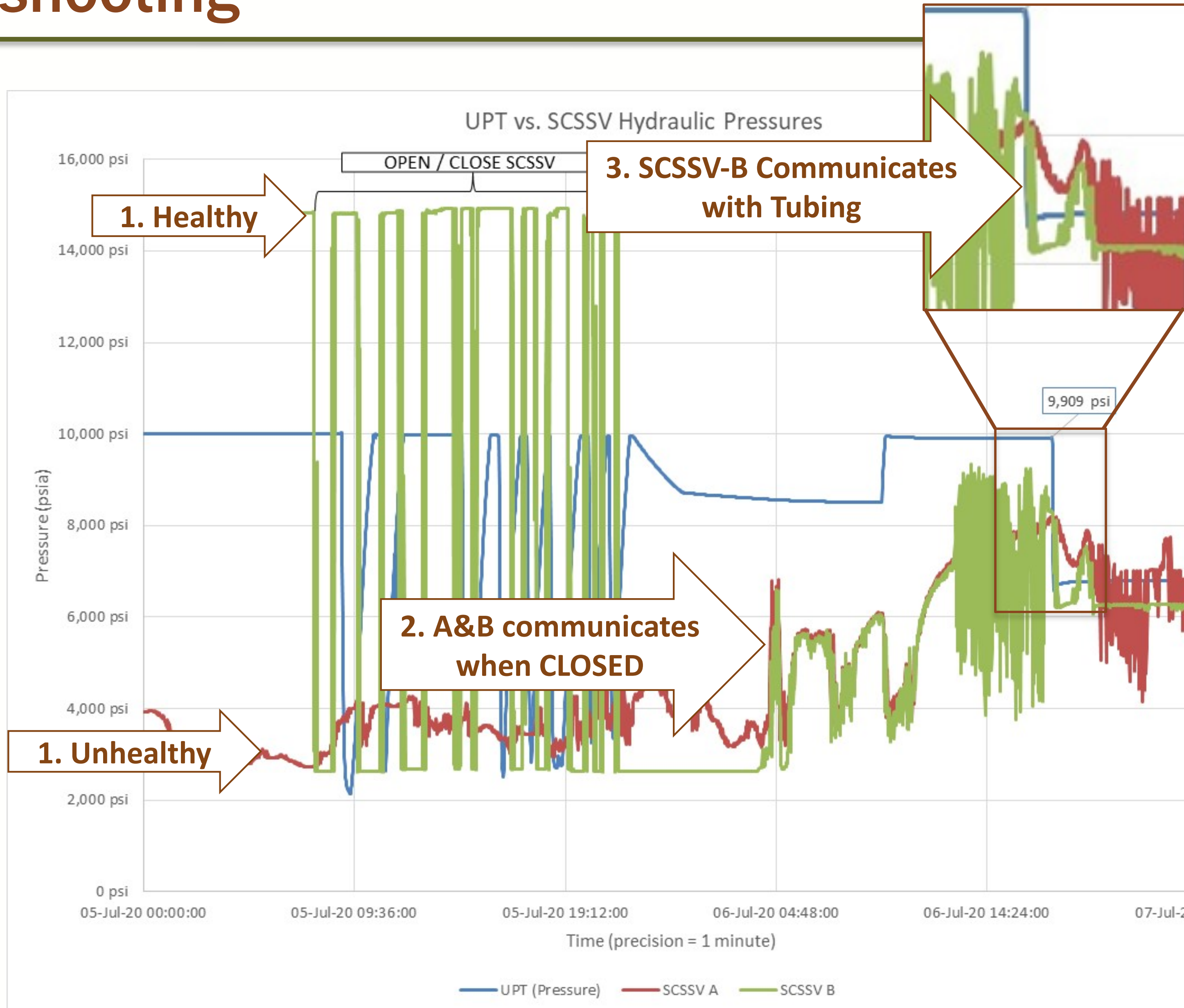
- SCSSV-A did not respond to valve commands.
- SCSSV-B responded appropriately (green line), the system should work.

Observation 2:

- At about 0400 06-Jul-20, both SCSSV-A and SCSSV-B pressures began to tend together.
- Common return line!

Observation 3:

- We vented the tubing and SCSSV-B trended along with the tubing pressure.
- SCSSV-B hydraulic to production pressure boundary has failed.

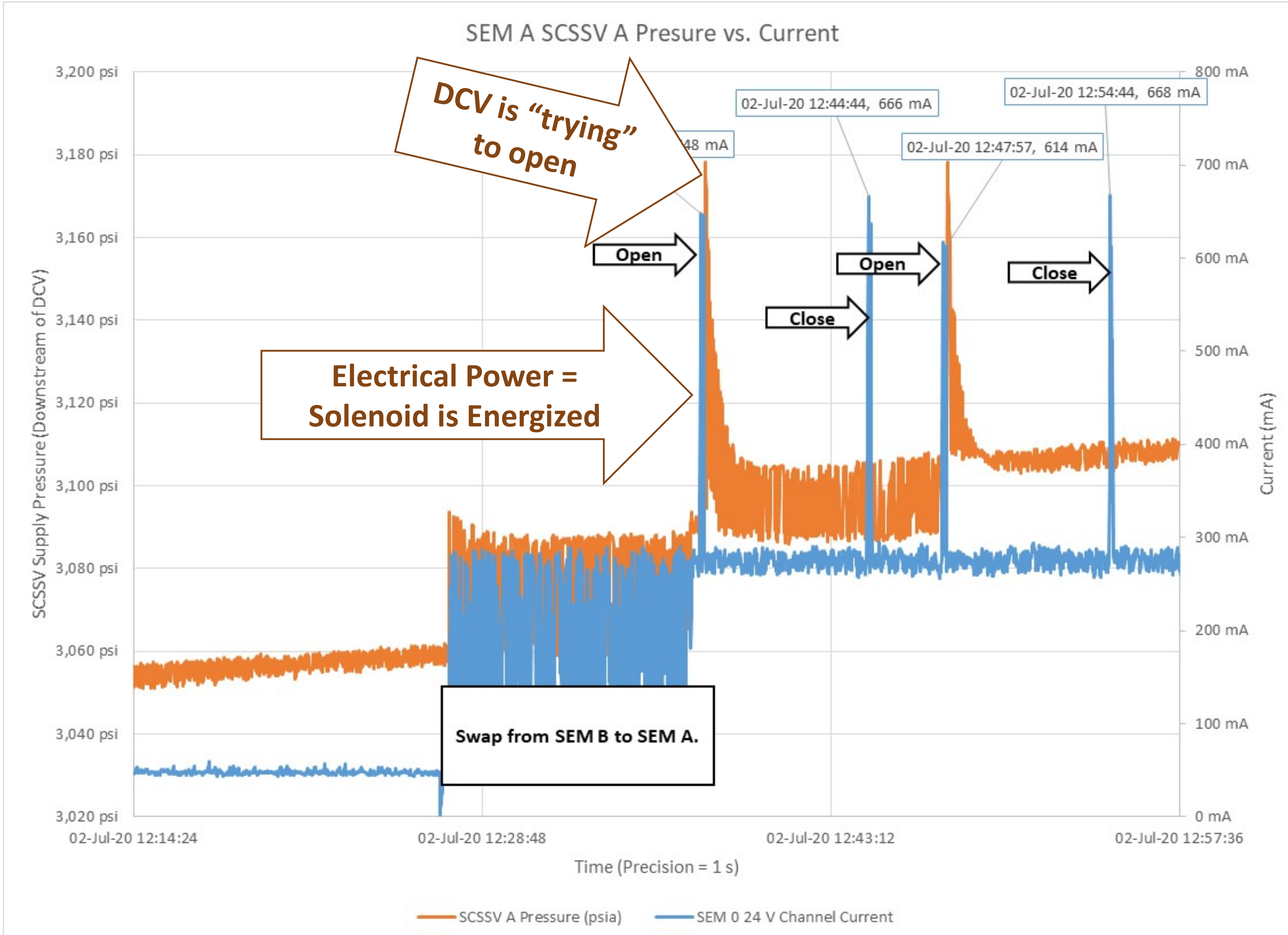


FIELDWOOD ENERGY

The DCV being Energized – Equipment is Working

- SEM current pulsed 4x times.
- Current (blue line) tracked valve command (orange line).
- The DCV pulses the SCSSV-A solenoid both on OPEN and CLOSE.

Key Observation: The SCM is working.

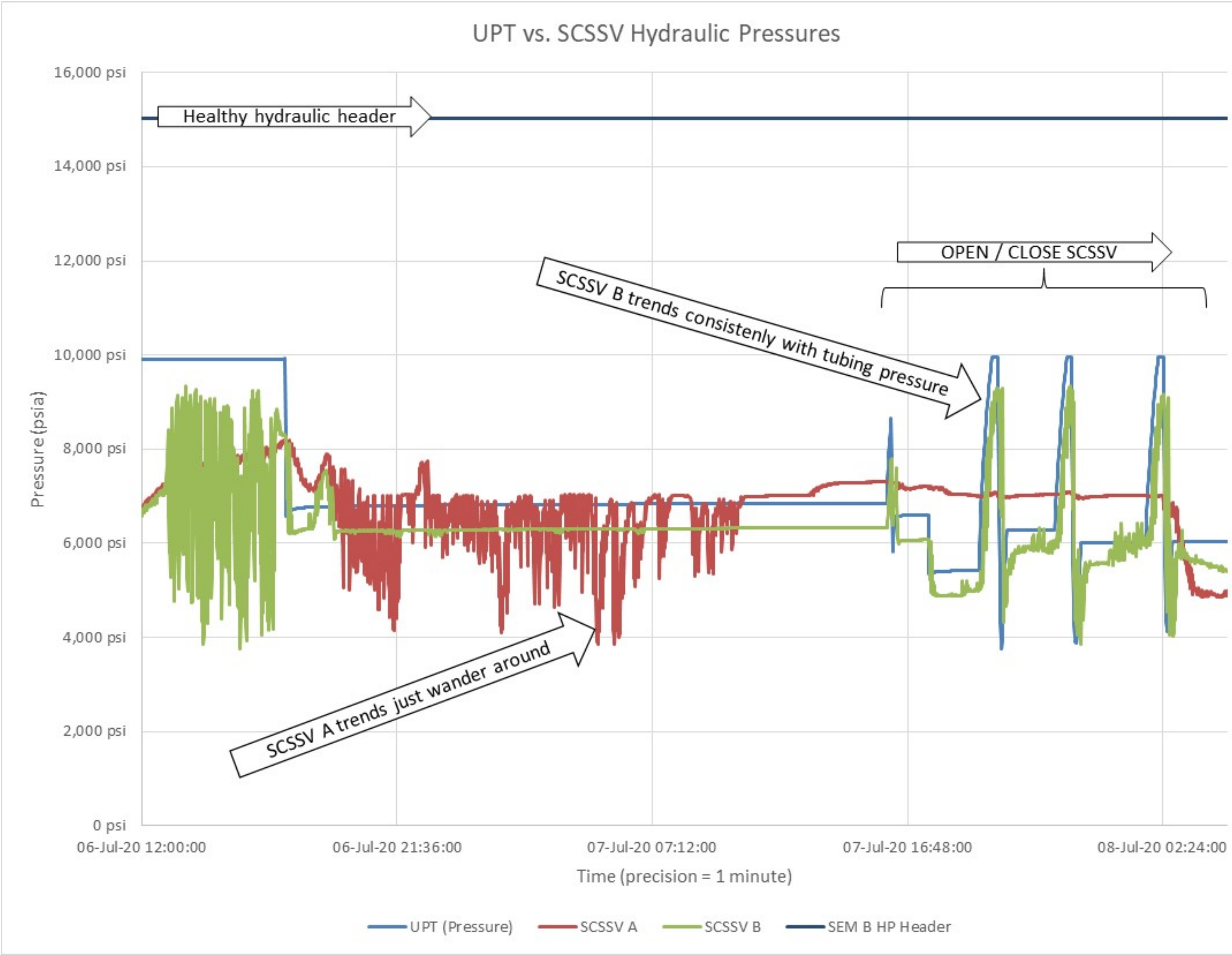


Fieldwood Energy

Further Troubleshooting

- SCSSV-B (green line) now consistently trends with the production tubing pressure (blue line).
- Probable production to hydraulic fluid communication.

- SCSSV-A (red line) is still not working.
- The response is indeterminate – we don't know why it doesn't work.
- The failure mode does not match the known failure at SCSSV-B.
- Production to hydraulic fluid communication is not evident.



FIELDWOOD ENERGY

Summary of Trend Review

- Trends were used to:
  - Verify the valve was in an indeterminate state.
  - Profiling the current (mA) allows us to verify the valve was being "commanded" to open and close. The control system was working properly.
  - Understanding the discrete thresholds and common return line allowed us to come to the only plausible conclusion:
    - Gas ingress and hydrate formation in one or both control lines.
    - Seal failure on SCSSV-B. SCSSV-B should be placed Out of Service (OOS).

FIELDWOOD ENERGY

End of Presentation

- Thanks for your time and attention!
- Trend analysis and understanding how the valve works allows us to troubleshoot subsea systems.
- The system’s inferred state may not match the actual state.
- Sometimes its imperative to take immediate action against an anomaly.
- But sometimes its best not to take action immediate against an anomaly!