Ask Echometer Online Seminar – July 08, 2020

Troubleshoot and Analyze Sucker Rod Wells Using Reference Load Lines and Pressure Annotations

TOTAL ASSET MONITOR (TAM)

http://www.echometer.com/Software/Total-Asset-Monitor

"Reference Load Lines Aid in Analysis of the Downhole Dynamometer Pump Card", Rowlan, McCoy, Podio, SWPSC 2009

"Effect of Fluid Buoyancy on Rod String Loads and Stresses", Rowlan, 44th Annual Southwest Petroleum Short Course, 1998

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What Should be Known in Order to Trouble Shoot a Well?

- Recent and/or Representative Well Test
- Pump Capacity (or, Pump Card)
- Producing BHP & Static BHP
- Artificial Lift System Description
- Energy Efficiency
- Wellbore description
- Artificial Lift System Design
- Fluid Properties
- Past History

Use Annotations to Aid Analysis

Annotations

- [x] Surface and Pump Cards on One Plot
- [x] Show Power Slider
- [ ] Show Permissible Load Lines
- [ ] Rod/Tubing Stretch on Surface Card — 321 lb/in
- [ ] Tubing Stretch on Pump Card — 28289 lb/in
- [ ] Unanchored Tubing Stretch on Pump Card — 924 lb/in
- [ ] Measured Load TV — lb
- [ ] Measured Load SV — lb
- [ ] Calculated Buoyant Rod Weight + Fluid Max — 18940 lb
- [x] Calculated Buoyant Rod Weight + Fo FL — 17499 lb
- [x] Calculated Buoyant Rod Weight — 10467 lb
- [x] Fo Max Line — 8473 lb
- [x] Fo Calculated From PIP of Fluid Level (Fo FL) — 7032 lb
- [ ] Fo Calculated From Valve Check Analysis — lb
- [ ] Show CBE Load — 0 lb

Previous Strokes...

- [x] Valve Open/Close Points
- [x] Zero Load Line — 0 lb
- [x] Effective Plunger Travel (EPT) — 146.61 in
- [ ] Maximum Plunger Travel (MPT) — 156.13 in
- [x] Gas Free Fillage Line — 145.32 in
- [ ] Show Tubing Pressure
- [x] Pump Intake Pressure — 423.7 psi (g)
- [x] Pump Discharge Pressure — 2131.1 psi (g)
- [x] Pump Intake Pressure Fluid Level — 362.6 psi (g)
- [x] Show Current Chamber Pressure

Liquid Level Association

The liquid level test used for analysis:

06/07/2000 01:38:55PM(Automatically selected)

Select | Reset

Valve Test Association

The valve test used for analysis:

None (Automatically selected)

Select | Reset

PIP FL = 363 psi (g)

EPT = 146.61 in

0 20 40 60 80 100 120 140 160 in

Stroke: 5 00:00:52

Unanchored Kt 924 lb/in Kr 321 lb/in

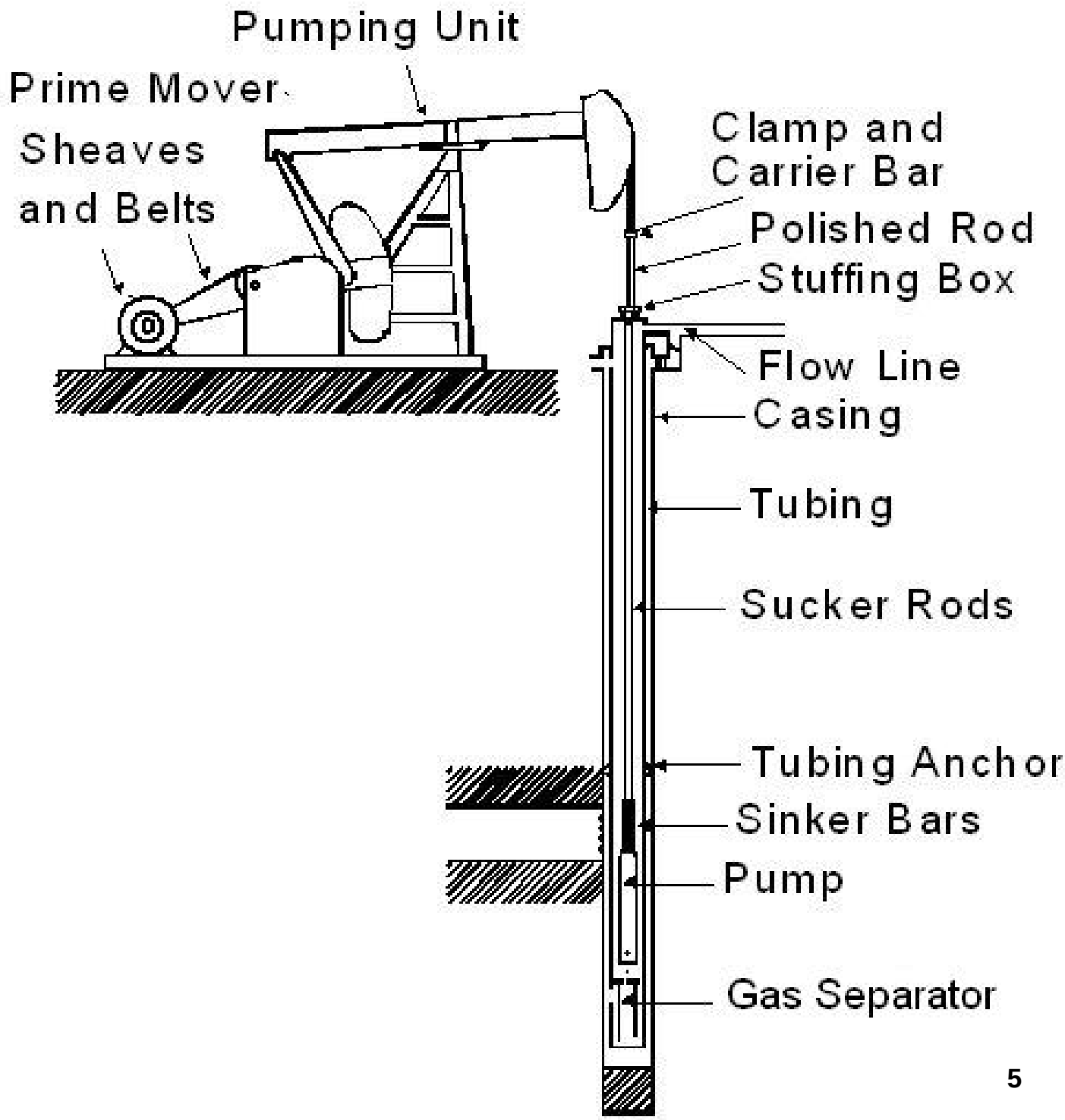
Annotations

Pump Card Analysis

Analysis STEPS to Troubleshoot and Analyze Sucker Rod Lifted Wells

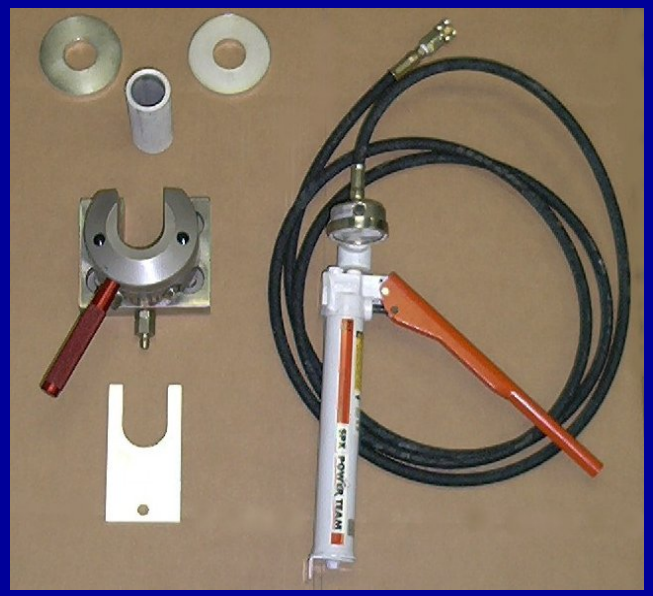
1. Analyze the well's inflow performance to determine if additional production is available.
2. Determine the overall efficiency to identify wells that are candidates for improvement.
3. Analyze the performance of the pump.
4. Analyze the performance of the down hole gas separator.
5. *Analyze mechanical loading of rods and pumping unit*.
6. Analyze performance of prime mover.
7. Design modifications to existing system.
8. Implement changes and verify improvement.

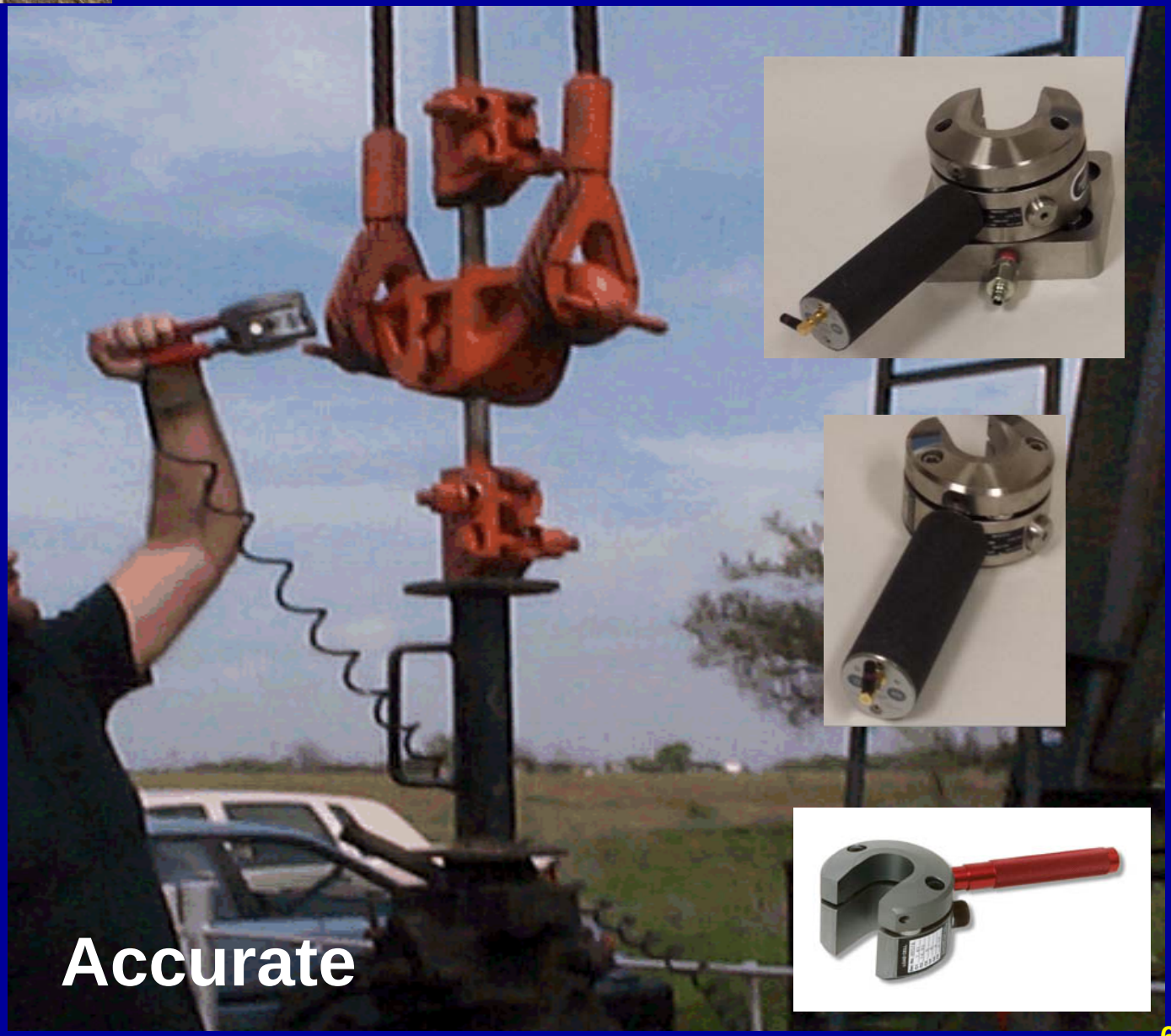
Recording polished rod load and position data on sucker rod lifted wells with a dynamometer transducer has been performed in the oil field for many years



Use Any of these Transducers to Perform a Dynamometer Survey

Safe & Quick



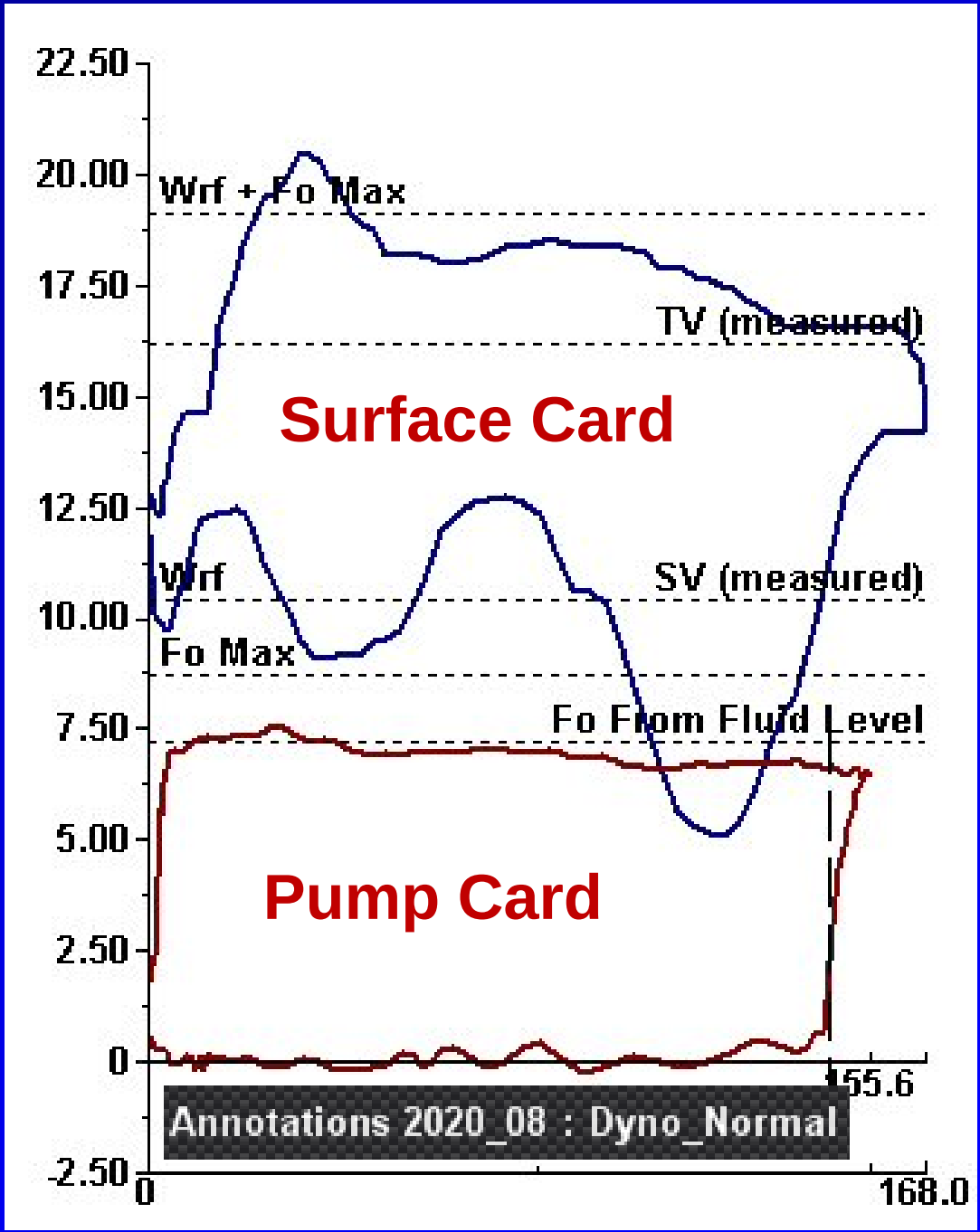


Accurate

Dynamometer Card Definition

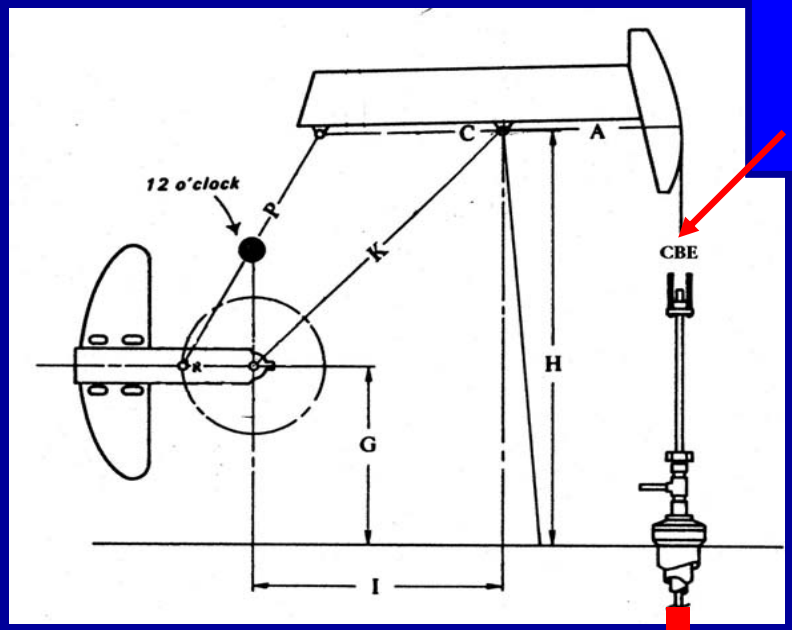
1) Surface dynamometer card is the plot of the measured rod loads at the various positions throughout a complete stroke; the load is usually displayed in pounds of force and the position is usually displayed in inches.

2) Pump dynamometer card is a plot of the calculated loads at various positions of pump stroke and represents the fluid load the pump applies to the bottom of the rod string.

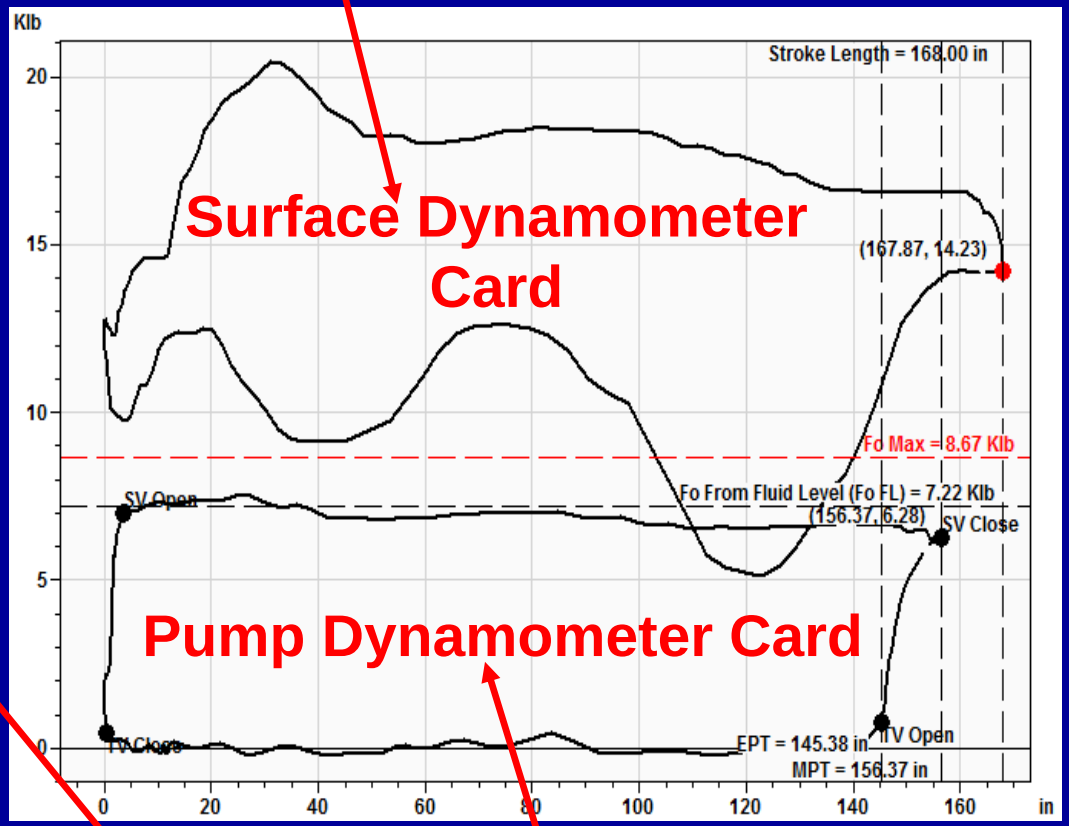


Surface Load 14,820 Lbs at Top of Stroke

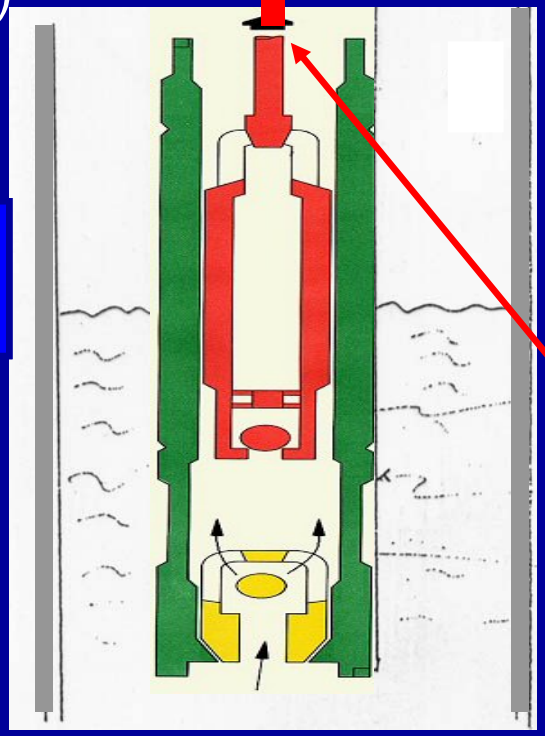
1960s, S.G. Gibbs Mathematically "Wave Down"



Surface Dynamometer Card: Load vs. Polished Rod Position



Sucker Rods: 10,434 Lbs (Wrf)



Fluid Load 6,280 Lbs at SV Close

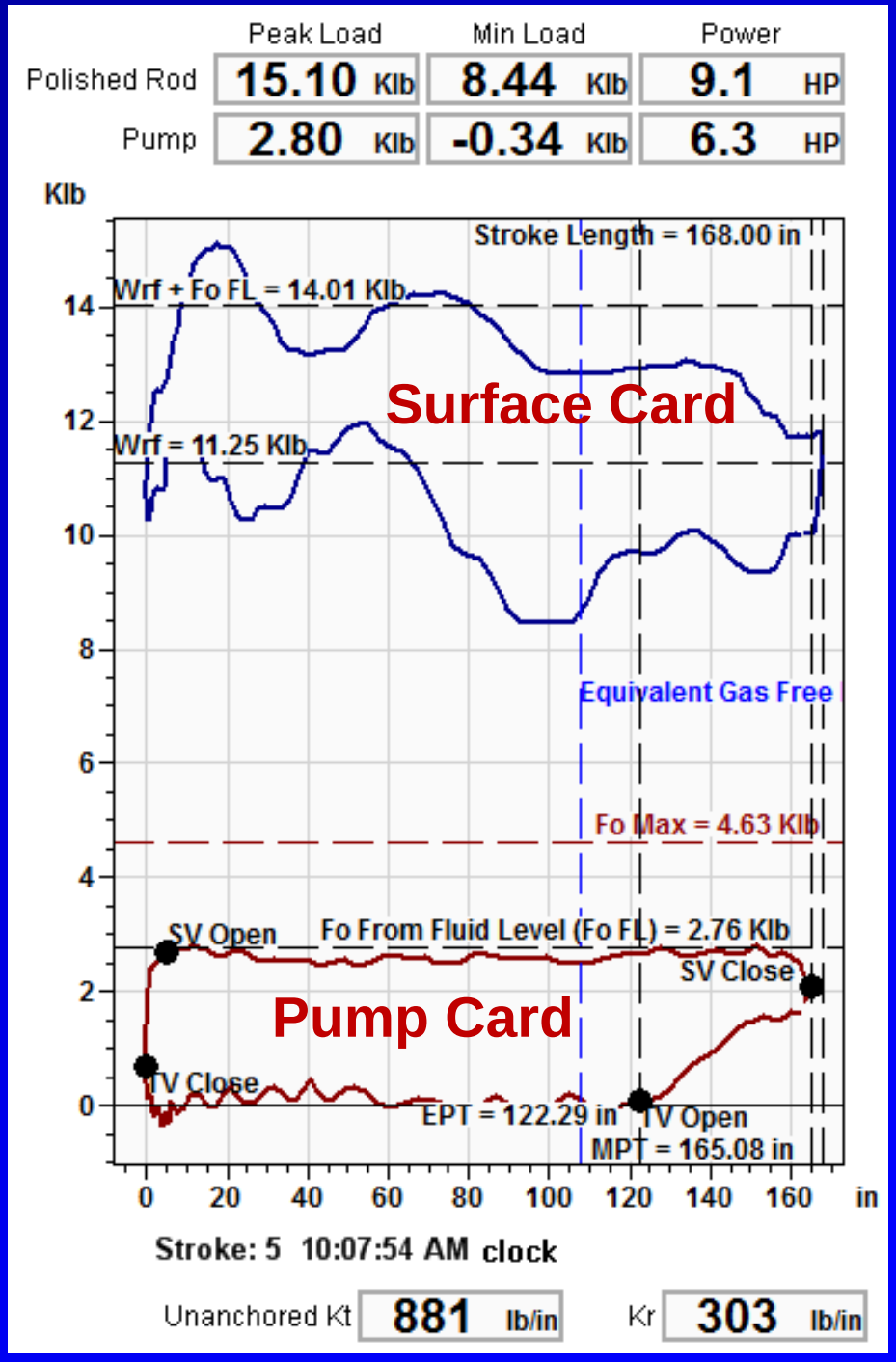
Fluid Load 0 Lbs at TV Open

Pump Dynamometer Card: Load vs. Pump Rod Position

Analyze w/ Surface & Pump Cards

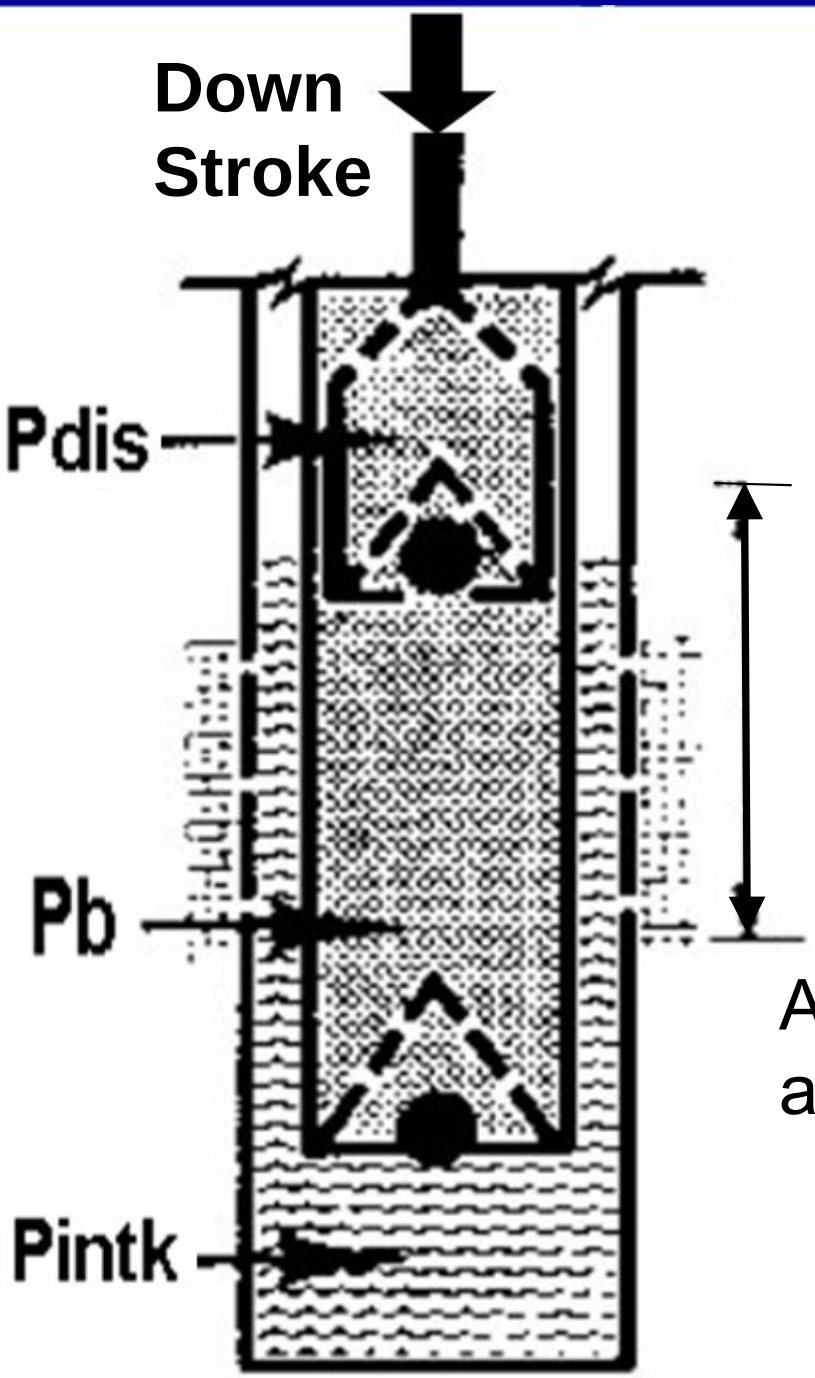
1) **Surface Dynamometer cards for designing and diagnosing surface problems.**
   - Rod String
   - Pumping Unit
   - Pump Problems
   - Excessive Friction

2) **Pump card for analysis of downhole problems.**
   - Unanchored Tubing
   - Tubing Leak
   - Pump Problems
   - Pump Displacement



Echometer Online : Annotations 2020_08 : Sandia

Zero Load on Down Stroke



Fo = 0

Plunger
Stroke
Length

After SV Close
and TV Opens:

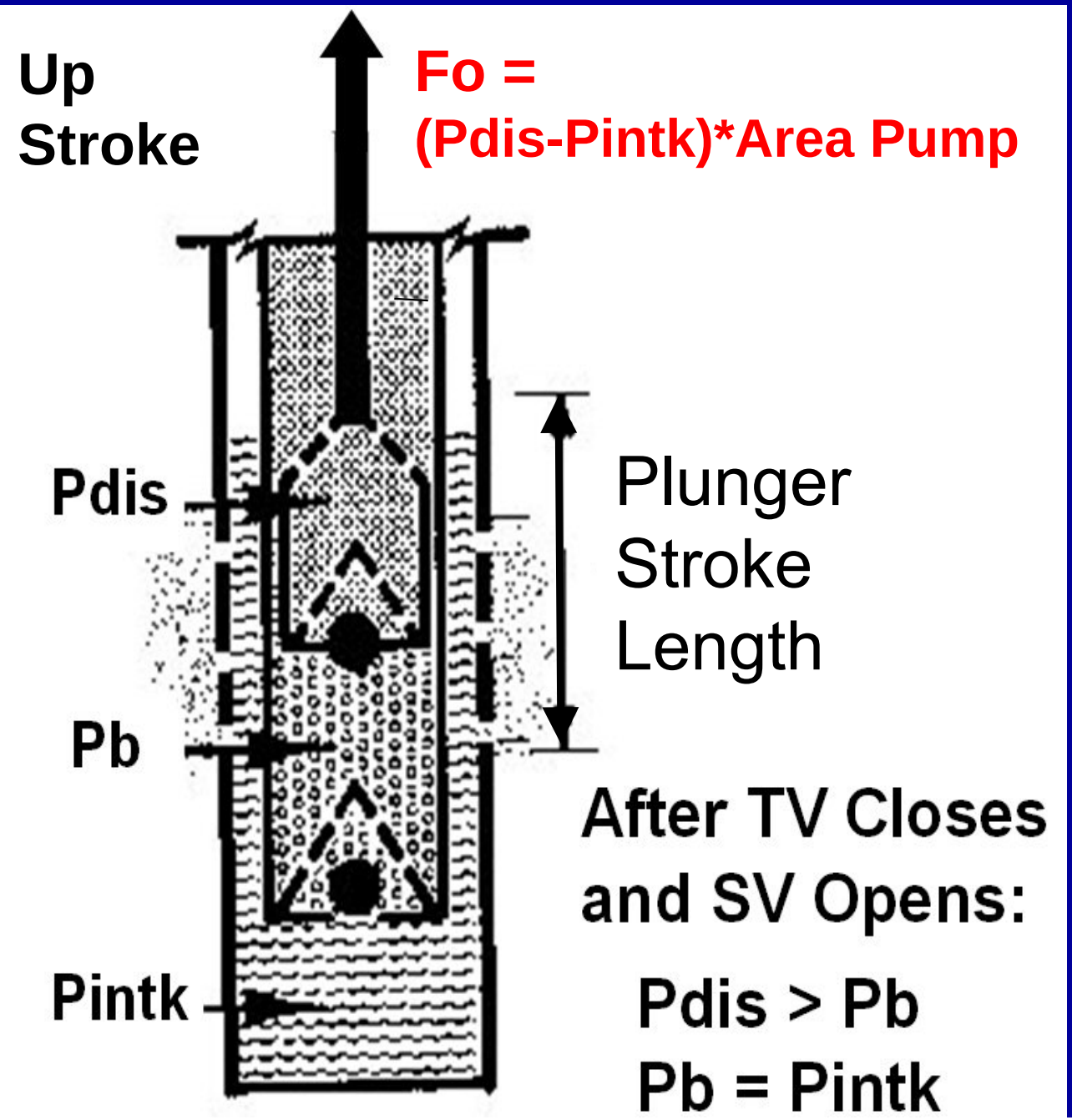
Pb = Pdis
Pb > Pintk

Pump discharge pressure (Pdis) equals the static tubing pressure (Pb), and the traveling valve opens. (Pdis) carried by tubing.

Pump Applies Little OR Zero Load on Rods from Plunger

Fo From Fluid Level

Load Reference Line on Up Stroke

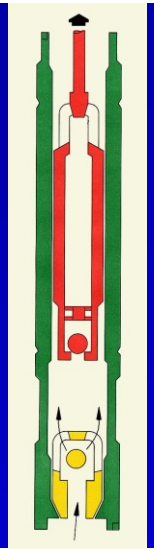


Plunger applies Fluid load, Fo, to the rods.

Due differential pressure (Pdis-PIntk) acting across closed TV

Well fluids are drawn into the pump through open SV.

Steps in the Pump Operation



A) Start of the upstroke, the traveling valve and standing valve are both closed.

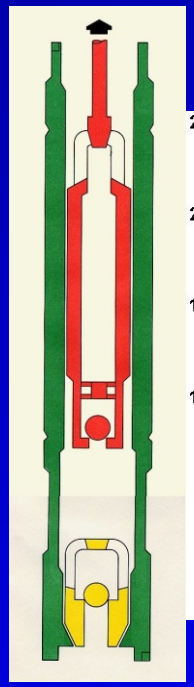
B) Standing Valve opens, when rods stretch to pick up fluid load, Fo, from tubing.

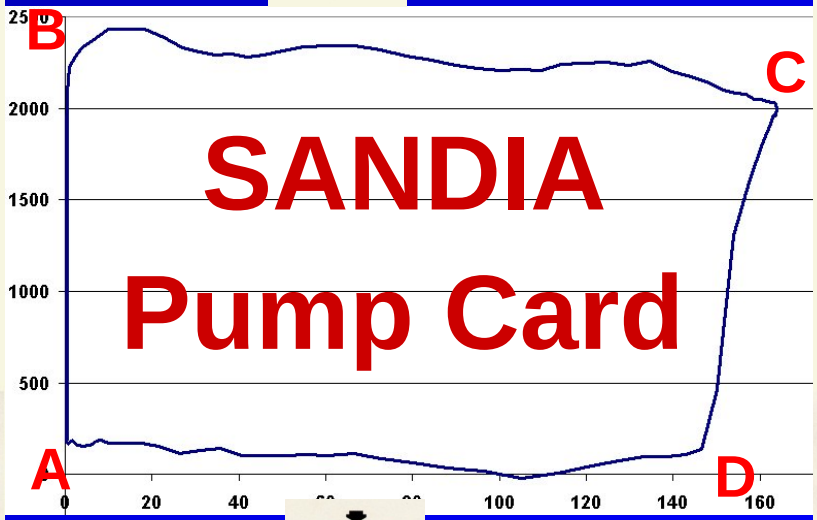
B-C) Fluid load, Fo, is carried by the rods as well fluids are drawn thru the pump intake.

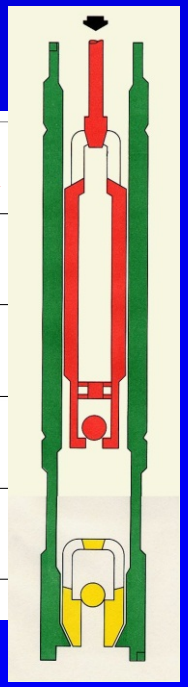
C) Standing valve closes and the traveling valve remains closed.

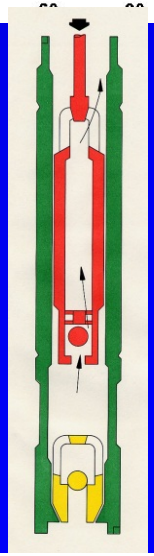
C-D) Pressure inside the pump (Pb) increases until it is slightly greater than the pump discharge pressure.

D) Pump inside the pump (Pb) equals the static tubing pressure (Pt), and the traveling valve opens. Fluid load, Fo, is carried by tubing.





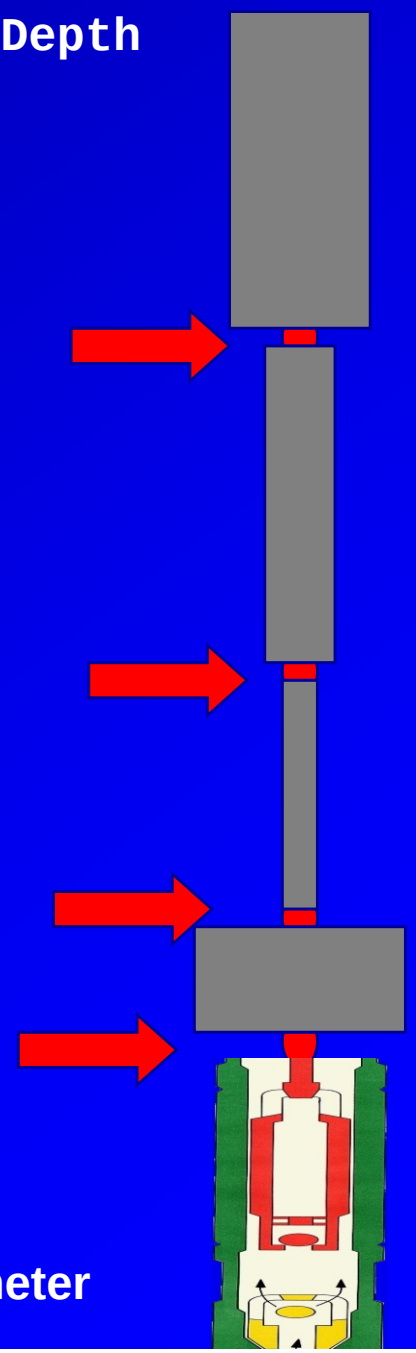




D-A with TV Open, the fluid in the pump is displaced through the traveling valve into the tubing and **ZERO** fluid load is on rods.

1986 Glen Albert Developed an Electronic Downhole Dynamometer – Used by SANDIA

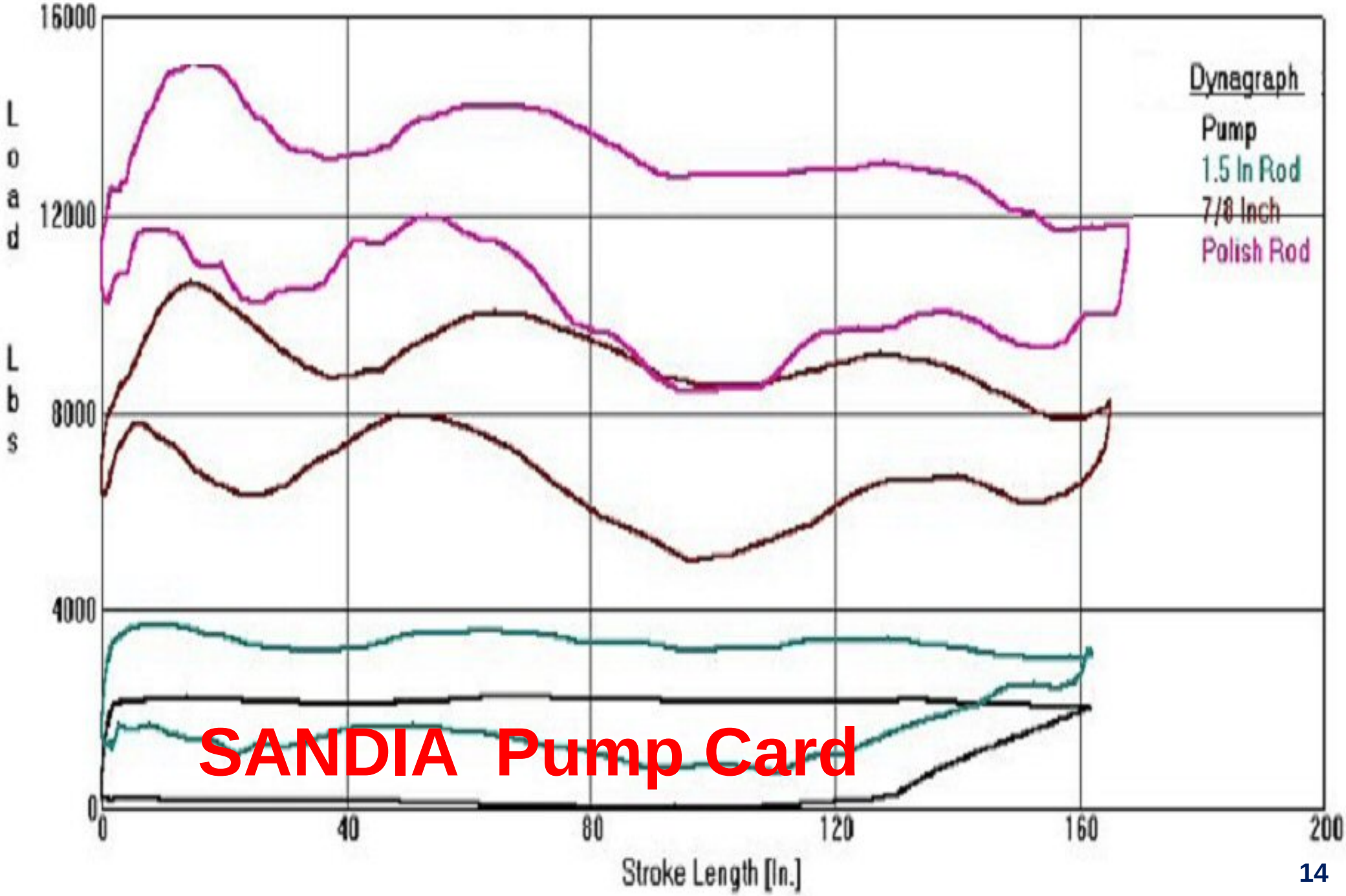
-Size-	-Description-	Length Ea.	Number	Cum.Depth
1.5"	Polished Rod	30'	1	0'
1.0"	API Grade 'D' Steel	4'	1	4'
1.0"	API Grade 'D' Steel	2'	1	6'
1.0"	API Grade 'D' Steel	6'	1	10'
1.0"	API Grade 'D' Steel	25'	60	1510'
	DHLC Tool #5	2'	1	1512'
0.875"	API Grade 'D' Steel	25'	64	3112'
	DHLC Tool #4	2'	1	3114'
0.75"	API Grade 'D' Steel	25'	65	4739'
	DHLC Tool #3	2'	1	4741'
1.5"	Sinkerbars	25'	10	4991'
	DHLC Tool #2	2'	1	4993'
	Flexbar Stabilizer	4'	1	4997'
	2” Pump	24'		5060'



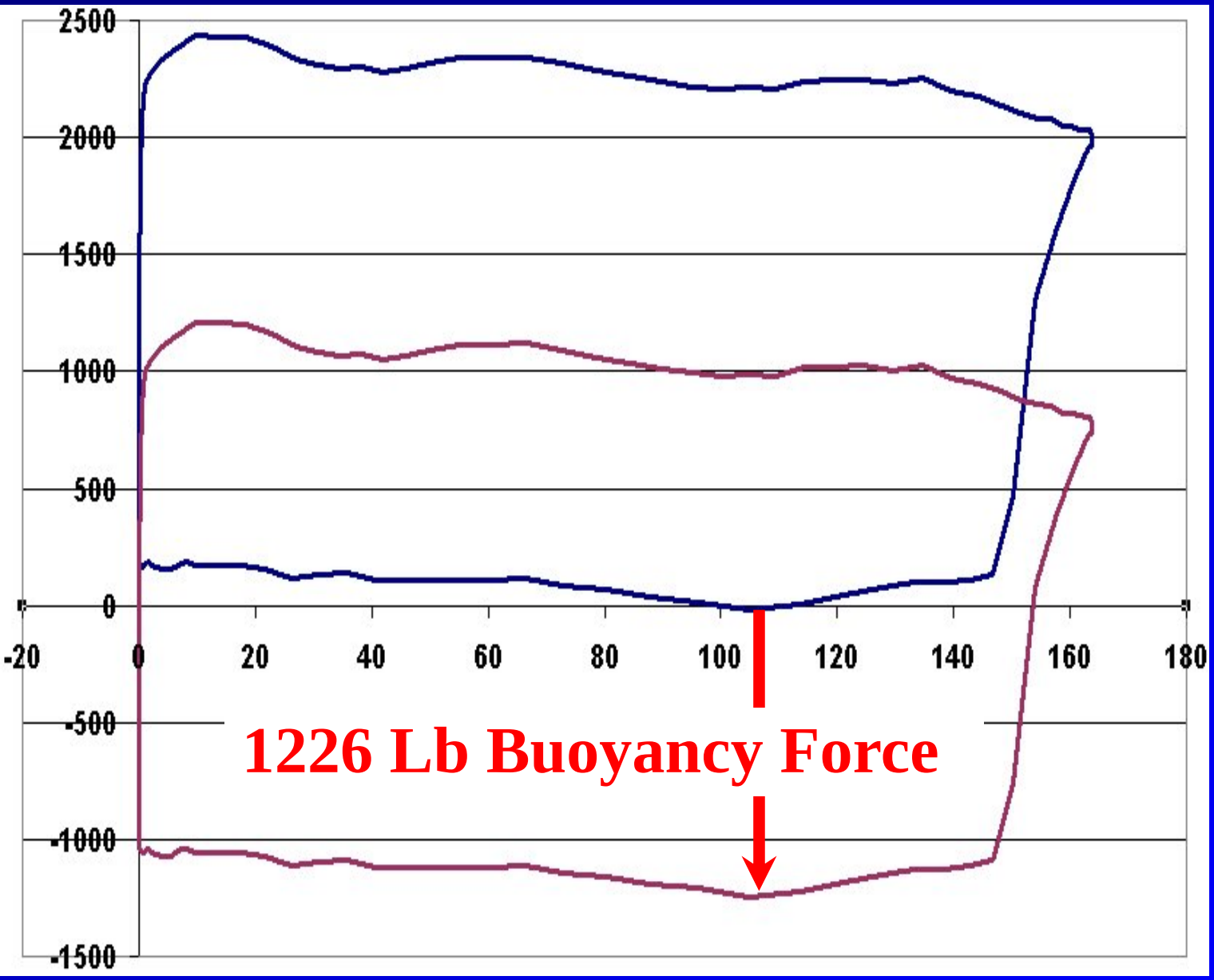
Well Depth: 5278' w/ Casing of 5.5" to 5090'
Tubing: 2.875" to 5060', seating nipple – 5060'
, tubing anchor - 4970'

1936 W.E. Gilbert of Shell developed a mechanical downhole dynamometer

SANDIA Downhole Dynamometer

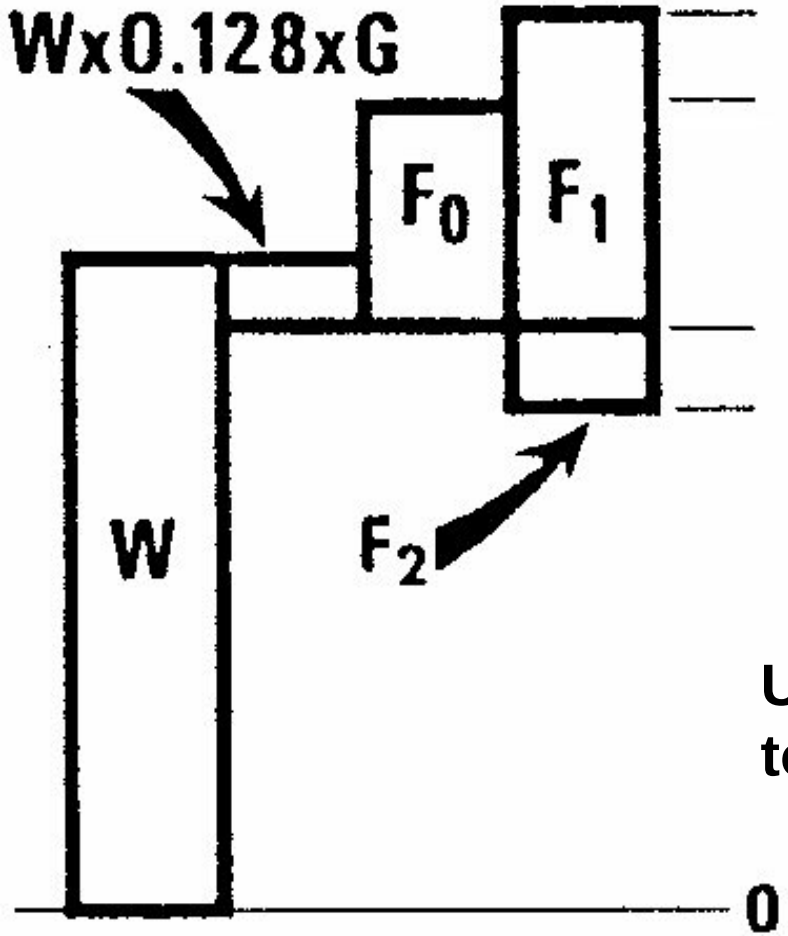


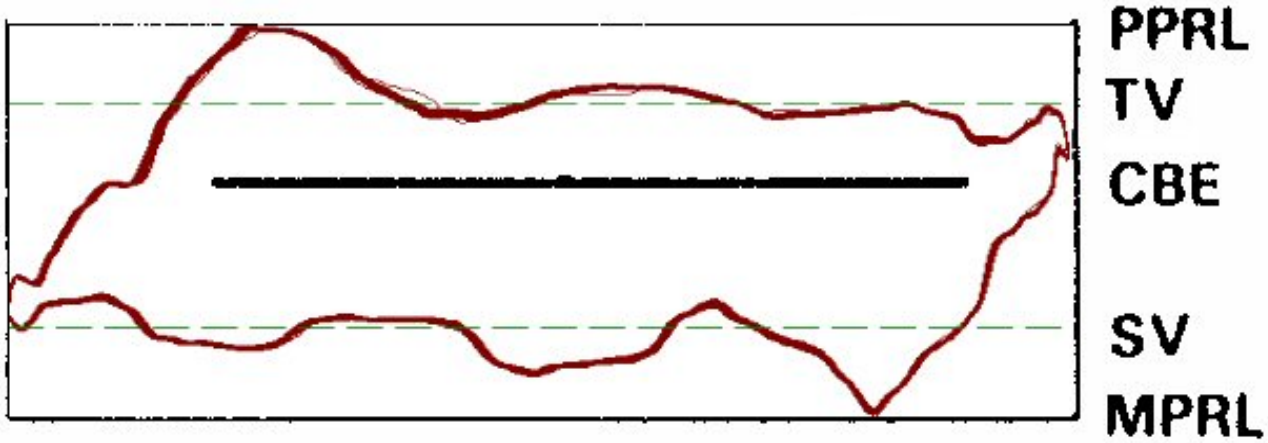
True Load = Dynamic Load - Buoyancy Force



- Solved Wave Eq. without gravity term
- No Buoyancy Effective on Dynamic Pump Loads
- Pump Card loads shifted down below the zero load line.

Predicting Behavior Sucker Rod Systems, S. Gibbs, SPE588, July 1963



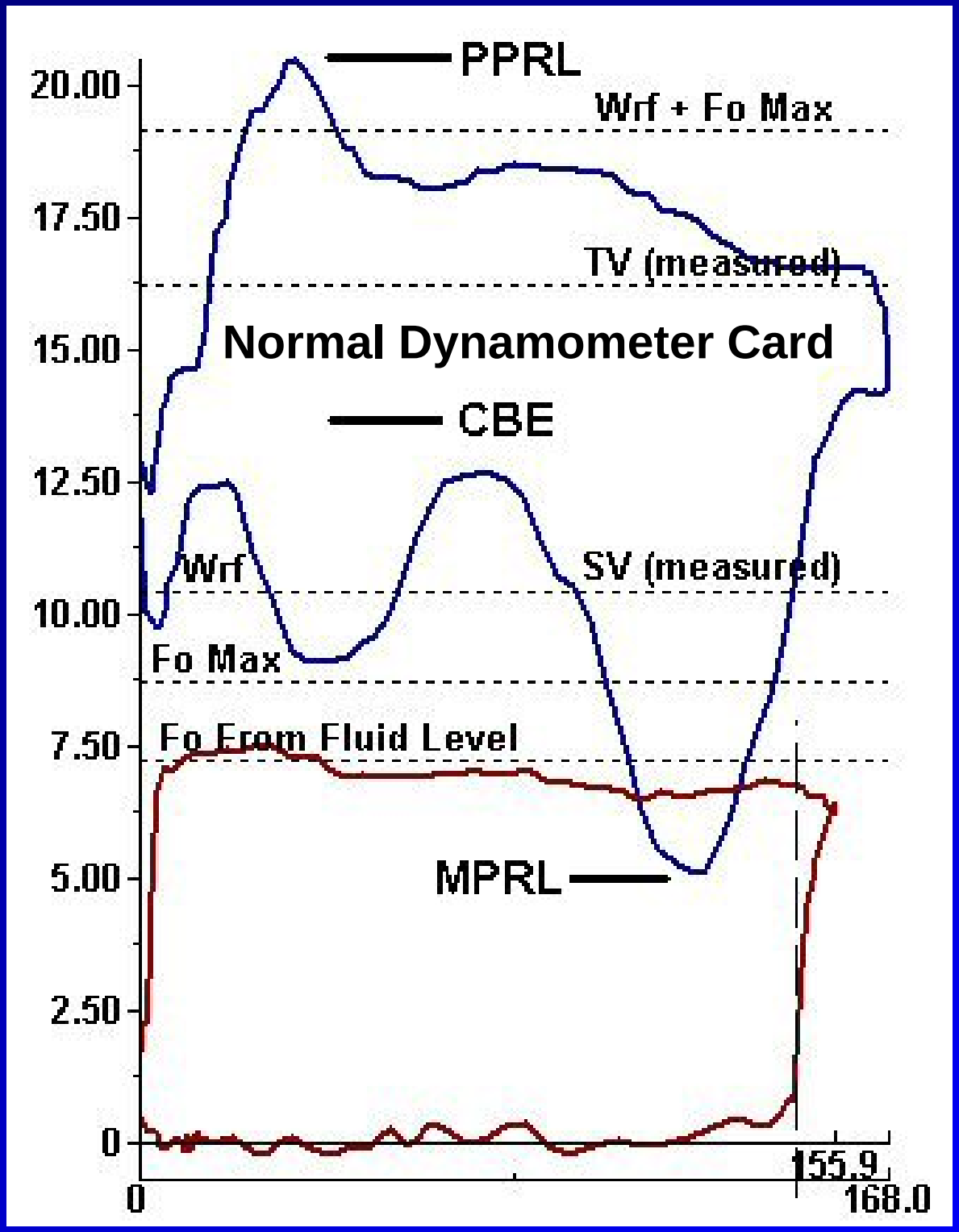


Sucker Rod Loads

Understanding six(6) basic loads are critical to analyzing the sucker rod pumping cycle:

Gipson & Swaim

- **Zero Load [0],**
- **Peak Polished Rod Load [PPRL],**
- **Minimum Polished Rod Load [MPRL],**
- **Counterbalance Effect [CBE],**
- **Standing Valve Load [SV], and the**
- **Traveling Valve Load [TV].**



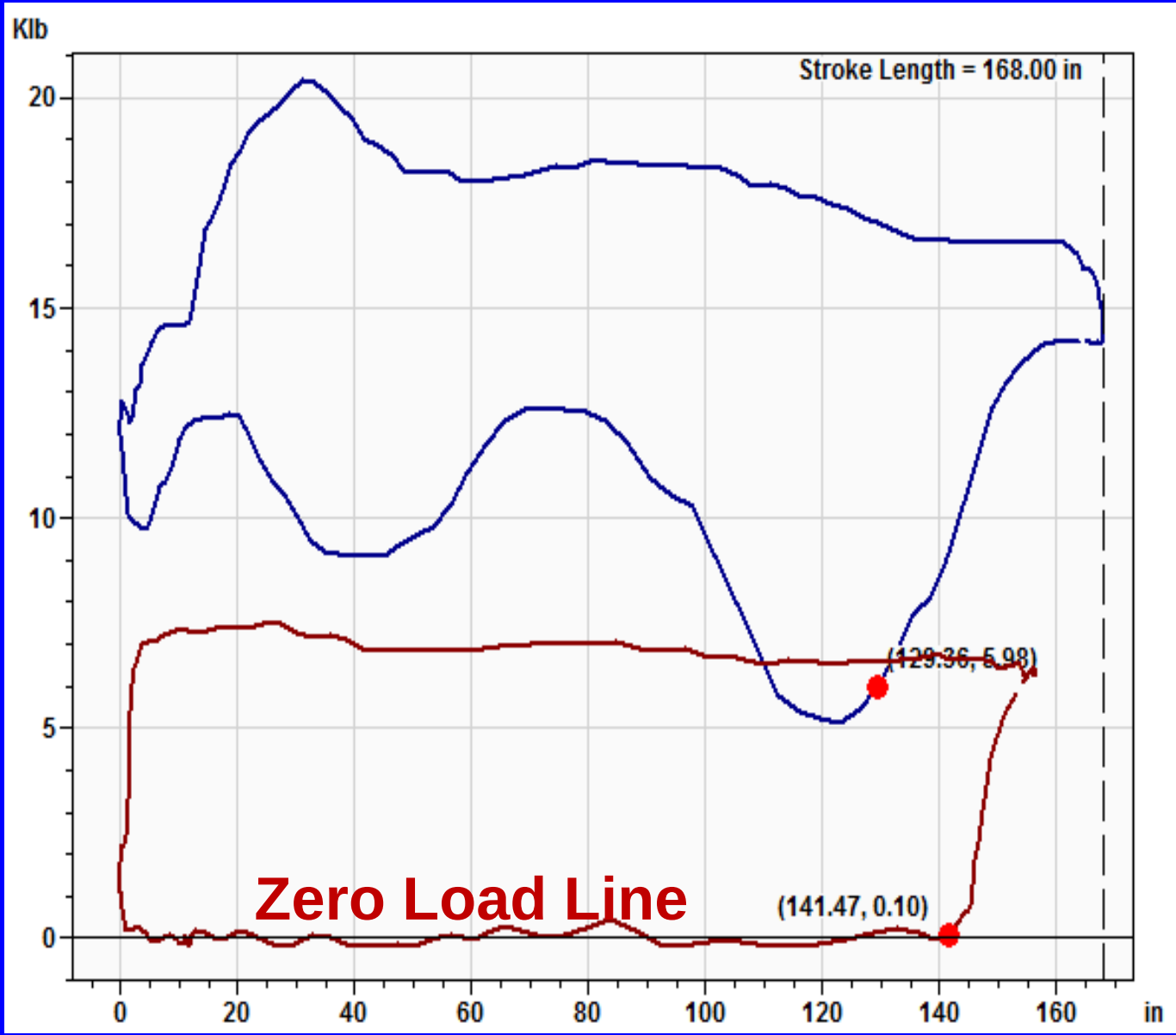
PPRL Peak Polished Rod Load experienced during a stroke.
Wrf + Fo Max (TV) Weight of Rods in Fluid plus the fluid load applied to the rods by the pump
CBE load at the polished rod due to the effect of the cranks and weights when horizontal.
Wrf (SV) Weight of Rods in Fluid, TV open and plunger is applying no load to the rods.
MPRL Minimum Polished Rod Load experienced during the pumping cycle.

LOAD RANGE (PPRL – MPRL) used in calculating % rod loading based on max and min sucker rod stresses and API Modified Goodman Guide

Zero Load Line

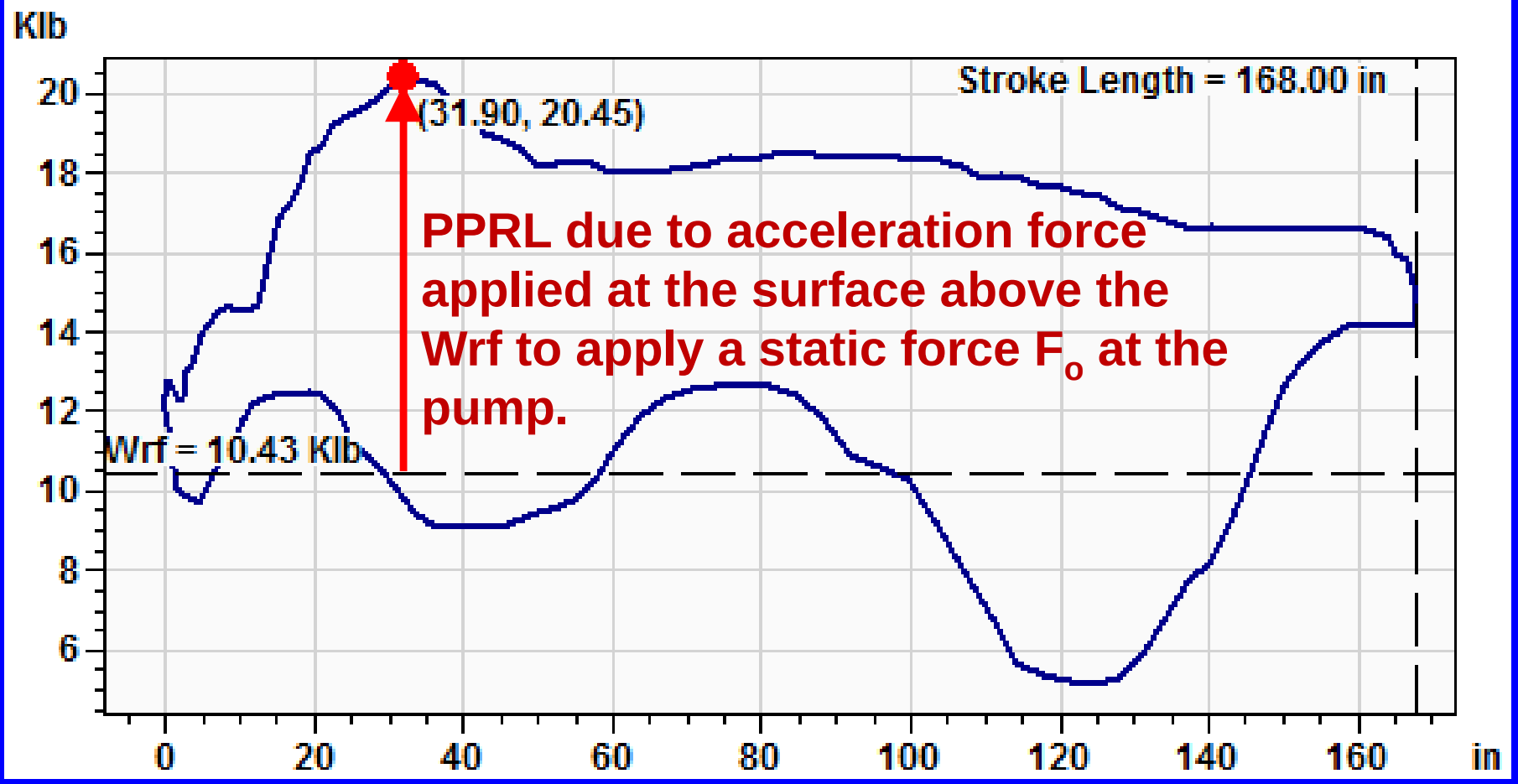
1) The zero load is the starting point.

2) Set the Zero offset during calibration process for no-load conditions on the load cell.



Peak Polished Rod Load, [PPRL]

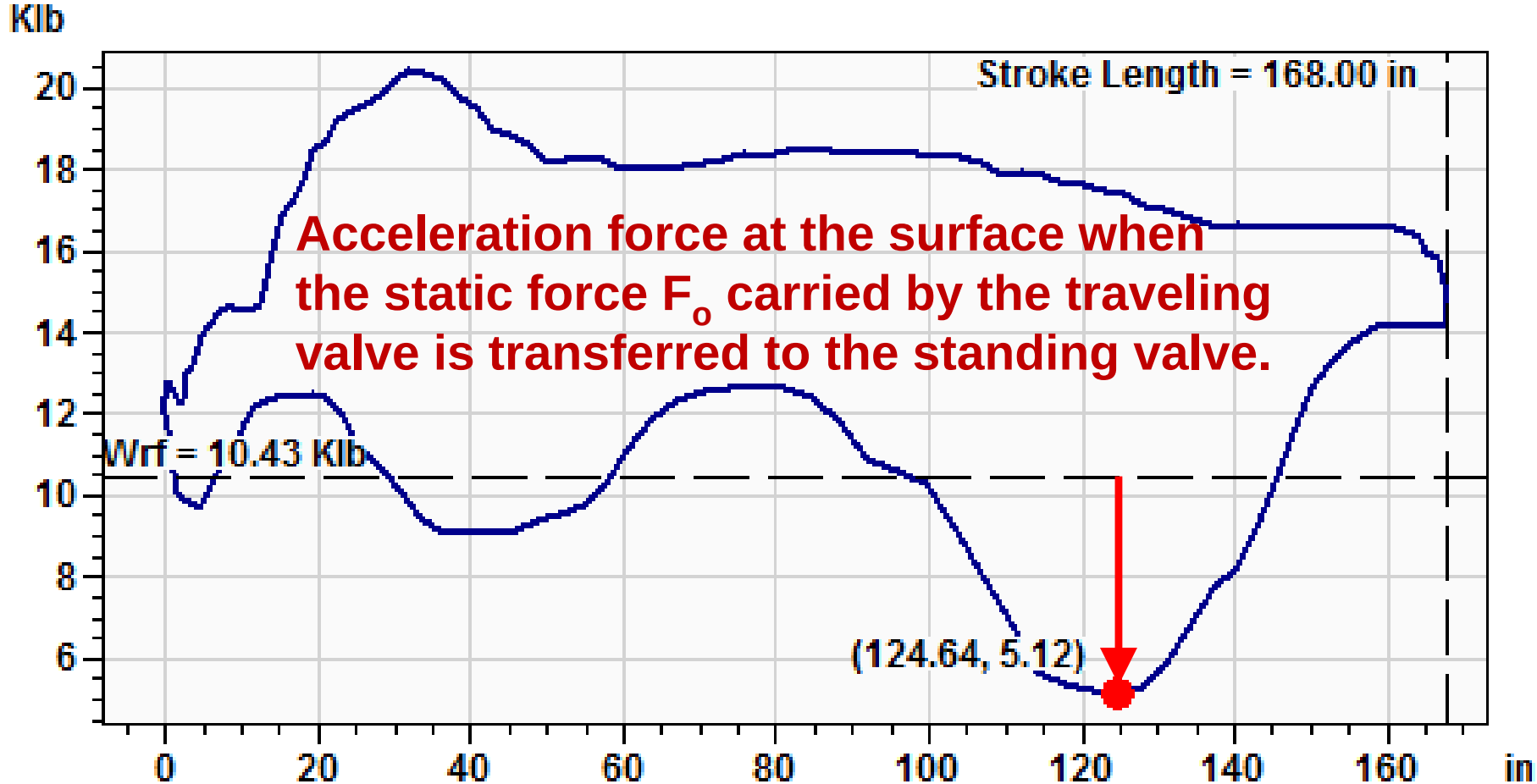
	Peak Load	Min Load	Power
Polished Rod	20.45 Klb	5.12 Klb	21.3 HP
Pump	7.53 Klb	-0.20 Klb	17.5 HP



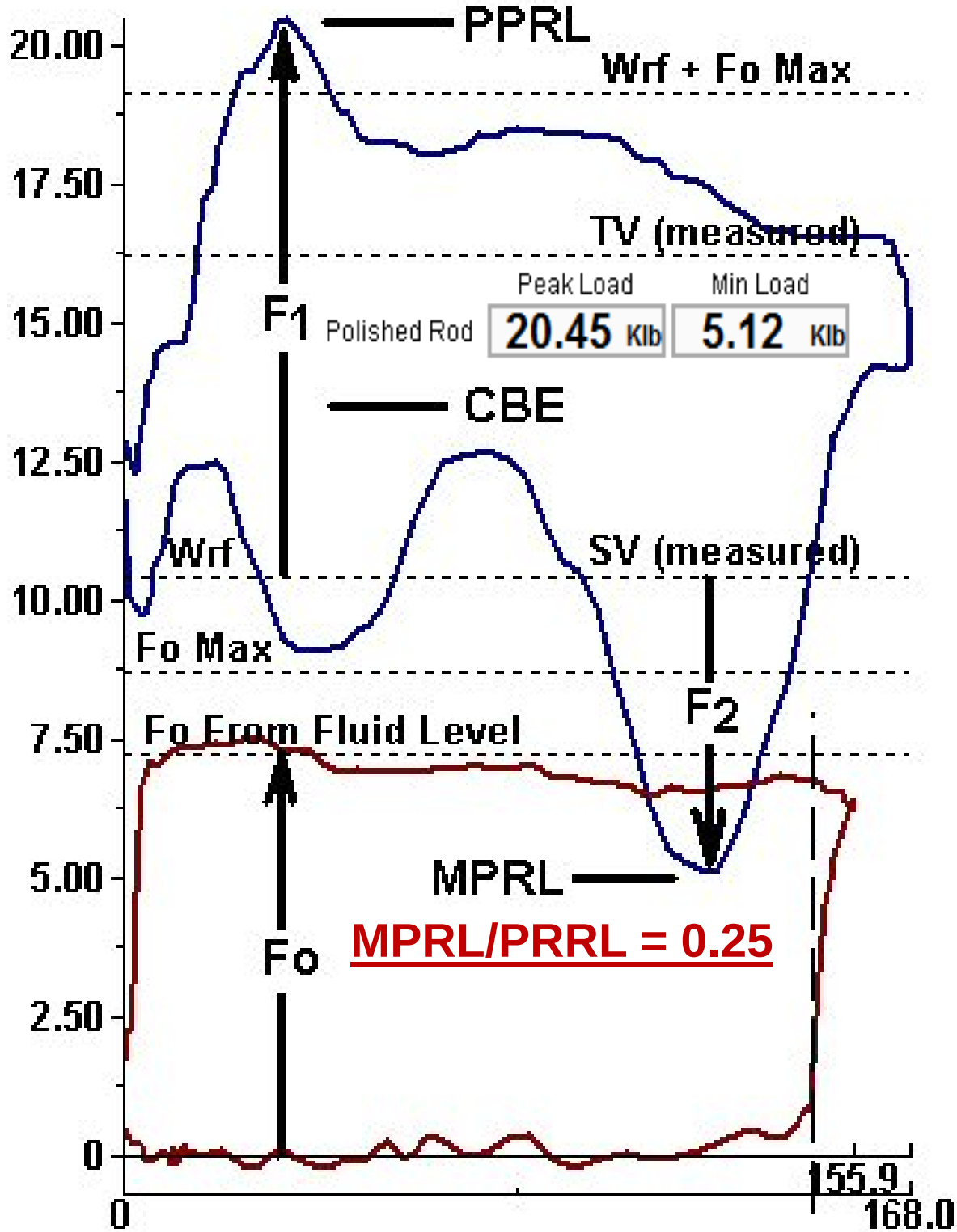
PPRL is the maximum load experienced during the pumping cycle.

Minimum Polished Rod Load, [MPRL]

	Peak Load	Min Load	Power
Polished Rod	20.45 Klb	5.12 Klb	21.3 HP
Pump	7.53 Klb	-0.20 Klb	17.5 HP



Minimum polished rod load is the minimum load experienced during the pumping cycle.



MPRL/PRRL > 0.1 per each 2500'/pump depth

Fo fluid load the pump applies to the rod string.

F1 dynamic force required at the surface to apply a static force Fo at the pump..

F2 dynamic surface force due to transferring the Fo carried by the traveling valve to the standing valve.

Pump Depth = 4836
MPRL/PRRL Limit = 1.9
OK 0.25 > 0.19

Fluid Load, TV & SV Relationships

$$SV = W_{ra} - W_{ra} * 0.128 * SG_{tbg}$$

1) Sanding Valve Load

$$P_{intk} = H_{fl} * 0.433 * SG_{csg} + P_{csg}$$

2) Pump Intake Pressure

$$P_{dis} = Z_{pmp} * SG_{tbg} * 0.433 + P_{tbg}$$

3) Pump Discharge Pressure

$$\Delta P_p = P_{dis} - P_{intk}$$

4) Delta P across the Plunger

$$F_o = \Delta P_p * A_p$$

5) Fluid Load

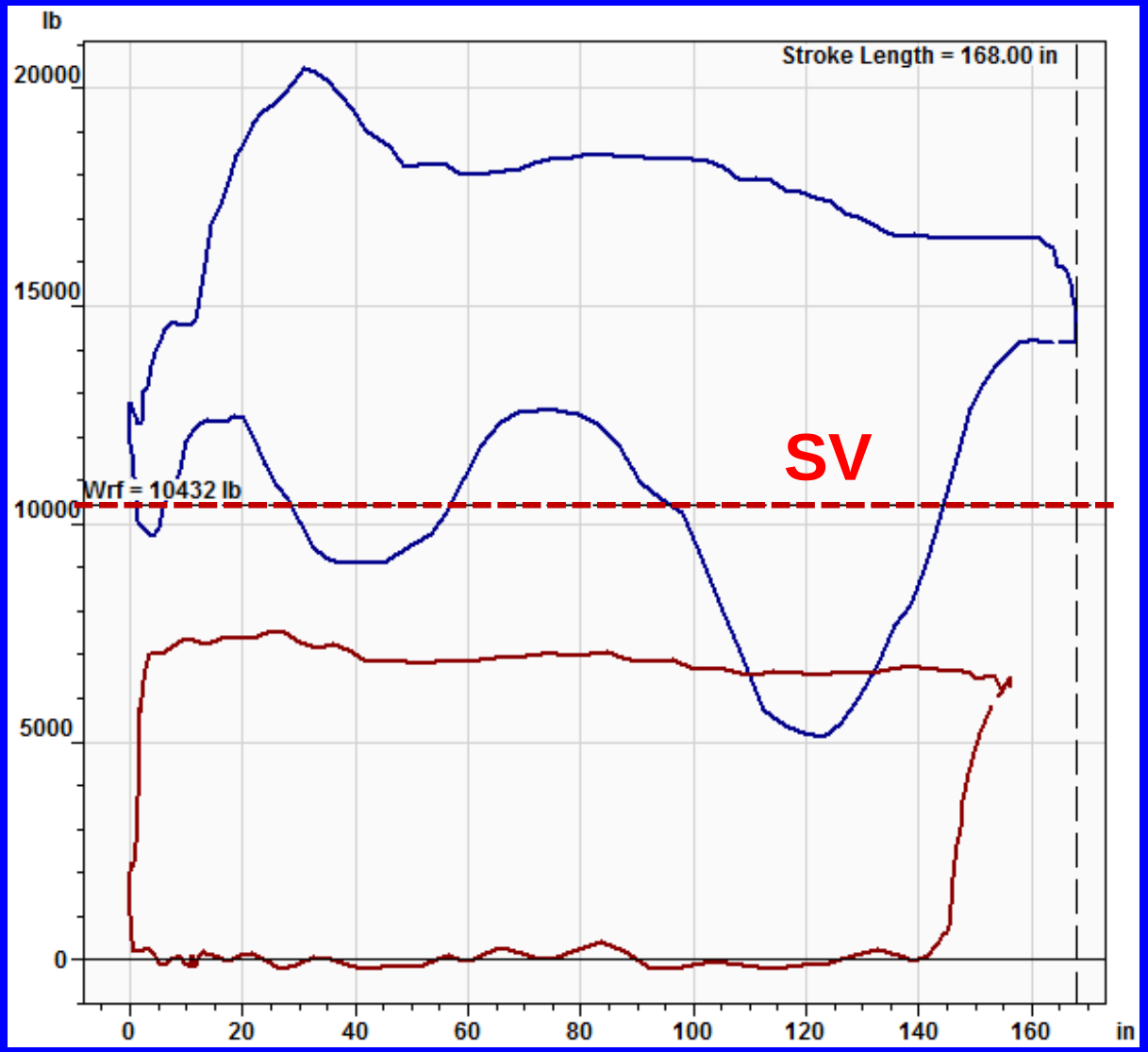
$$TV = W_{ra} - W_{ra} * 0.128 * SG_{tbg} + \Delta P * A_p$$

6) Traveling Valve Load

Standing Valve Load Line, [SV]

$$SV = W_{ra} - W_{ra} * 0.128 * SG_{tbg}$$

1. **Standing Valve Load Check** is generally taken about 0.67 to 0.75 into the down stroke by gently bringing the pumping unit to a stop.
2. **SV Load** is an important load in dynamometer card interpretation.
3. W_{ra} is the weight of the rod string suspended in air.
4. **$- W_{ra} * 0.128 * SG_{tbg}$**, reflects the buoyancy of the tubing fluid on the rod string, and is termed the "buoyancy" force[F_{buoy}].
5. **SV Load = $W_{ra} - W_{ra} * 0.128 * SG_{tbg}$**
6. 0.128 =62.4/487.5

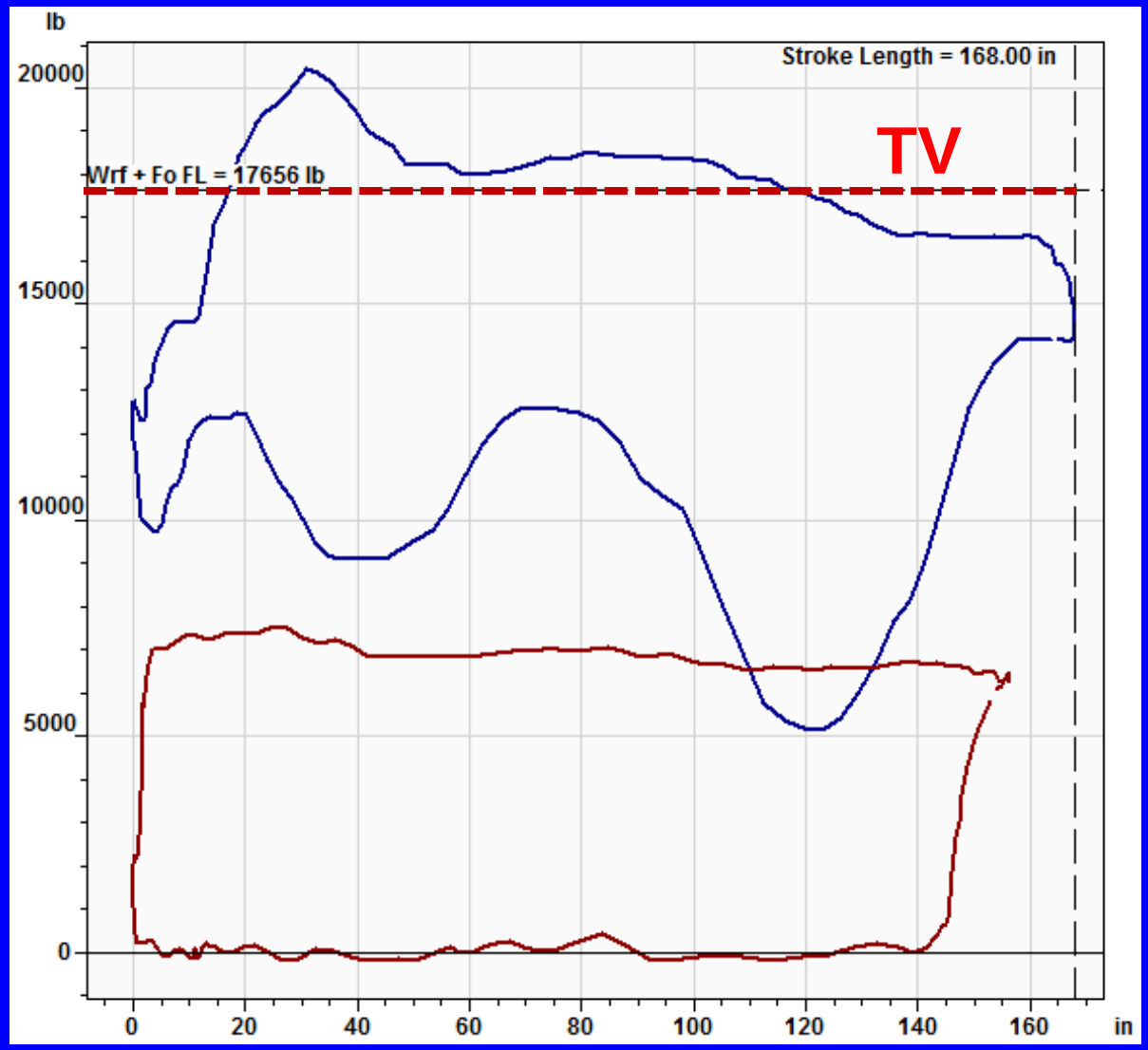


Traveling Valve Load Line

$$TV = W_{ra} - W_{ra} * 0.128 * SG_{tbg} + \Delta P * A_p$$

1) **Traveling Valve Load** is the other important load used in dynamometer card analysis. TV load indicates the condition of the traveling valve, the pump barrel and plunger and the tubing string.

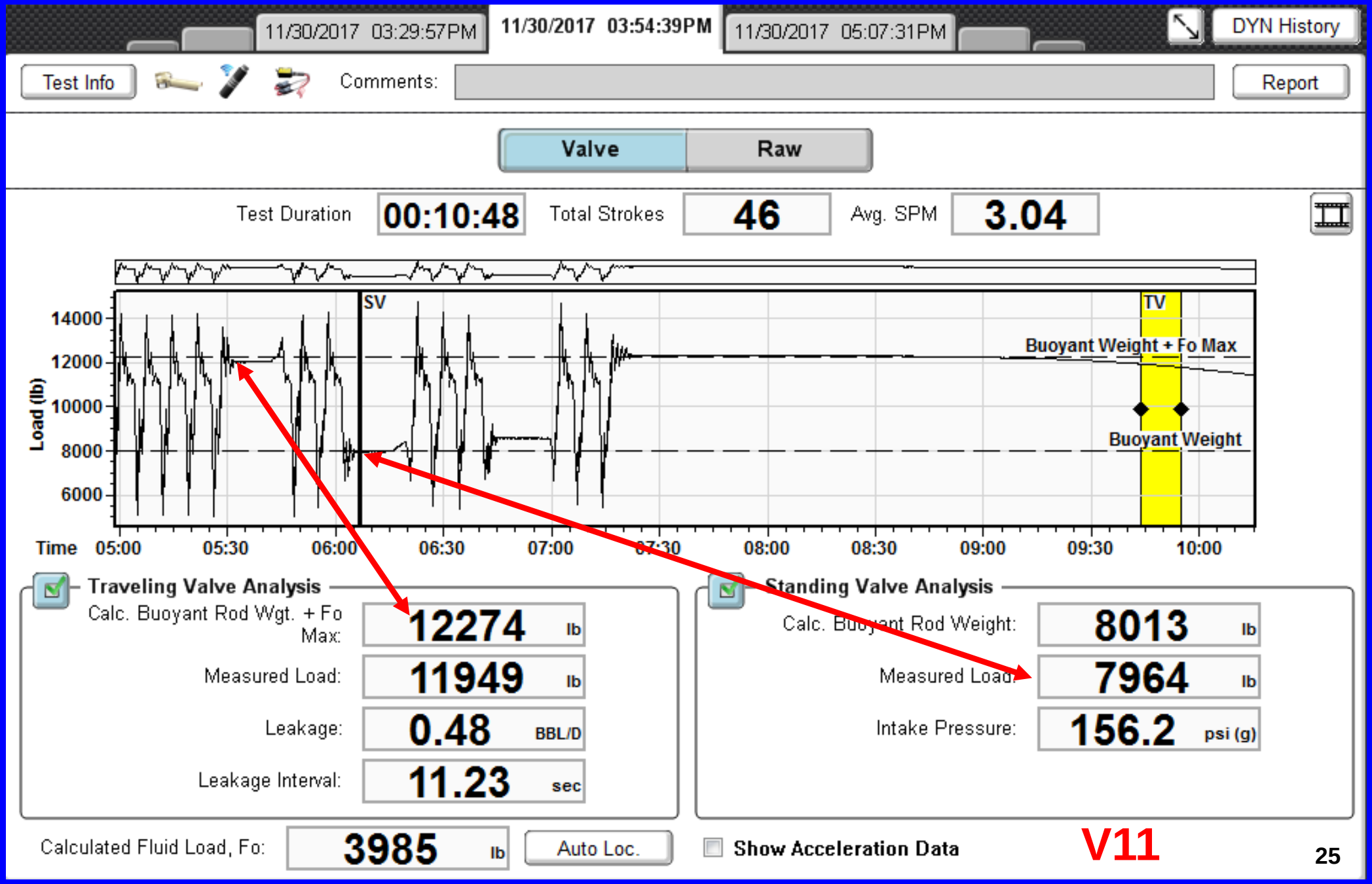
2) $\Delta P_p * A_p$, is the fluid load, F_o, on the cross-sectional area of the plunger [A_p]. ΔP_p is the differential pressure acting on the plunger and is difference between the discharge pressure, [P_{dis}], and the intake pressure, [P_{intk}].



$$\Delta P_p = P_{dis} - P_{intk}$$

$$F_o = \Delta P_p * A_p$$

Measured and Computed Valve Loads

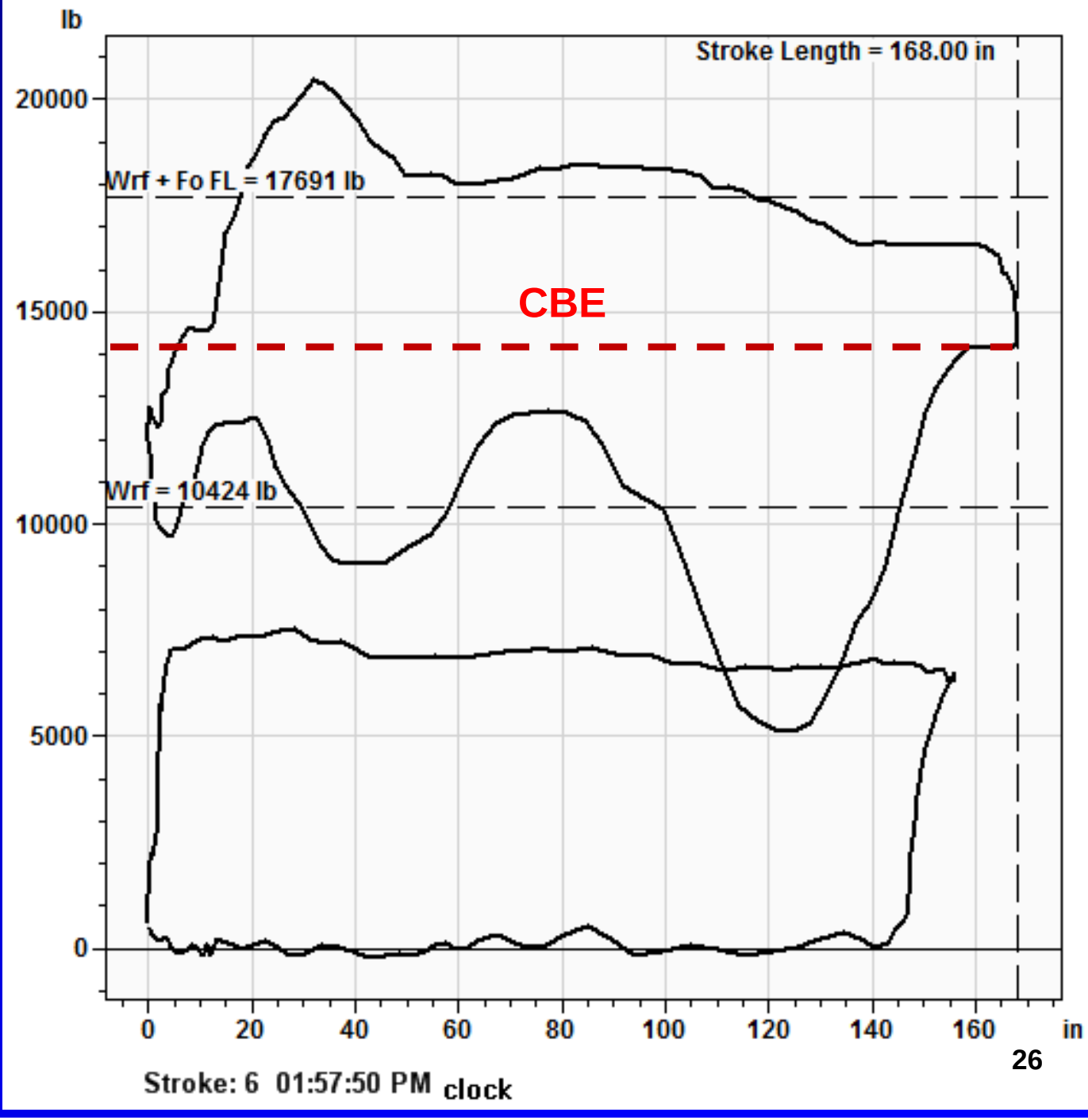


Counterbalance Effect Load Line

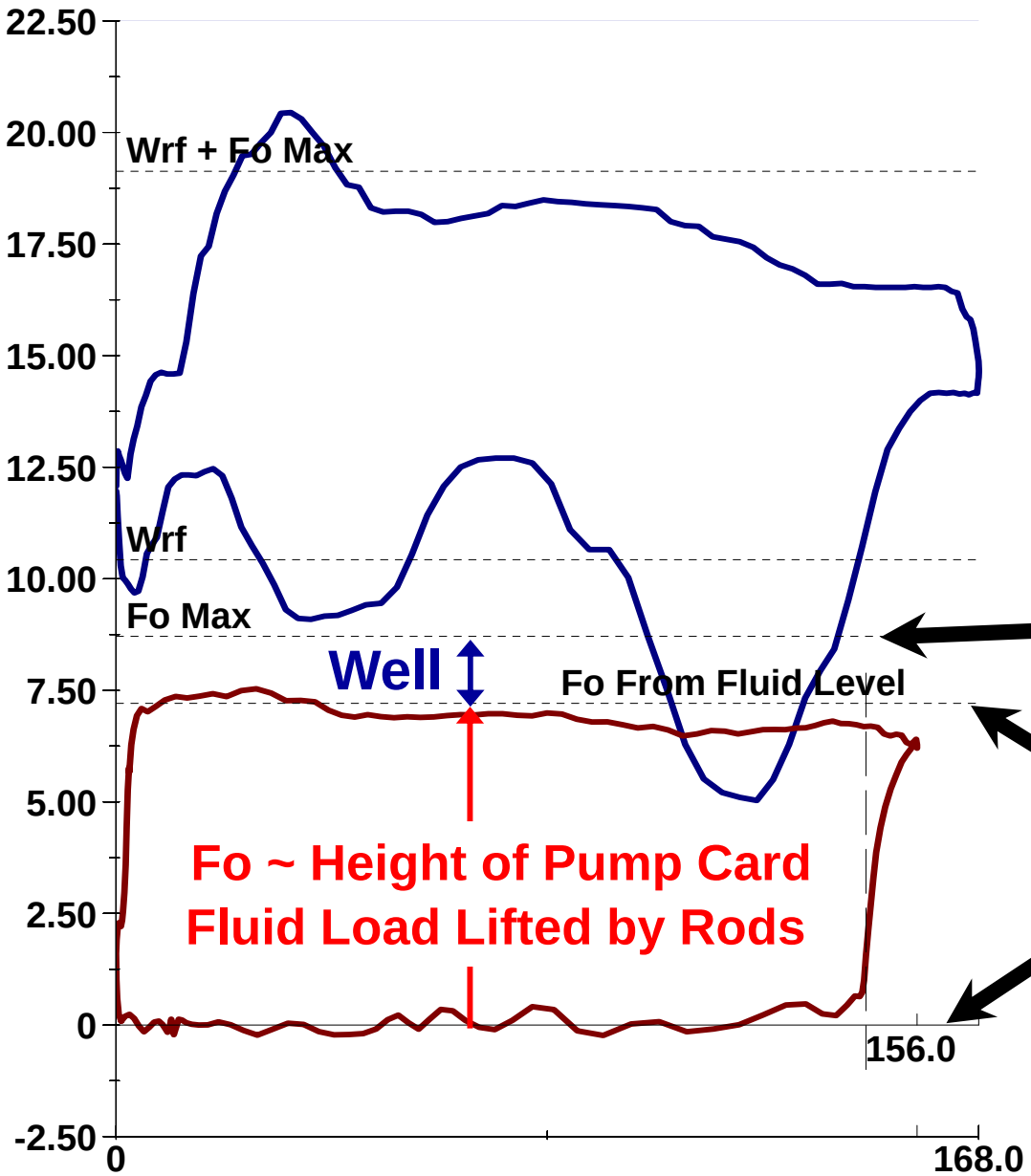
1) Stop pumping unit with the cranks level on the up stroke. Polished rod load approximately equals buoyant rod weight plus the fluid load. Initial load normally exceeds the CBE load. As the liquid load slips past the plunger, the polished rod load will drop. Release the brake when measured rod load = CBE load.

2) API RP-11L defines:

$$CBE = 1.06 * \left(W_{rf} + \frac{F_o}{2} \right)$$



Pump Card Reference: Zero Load Line ~ Down Stroke
Fo From Fluid Level ~ Up Stroke



Normal Pump Card Loads:

SV Open Upstroke:

Fo Max = (Pdis – 0)*Ap

Fo = (Pdis - Pintk)*Ap

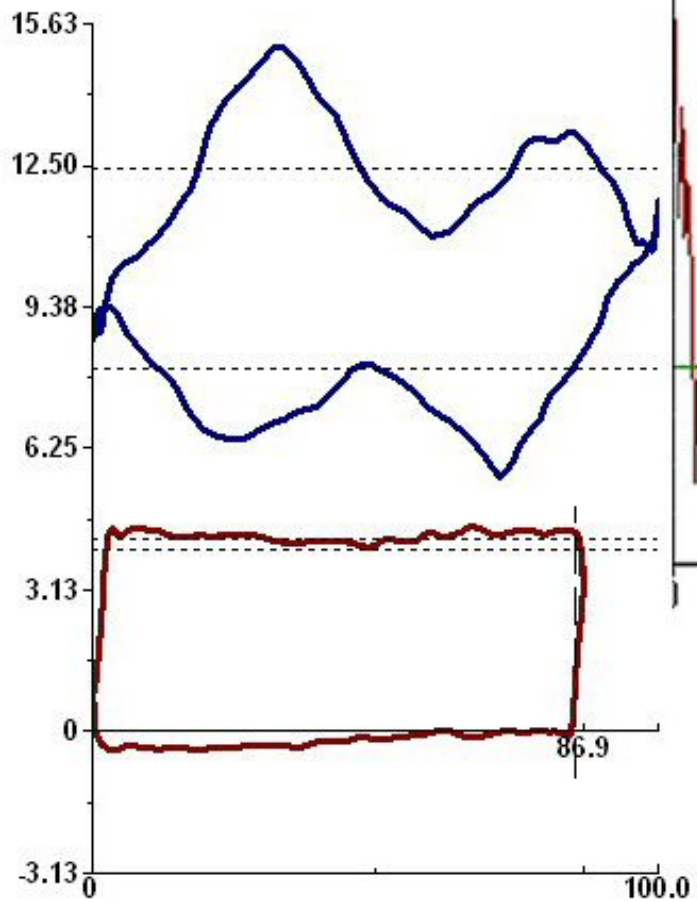
TV Open Downstroke:

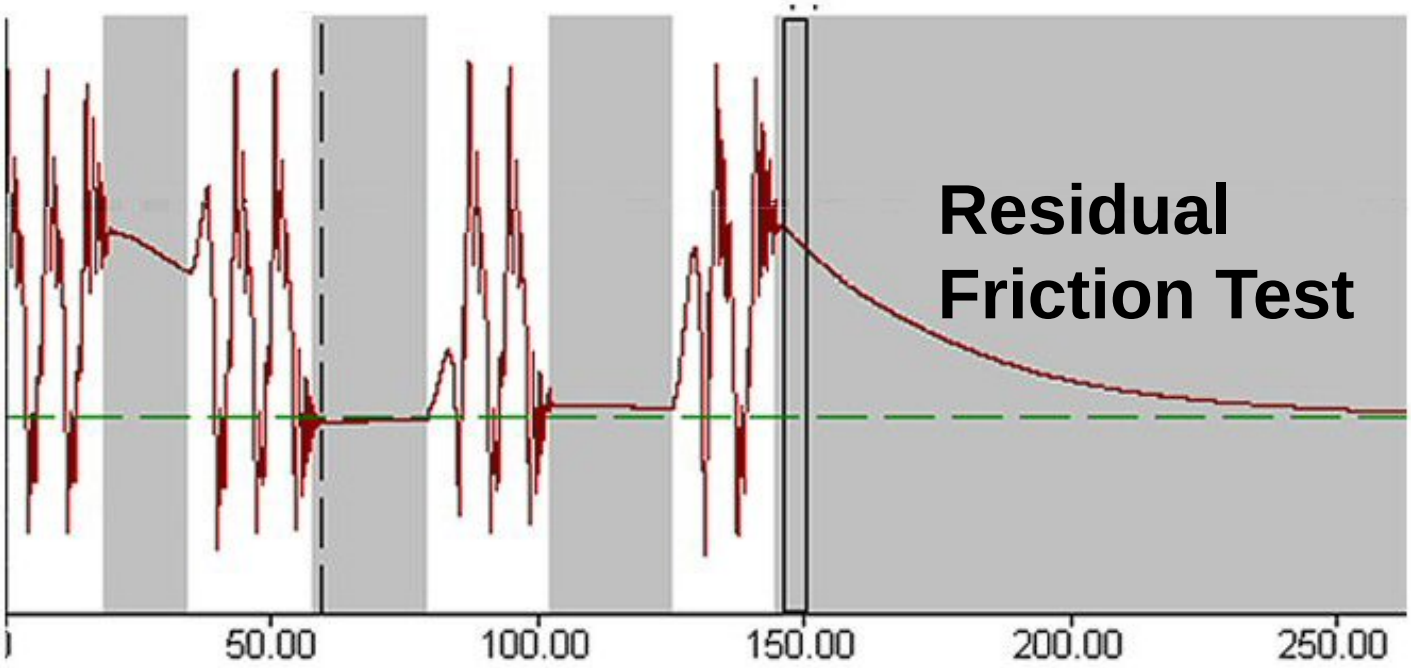
Fo = 0

Reference Lines:

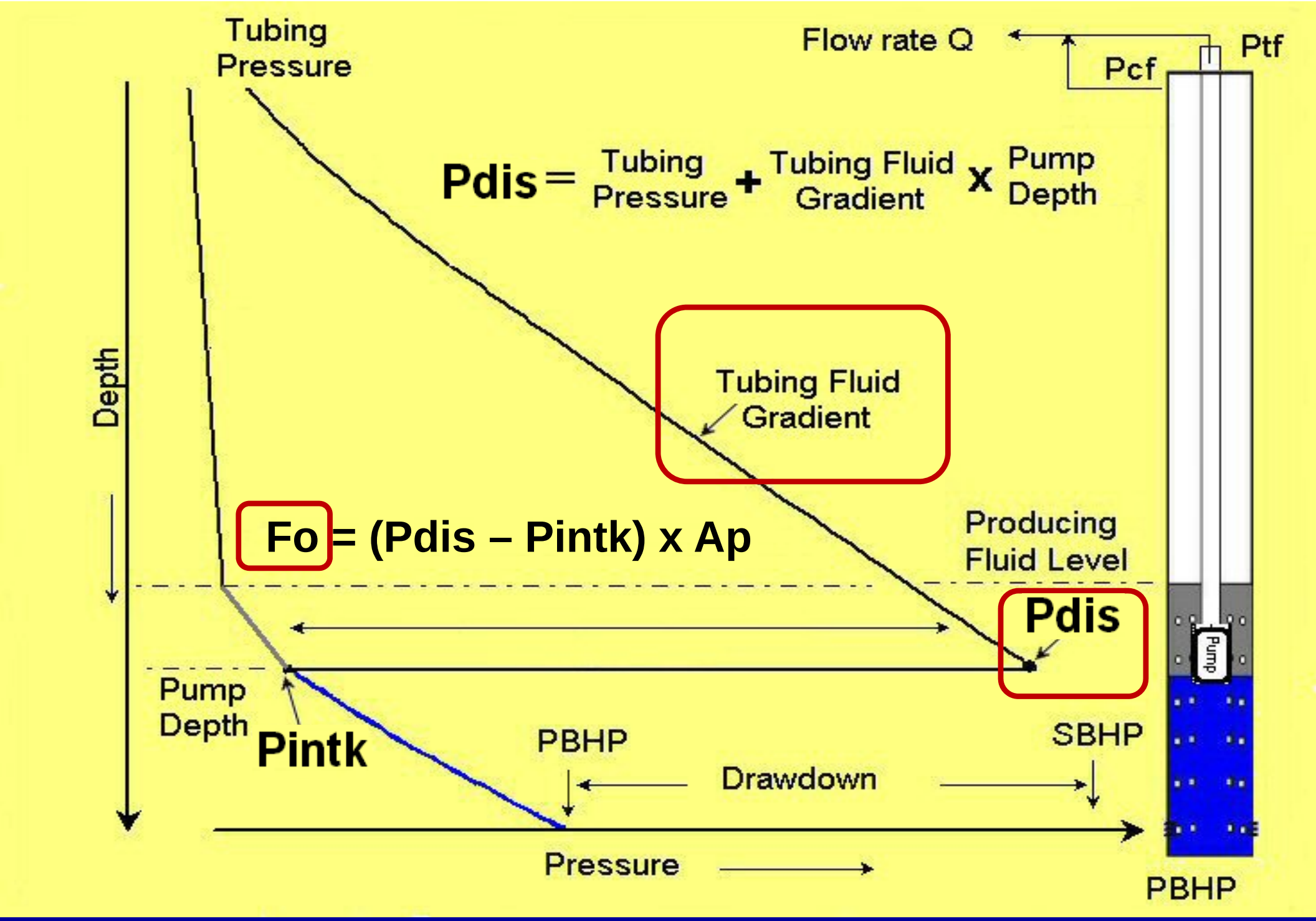
1. ***Fo Max*** **- assumes pump intake pressure is zero, where well provides no help in lifting the fluid to the surface.**
2. ***Fo From Fluid Level*** **- assumes pump intake pressure determined from fluid level shot, where well's PIP provides help in lifting the fluid.**
3. ***Zero Load Line*** **– assumes pressure above and below the plunger are equal; no friction due to fluid displacing through TV on down stroke**

Identify Reference Lines on Surface and Pump Card

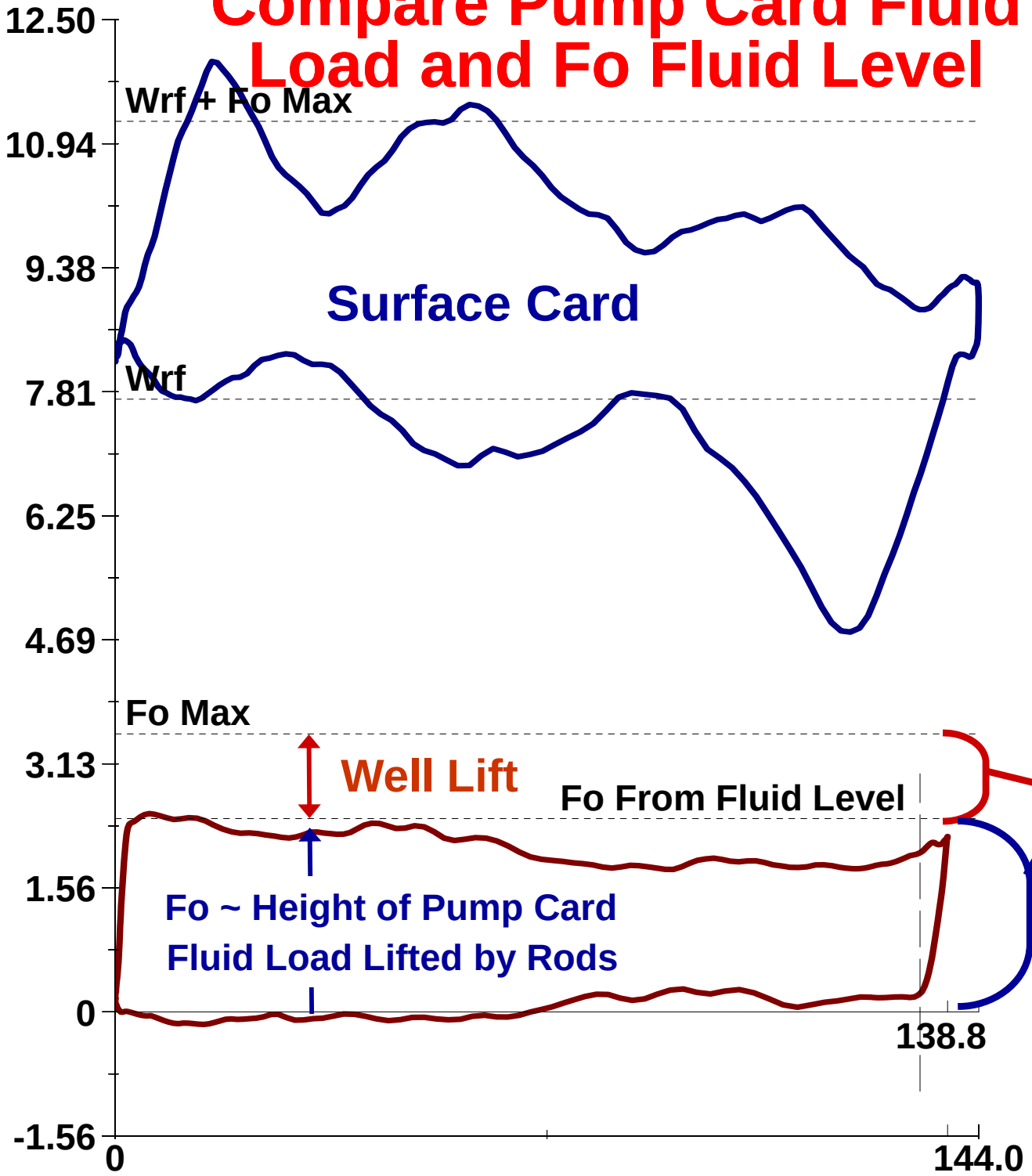


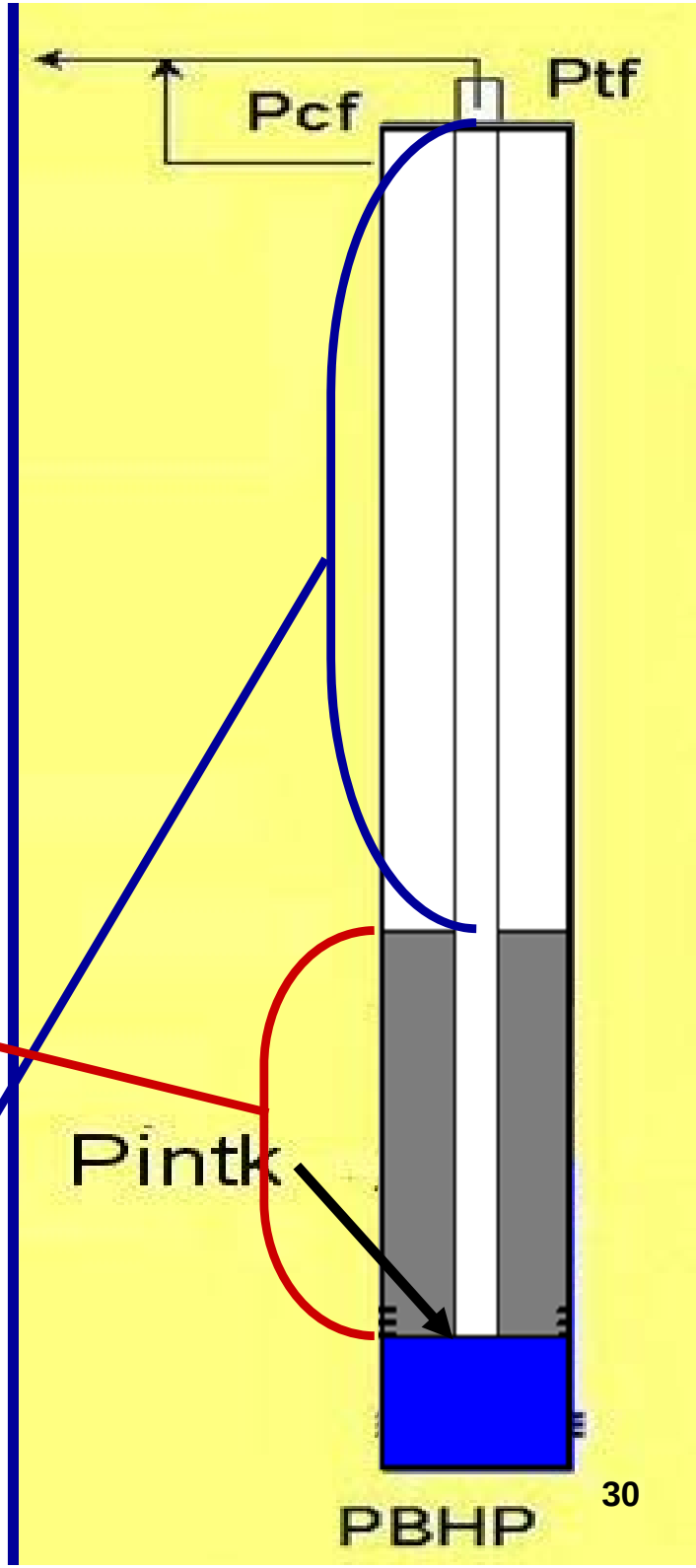


1. Zero Load [0]
2. Peak Polished Rod Load [PPRL]
3. Minimum Polished Rod Load [MPRL]
4. Counterbalance Effect [CBE]
5. Standing Valve Load [SV]
6. Traveling Valve Load [TV]
7. Fo Max
8. Fo From Fluid Level

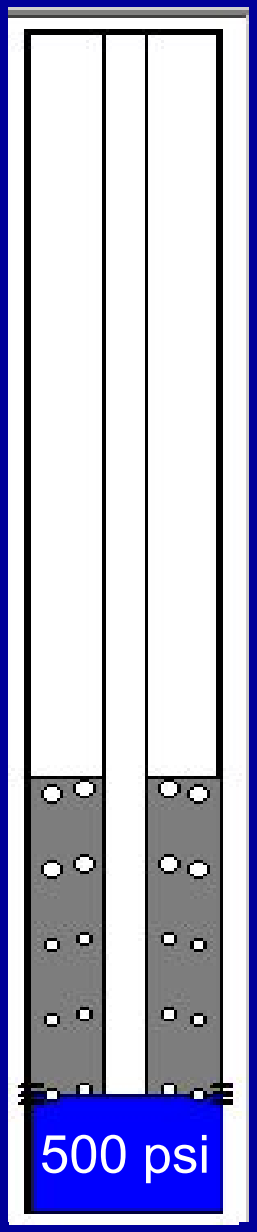

Tubing Pressure
Flow rate Q
Pcf
Ptf
Pdis = Tubing Pressure + Tubing Fluid Gradient x Pump Depth
Depth
Tubing Fluid Gradient
Fo = (Pdis – Pintk) x Ap
Producing Fluid Level
Pdis
Pump
Pump Depth
Pintk
PBHP
SBHP
Drawdown
Pressure
PBHP

Compare Pump Card Fluid Load and Fo Fluid Level





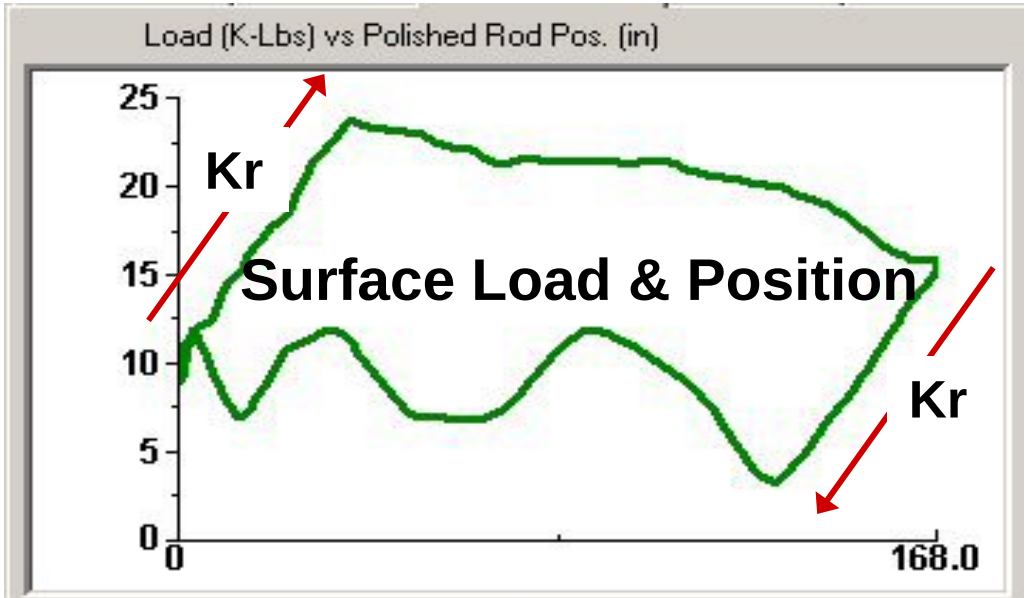
Fluid Load, Fo, Decreases as Pump Intake Pressure, Pintk, Increases

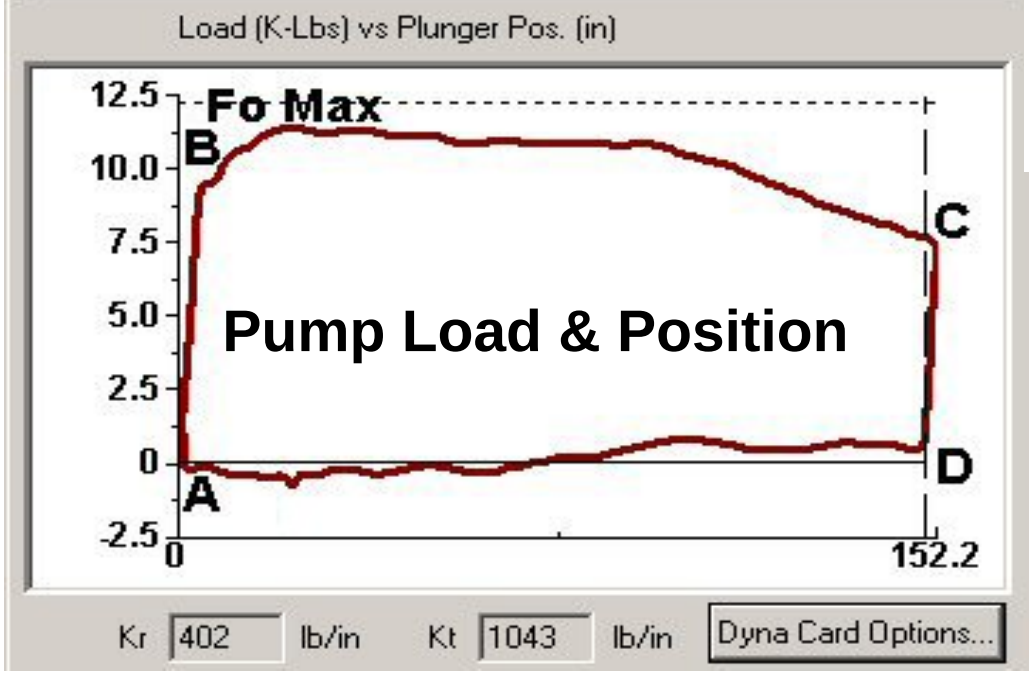


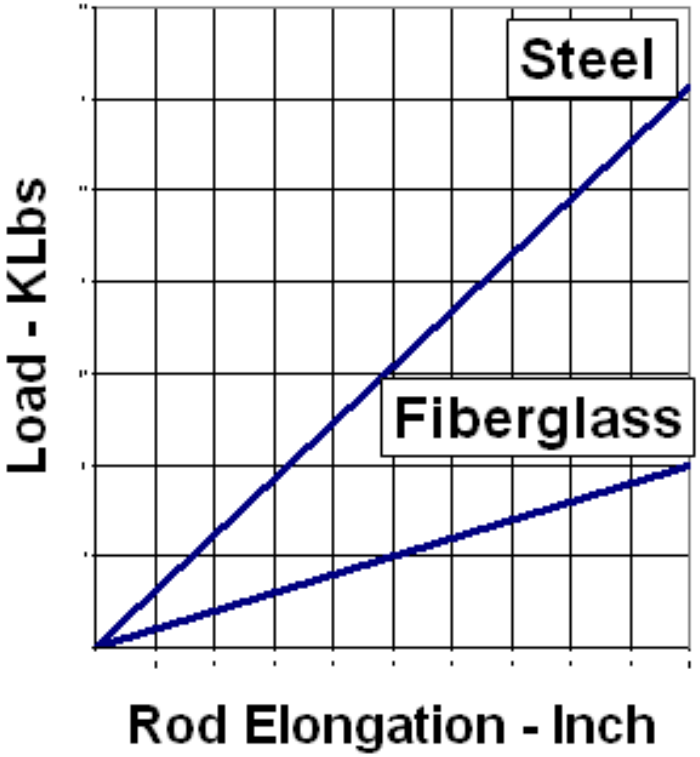
PPRL	15,617	psi	MPRL	6,575.9	lb	Fo	5,482.1	lb
Pump Stroke Length	80.72	in	Static Stretch	21.56	in	Overtravel	2.28	in
Fo/Skr	0.216		Kr	254	lb/in	Kt	894	lb/in

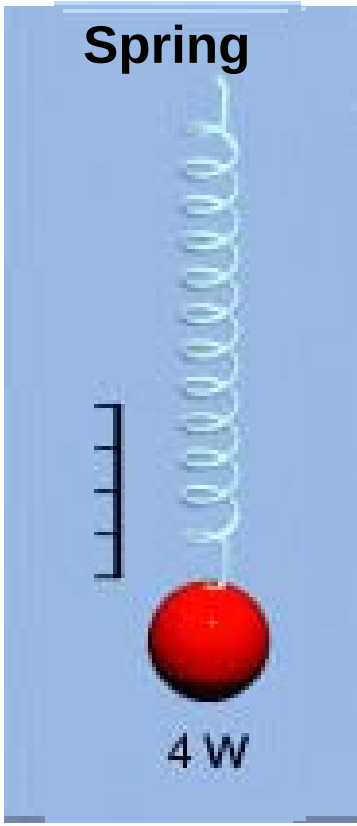
Anchored Tubing – Pump Does Not Move

Until Rods Elastically Stretch to Pick Up Fluid Load





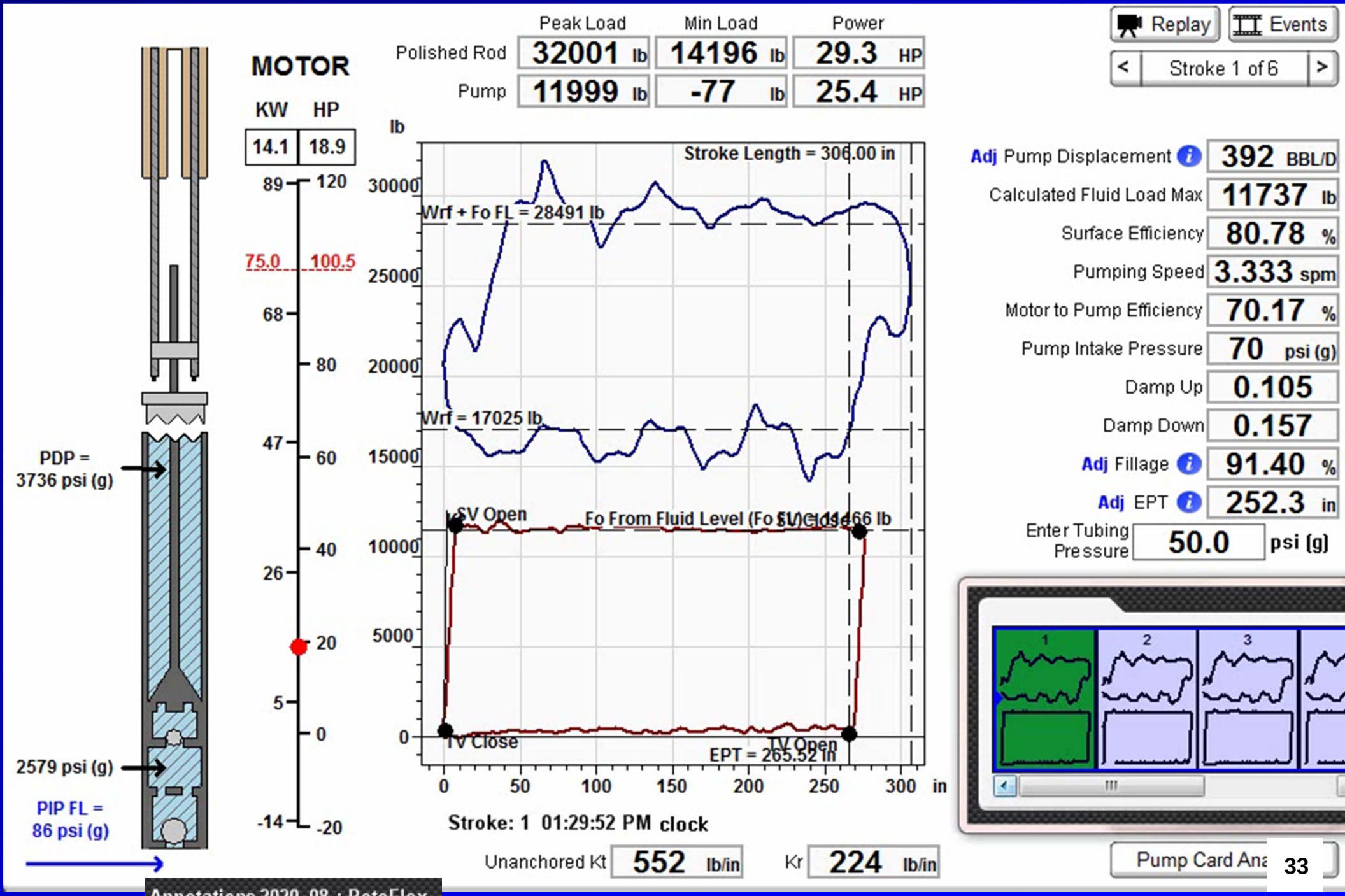




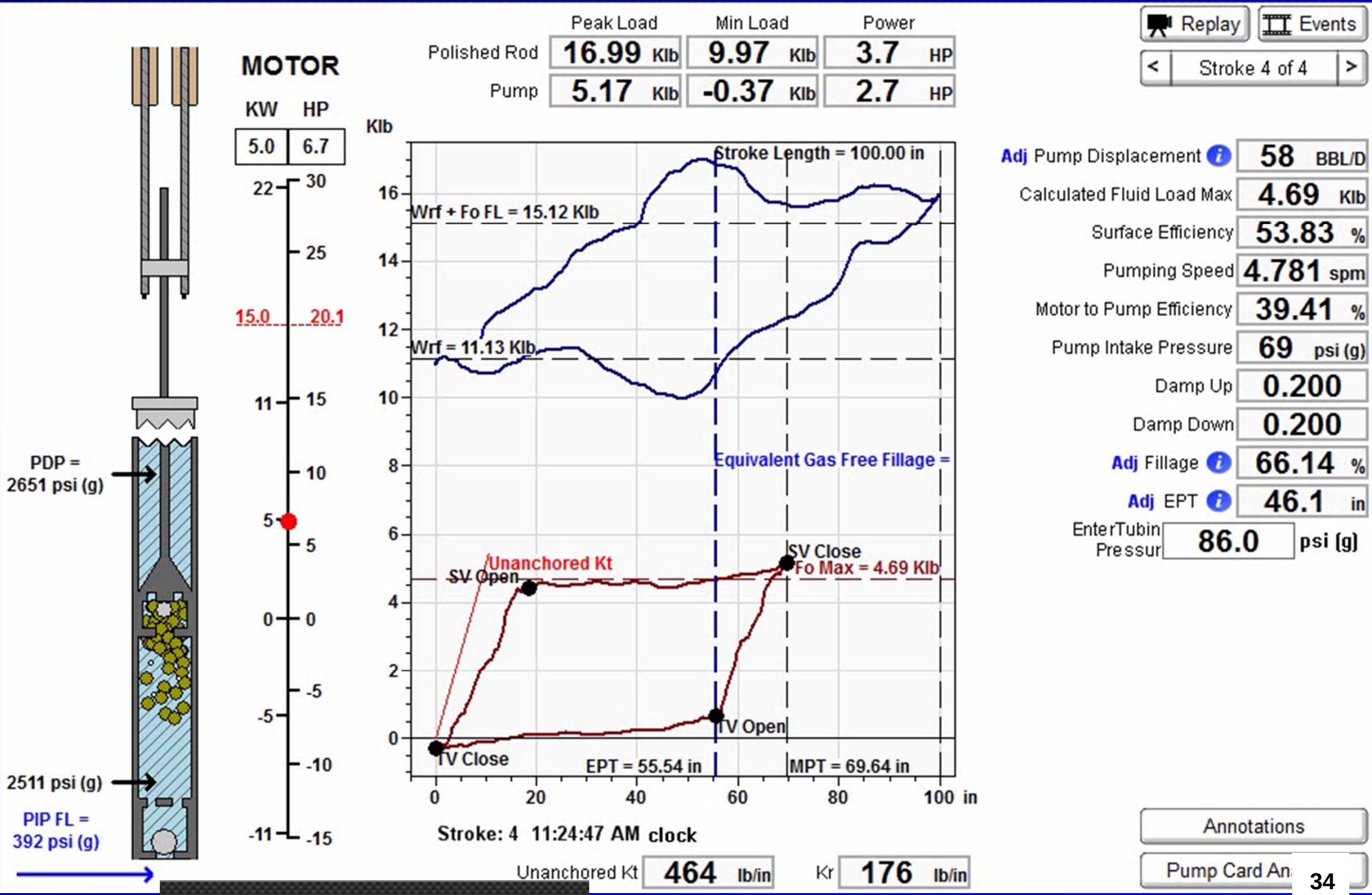
Rod Stretch = S x Fo/SKr

Rods Elastically Stretch to Pick Up Fo from A-B & Un-stretch to Release Fo from C-D

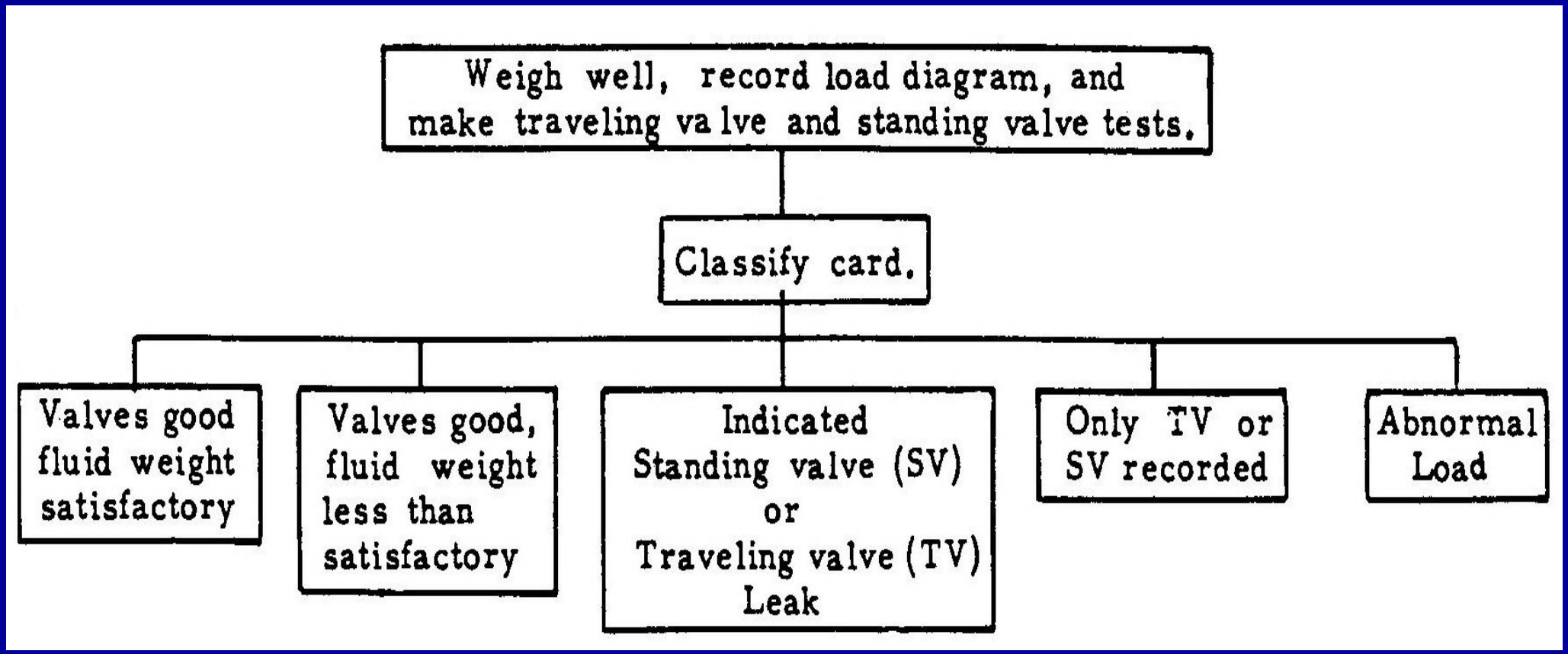
Anchored Tubing – Full Pump



Unanchored Tubing – Full Pump

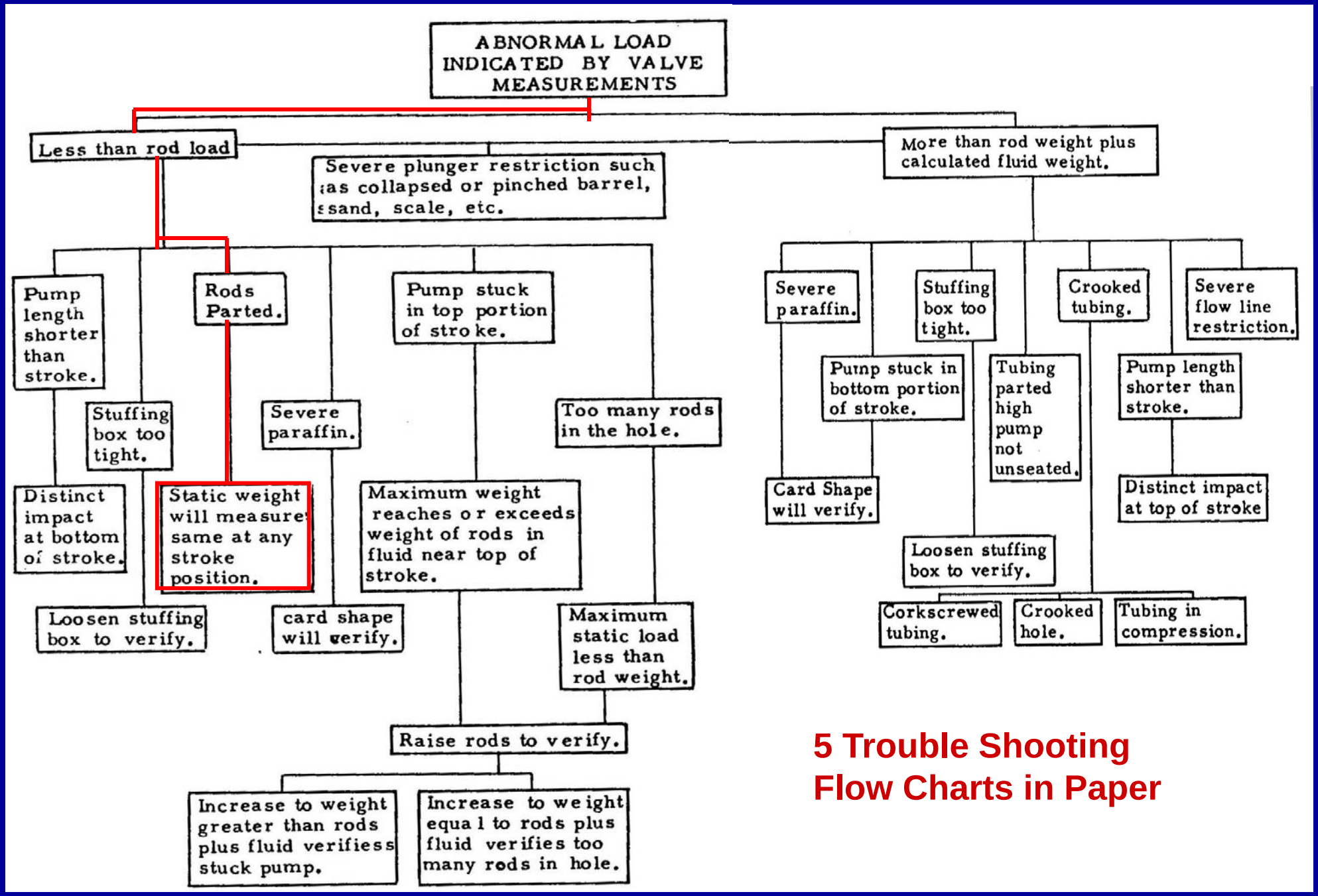


Dynamometer Testing for Trouble Shooting the Pumping Well Problem



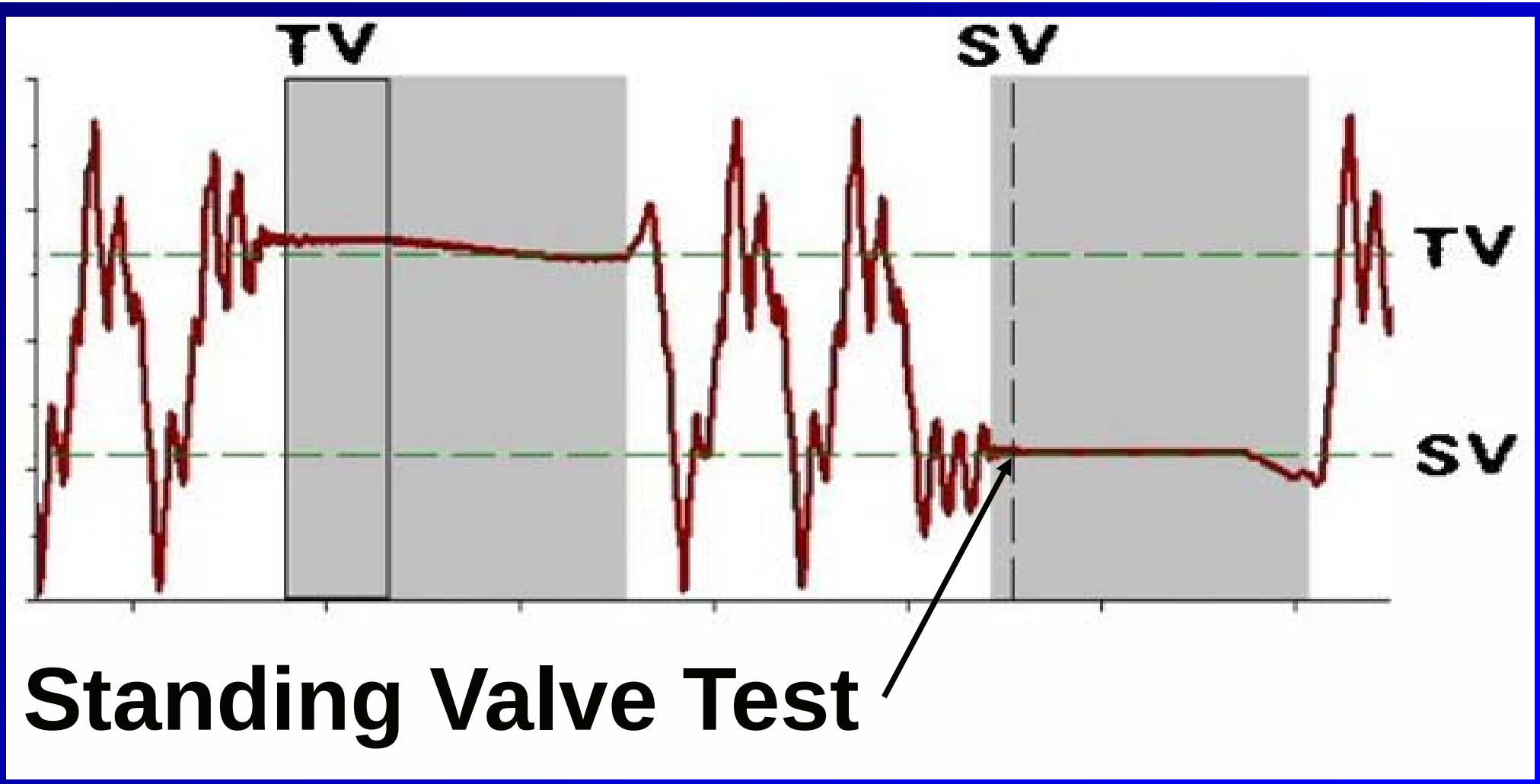
From "Dynamometer Testing for Analyzing the Pumping Well Problem",

By C. J. MERRYMAN & D. K. LAWRENCE, SWPSC 1958

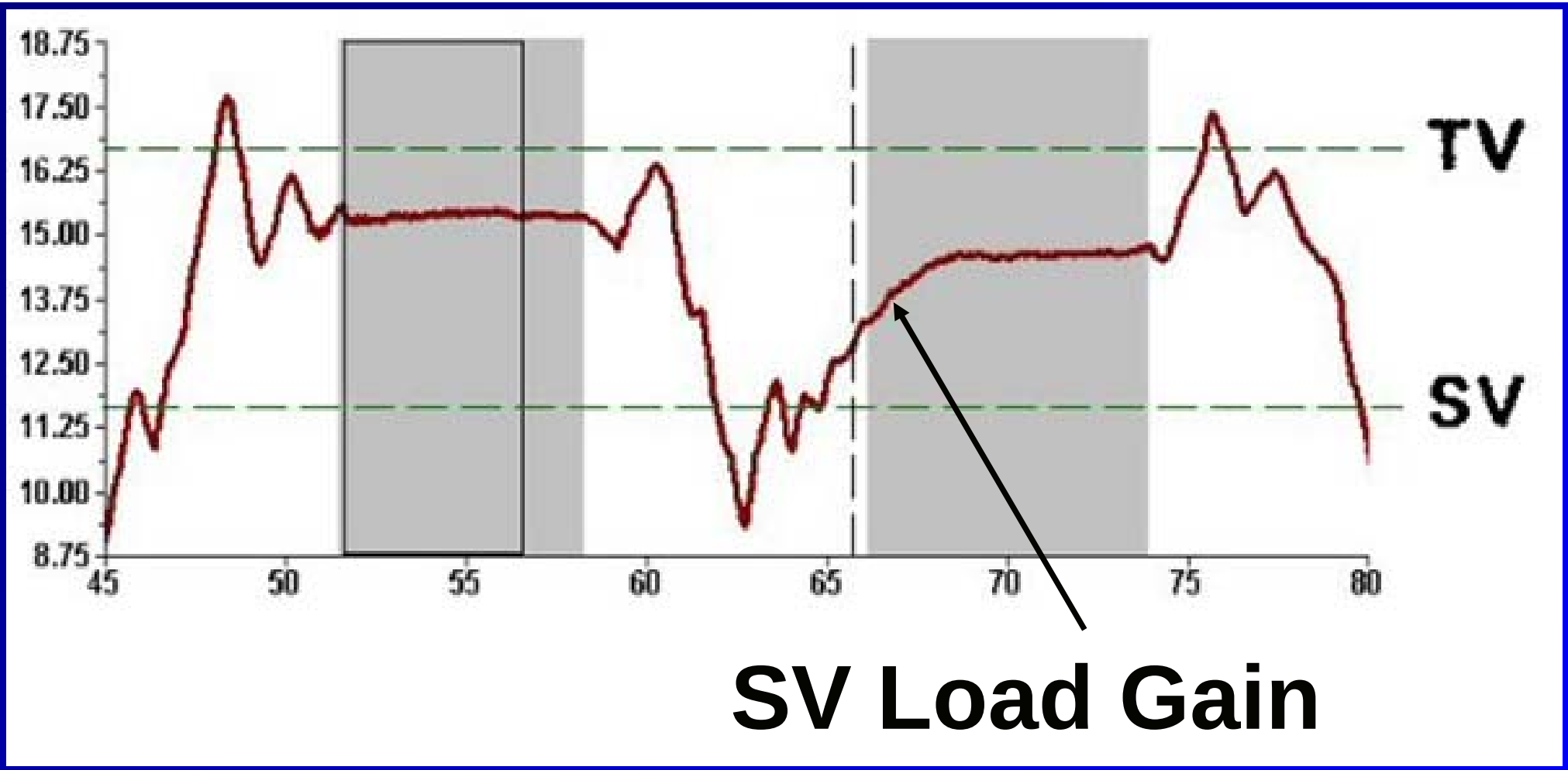


5 Trouble Shooting Flow Charts in Paper

From "Dynamometer Testing for Analyzing the Pumping Well Problem", By C. J. MERRYMAN & D. K. LAWRENCE, SWPSC 1958

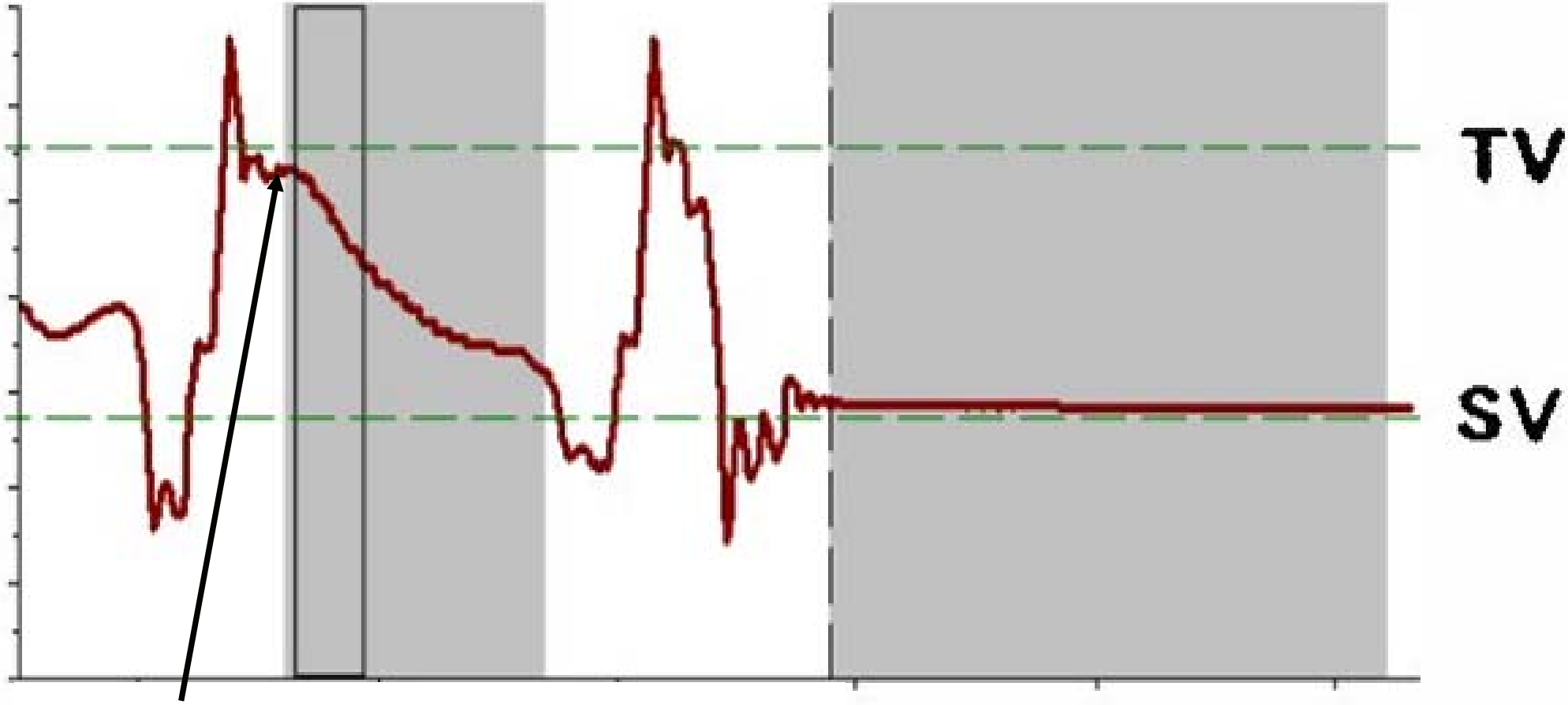


<u>Standing Valve Load Test</u> (above) is a representative and correctly taken standing valve test load. This load trace is located at the standing (SV) load line and is sometimes called Wrf. The term "standing valve test" is a misnomer, no differential pressure acting across the traveling valve results in no load acting on the sucker rod string in well fluid when the standing valve is not leaking. Usually will be a flat line with no weight gain unless the standing valve is leaking, or there is leakage from the pump or tubing.



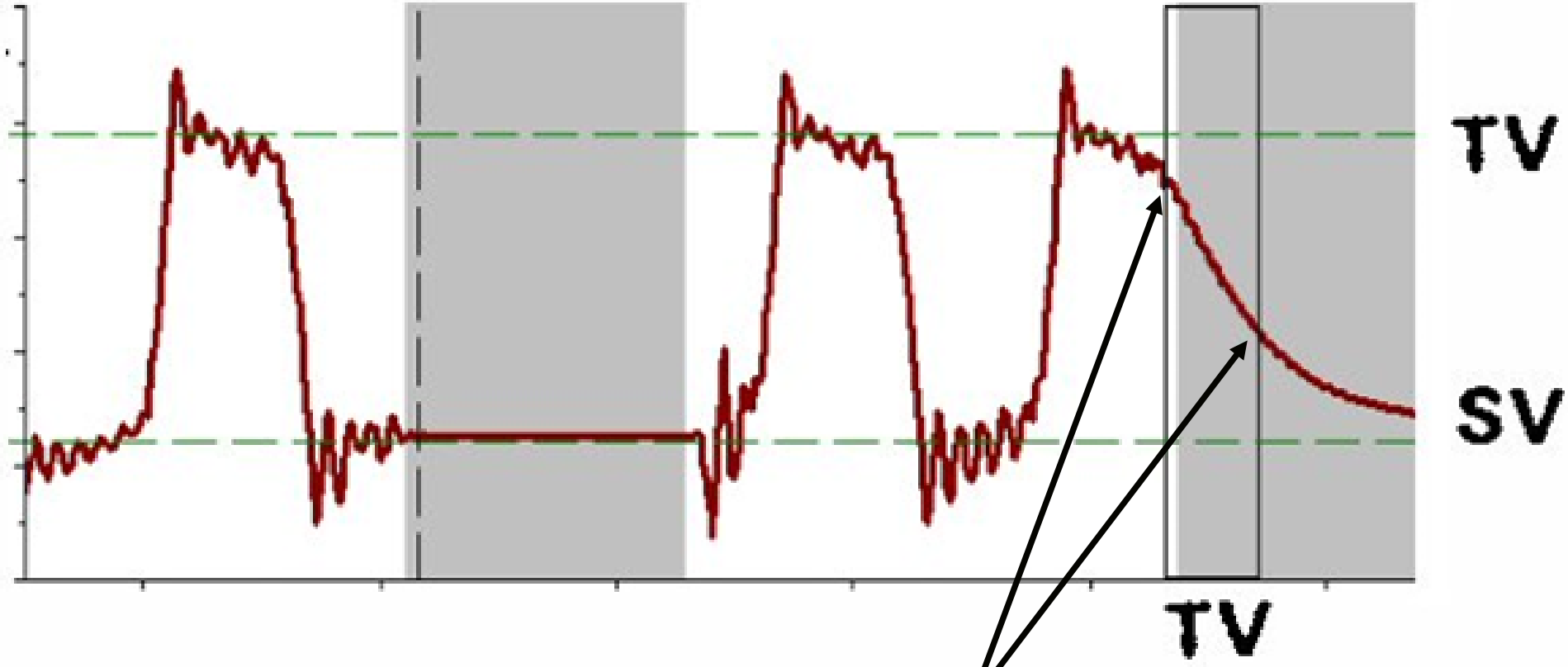
Standing Valve Load Test Gain (above) reflects a load gain during the standing valve test. There are other causes, but this weight gain is usually associated with a leaky standing valve due to leakage of tubing pressure past the SV into the wellbore. The leak can be of sufficient magnitude to cause the standing valve test load to gain weight until the trace is at the traveling valve test load.

NOTE: SV test should never have a weight loss.



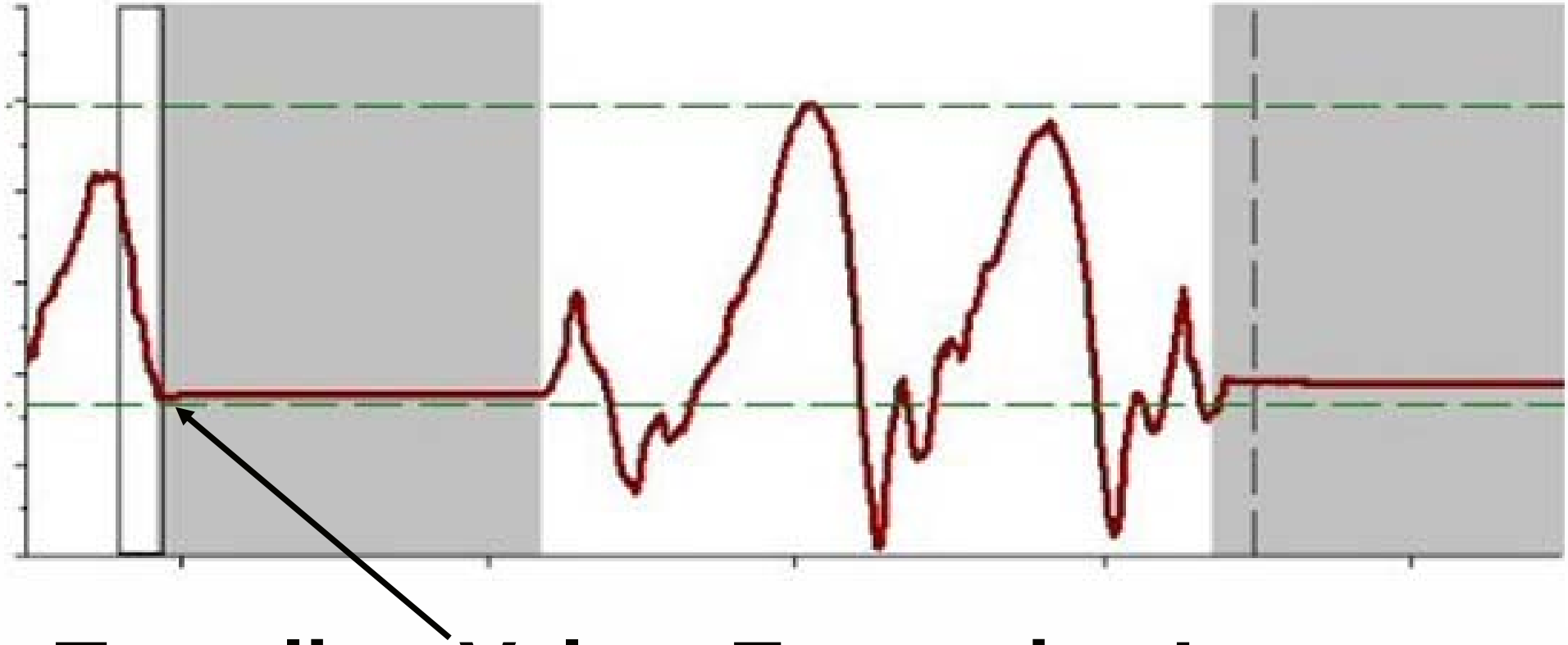
Traveling Valve Test

<u>Traveling Valve Load Test</u> shows a load loss during the traveling valve test. There are other causes, but this weight loss is usually associated with a leaky traveling valve or slippage of fluid through the pump clearances (0.006” above) between the pump plunger and the pump barrel. This load must be taken as the pumping unit is stopped on the upstroke. After the pumping unit has stopped, the uppermost trace should be approximately the pre-calculated TV test load.



Traveling Valve Load Loss

<u>Traveling Valve Test Load Loss</u> (above 0.009”) reflects a rapid weight loss during the traveling valve test. This could be caused by a leaky traveling valve, or the diametric clearances between the pump plunger and the pump barrel, or both. On the other hand this is to be expected if the pump clearance between the pump plunger and barrel is large. When the weight loss is of sufficient magnitude, the load trace can progress until it is at the standing valve test load line.



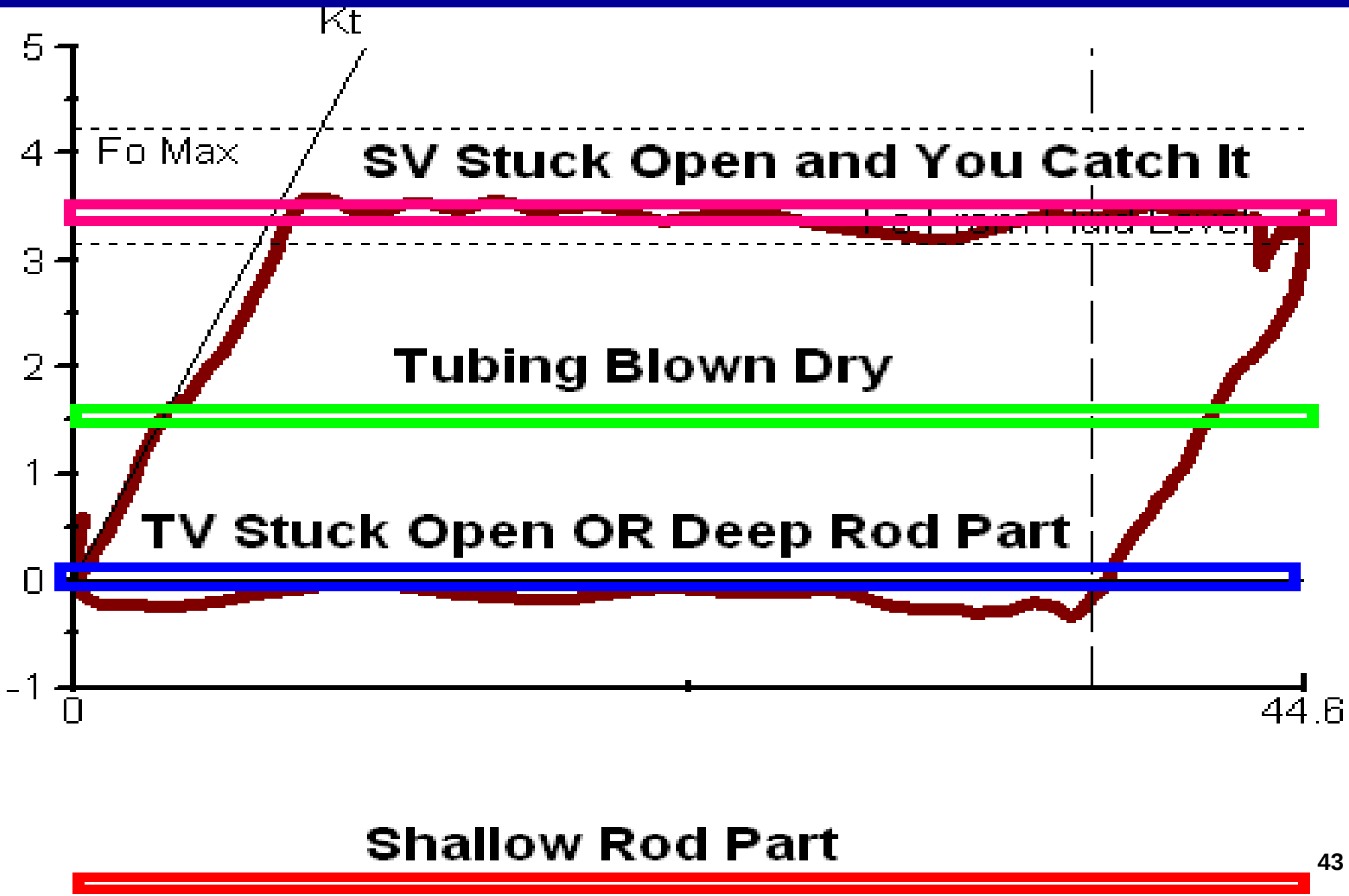
Traveling Valve Excessive Loss

<u>Traveling Valve Test Load Loss</u> represents the weight loss trace for an exceptionally high pump clearance pump or a leaky pump/plunger/traveling valve assembly. The loss quickly progresses until the load is at the standing valve test line. In this example (above) the worn pump cannot pickup the Fluid Load on the upstroke.

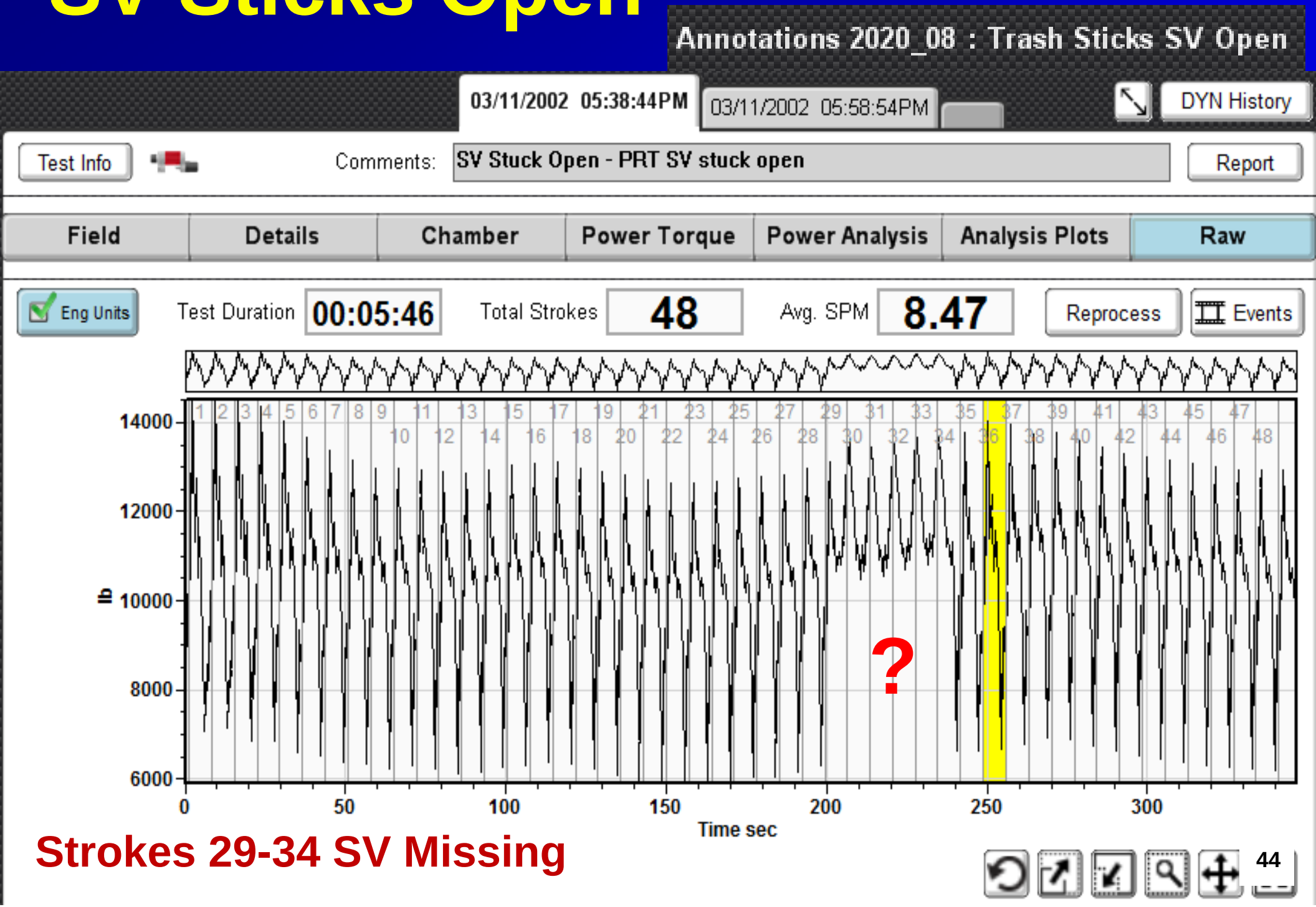
Flat Pump Card Load Lines

1) <u>TV Stuck Open</u> - Looks like Deep Rod Part but you can often tag or jar the rods and knock the debris out of the pump and re-start pump action.
2) <u>Deep Rod Part</u> – Plots on the Zero Load Line
3) <u>Shallow Rod Part</u> – Plots below the Zero Load Line by the amount of missing rod weight in fluid no longer attached to the polished rod.
4) <u>Tubing Blown Dry</u> – Plots as a flat line @ a height of Wra-Wrf pounds above the zero load line.
5) <u>SV Stuck Open</u> – Plots on the Fo from the Fluid Level line.

Horse Shoe Pump Card
Flat Load Lines

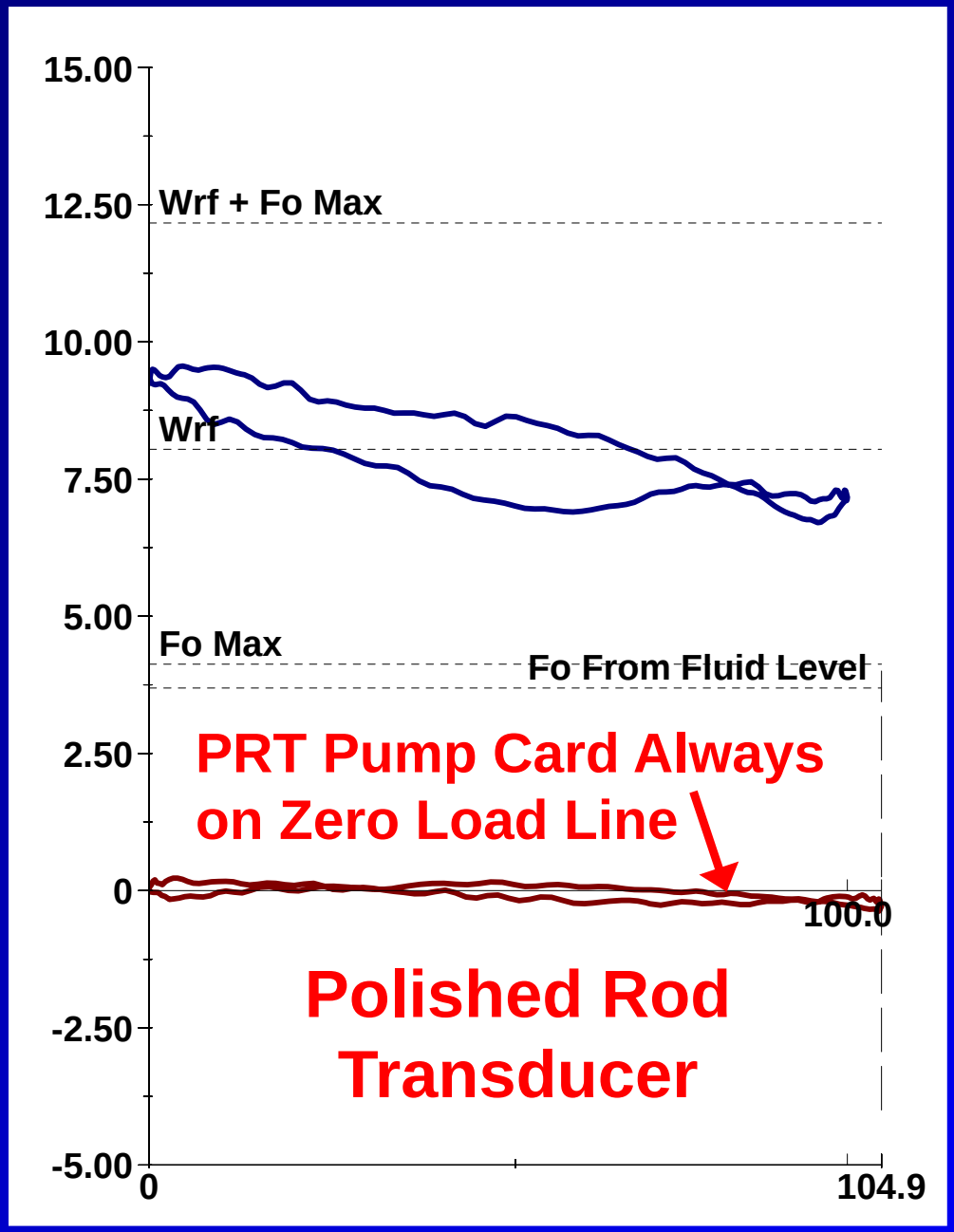


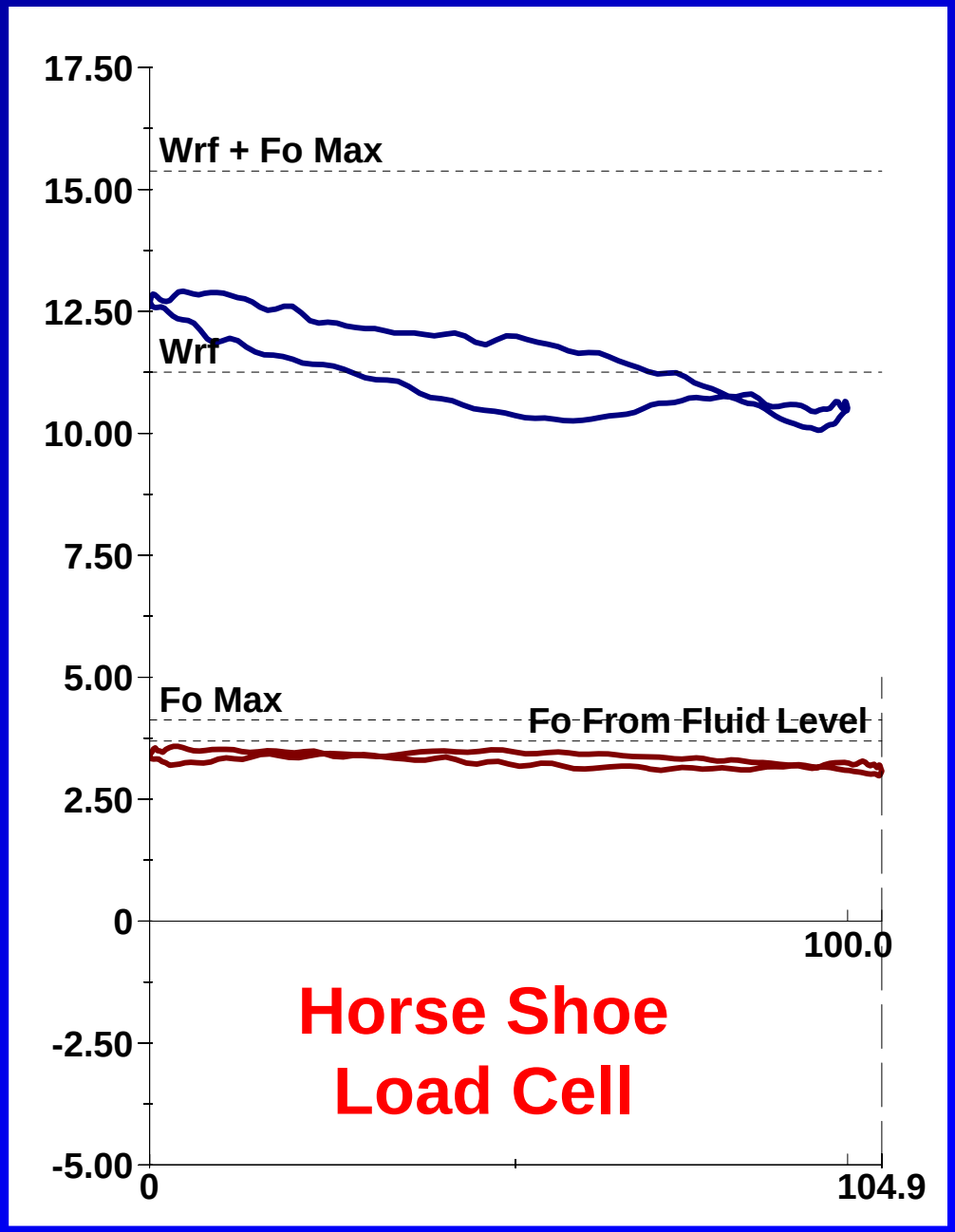
SV Sticks Open



Strokes 29-34 SV Missing

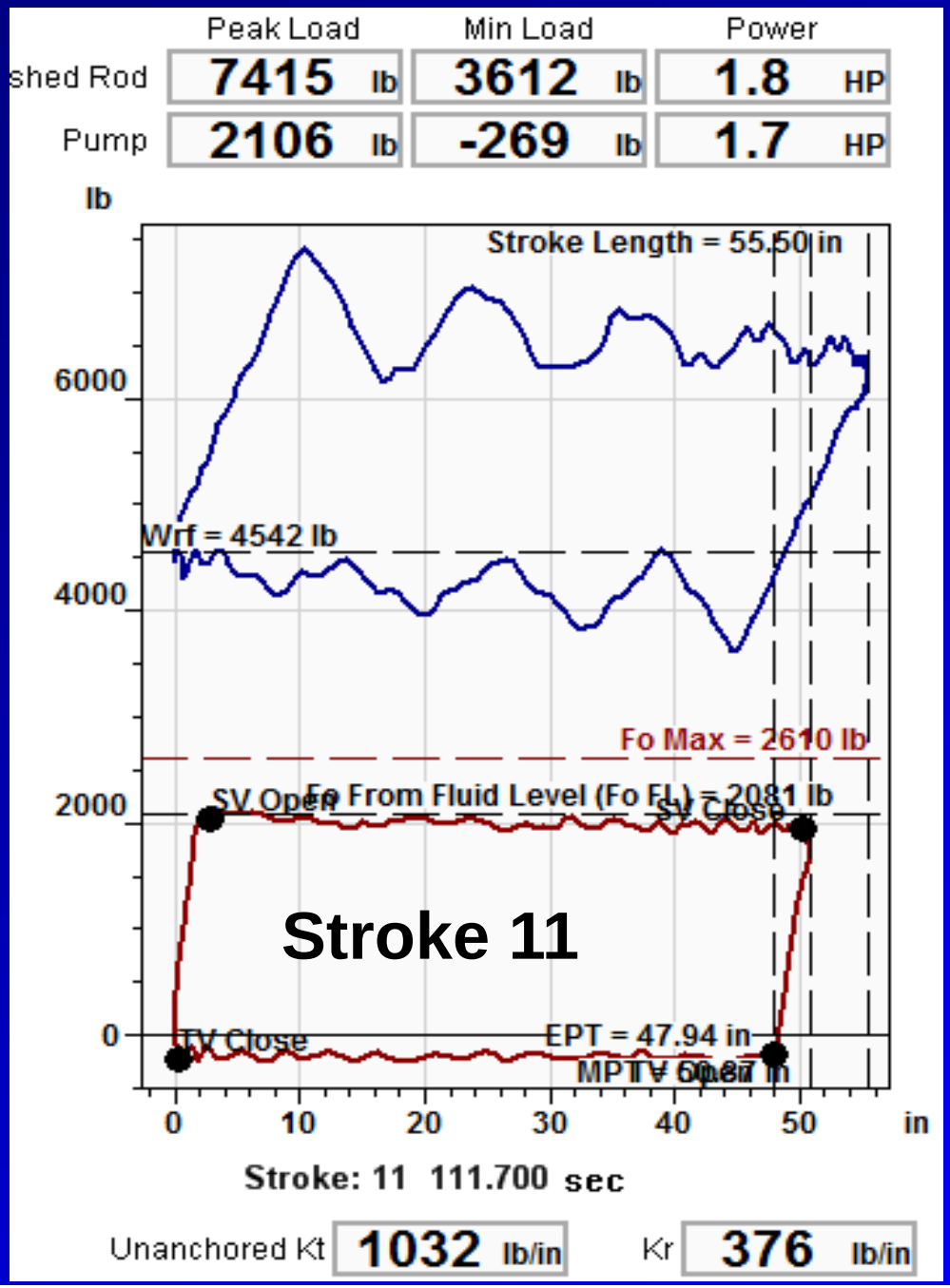
SV Sticks Open ~ TV OK?

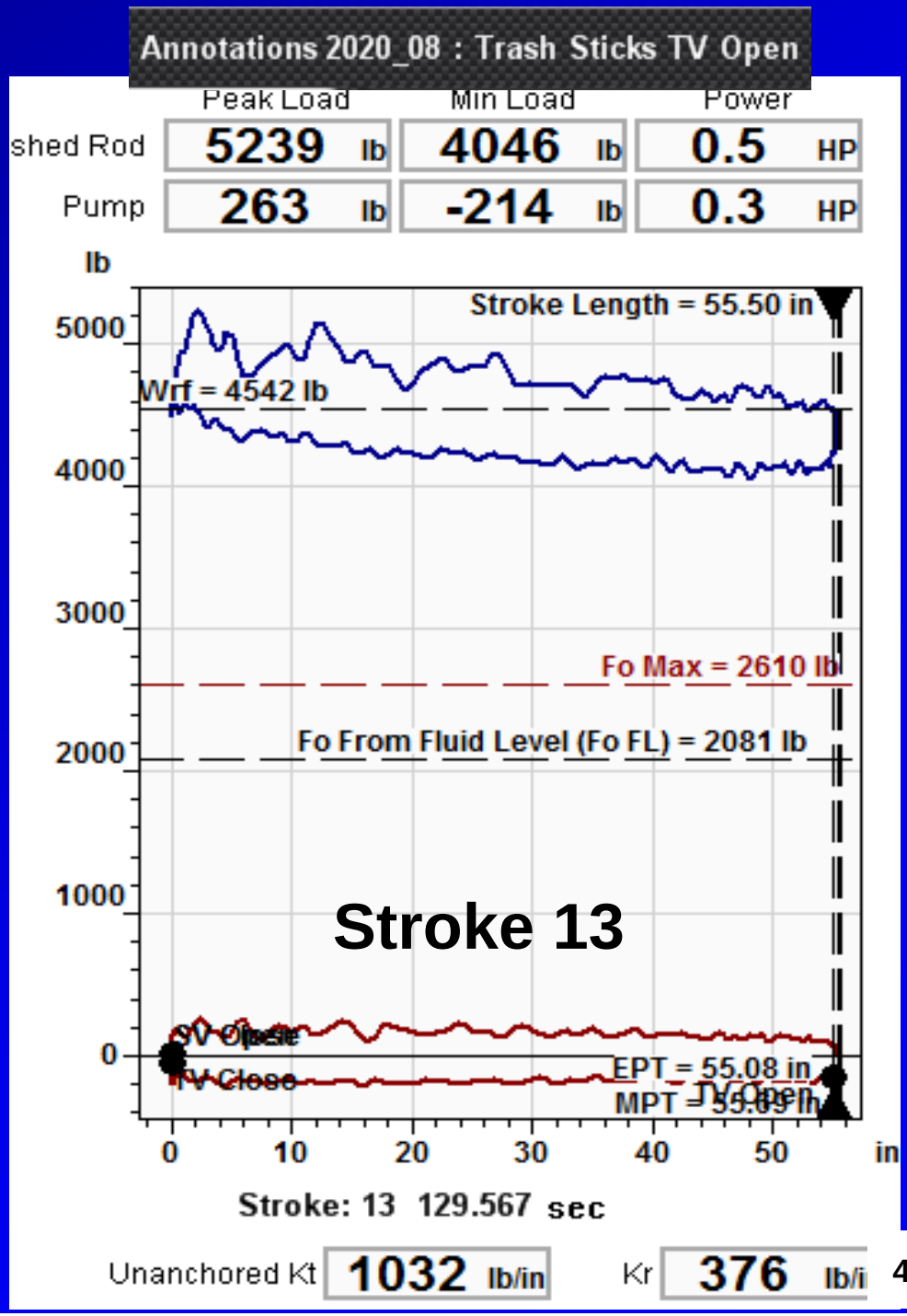


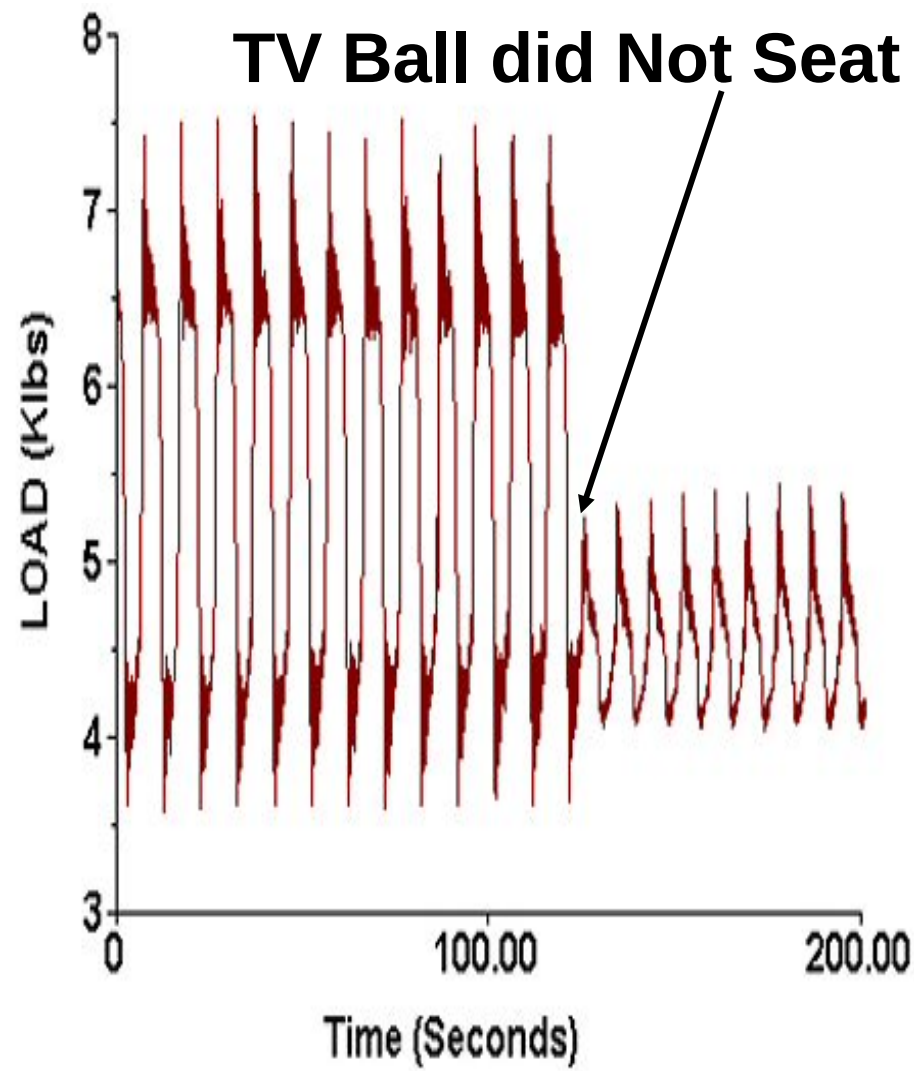


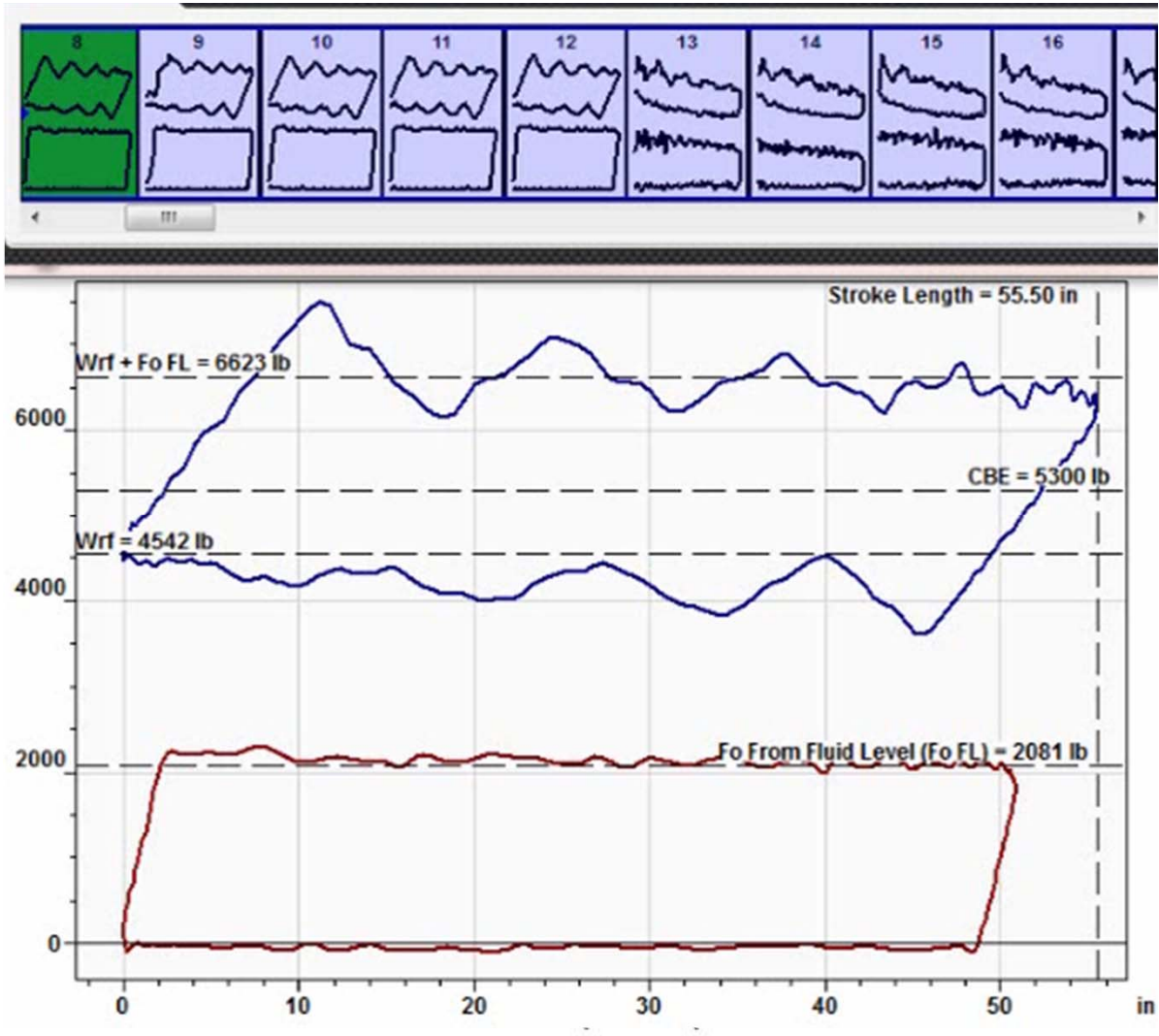
Lost TV Load

Strokes 10 seconds apart.
Is this a deep Rod Part?



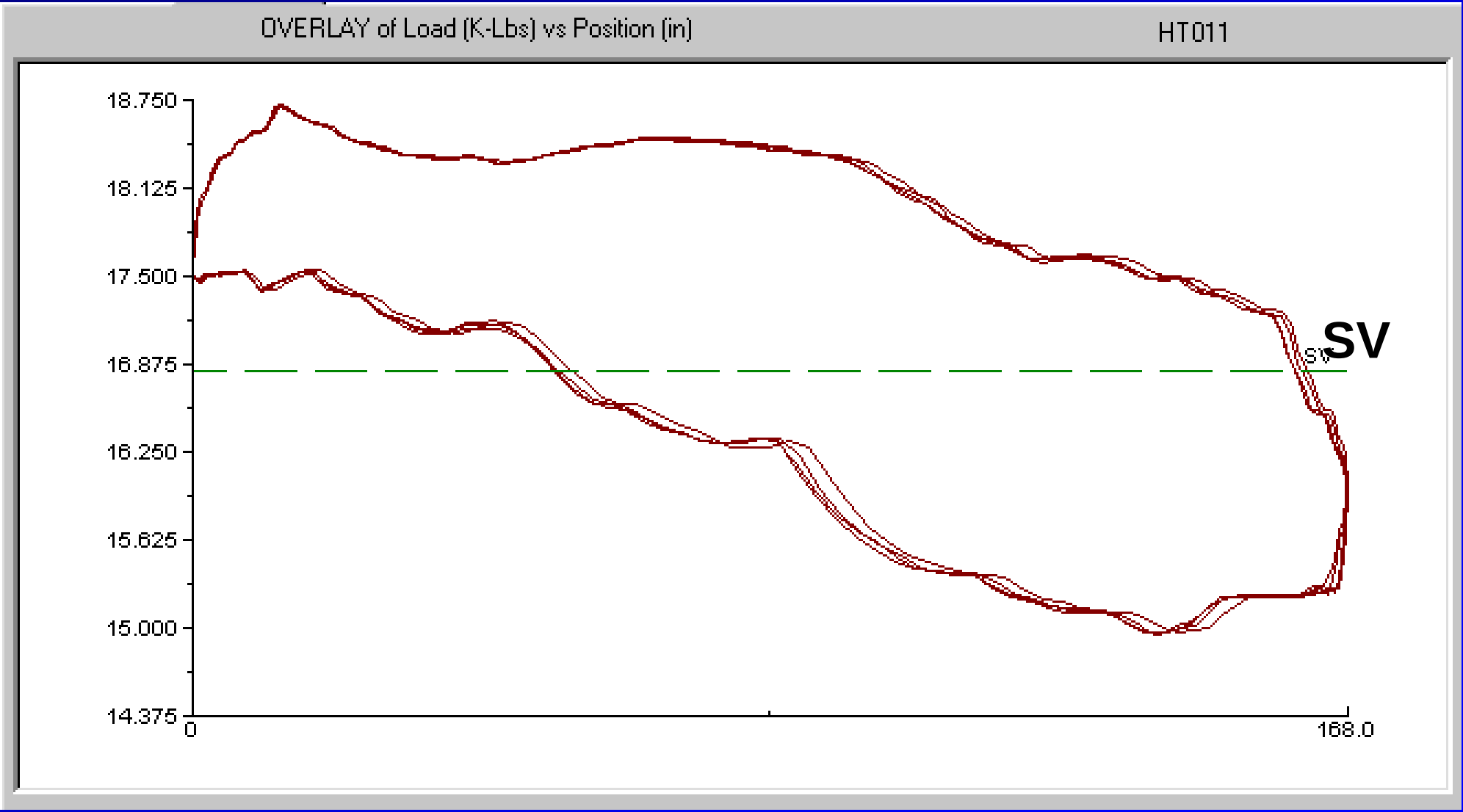


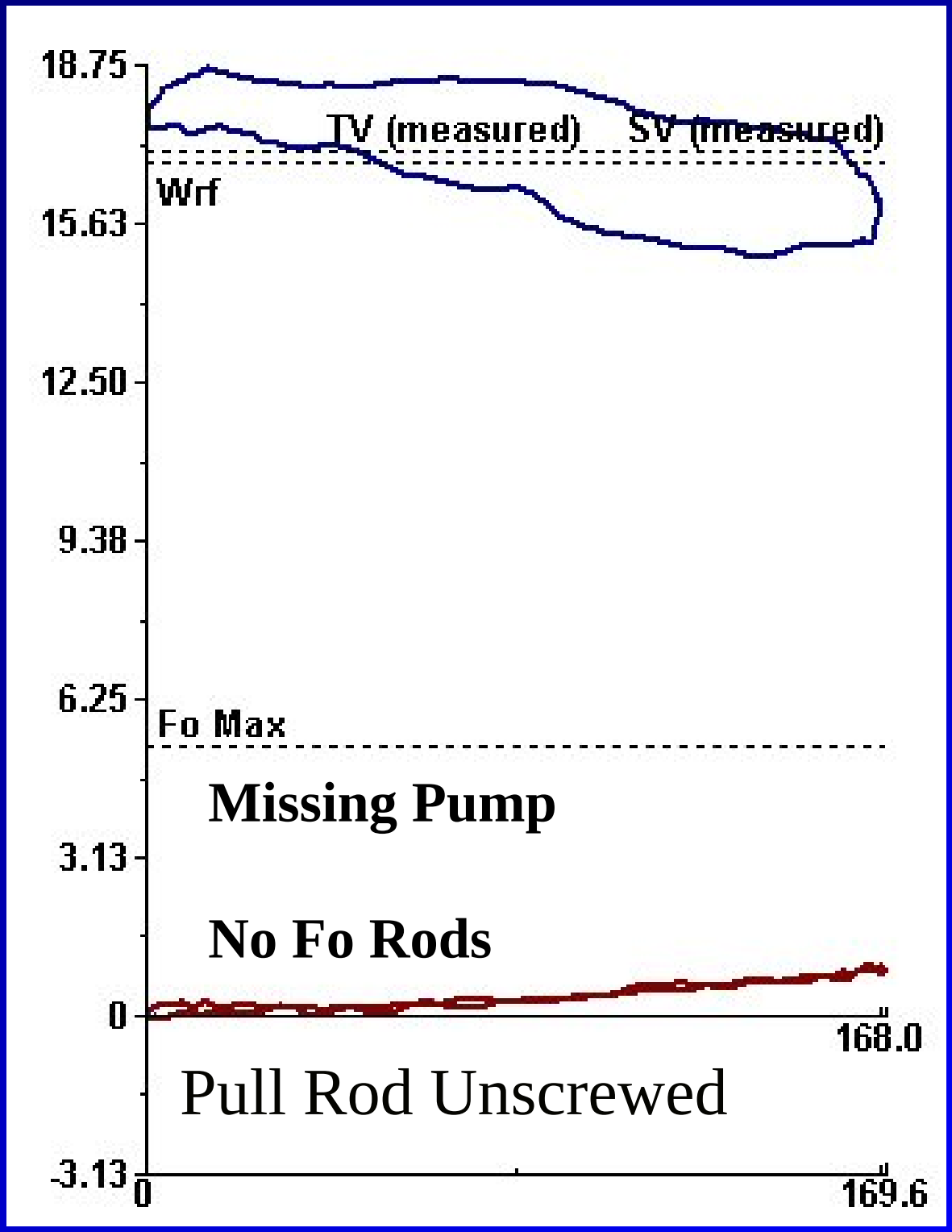




<u>Trash in TV</u> Notice normal appearing Surface Dynamometer Card, on the 13th stroke TV became stuck open due to trash. Same type of surface card could occur, if Pump unseated, Pull Rod became unscrewed or parted, or rods parted at the pump.

Surface card OK. Pump OK?





Rods Parted at Pump

No fluid load from pump being applied to rod string. Parted rods are overtravel cards, because there is no loss of downhole stroke due to the static stretch of rods picking up fluid load. Measured surface dynamometer card loads are near standing valve load (Wrf).

Note that both the standing and traveling valves measured test loads are at the calculated standing valve test load.

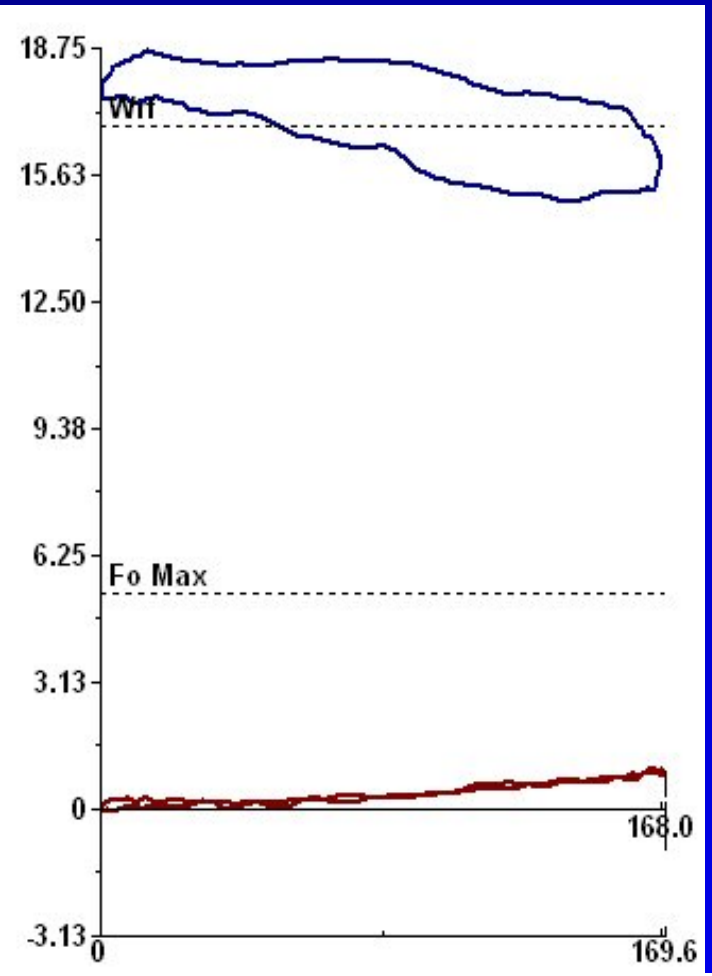
Sometimes trash in the pump keeps the traveling valve ball from going on seat. Tagging on the down stroke before pulling, may knock out trash.

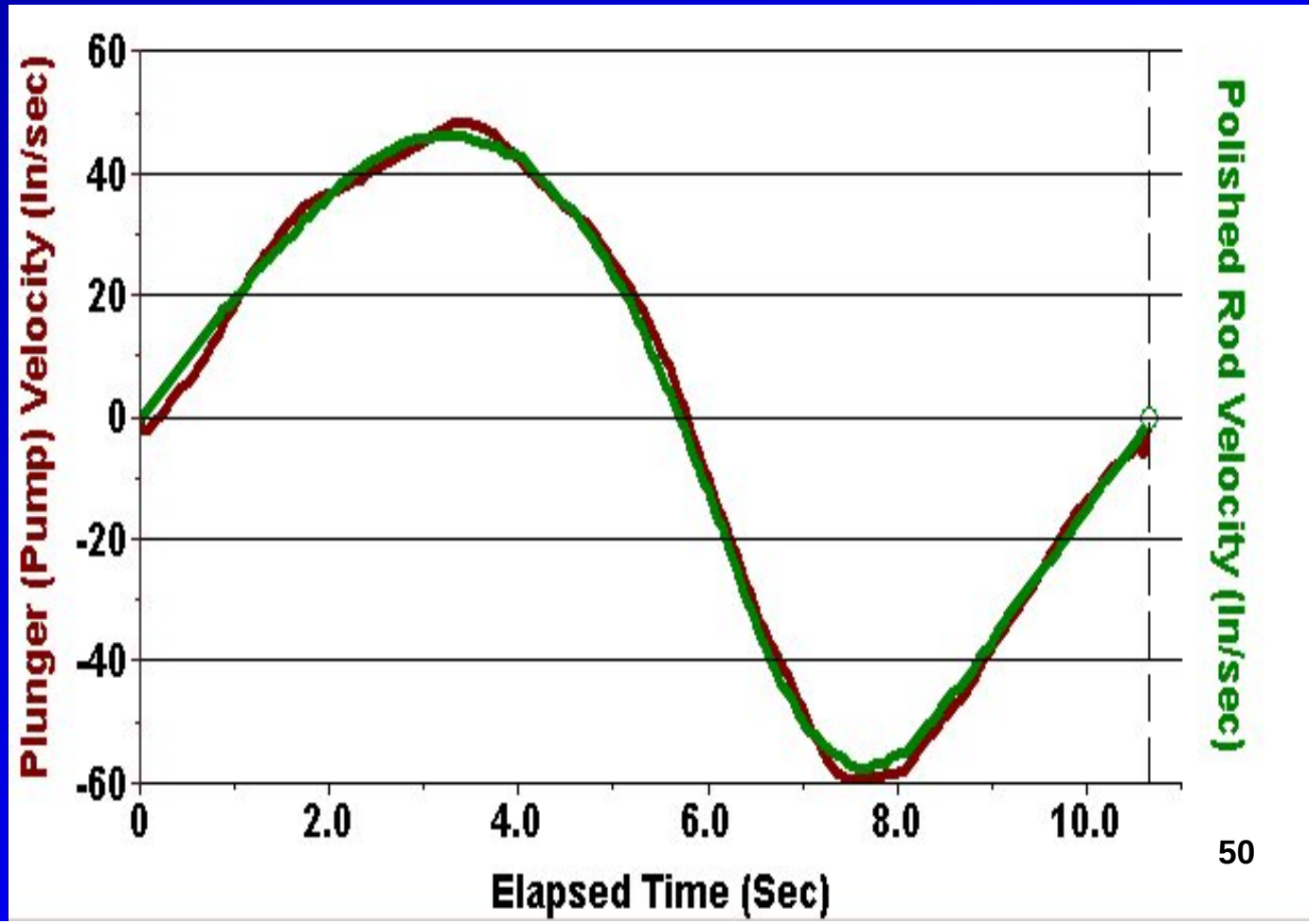
Deep Rod Part

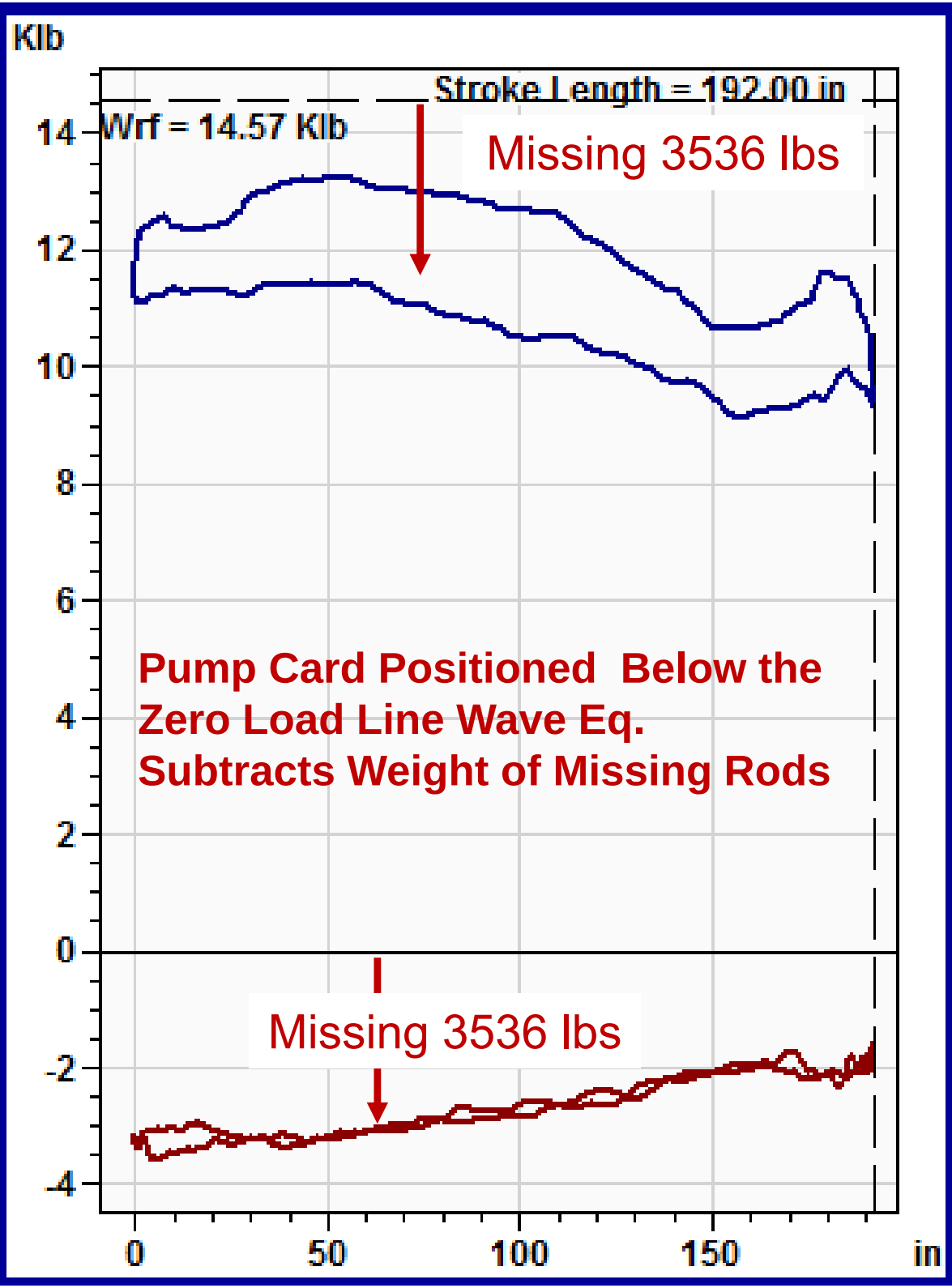
Pull Rod on Pump Parted

Plunger & Polished Rod Velocity Equal

1. No Fluid Produced to Surface
2. No Fluid Load – No Pump – No Rod Stretch
3. Plunger Does Not Stop while Rods Stretch
4. Momentum of Rod String results in Slight Over-travel of Rods at Pump Depth







Rods Parted Higher Above Pump results in dynamometer cards load measured below weight of rods in fluid. The actual location of the rod part will determine the trace's relative position with respect to the theoretical weight of rods in fluid.

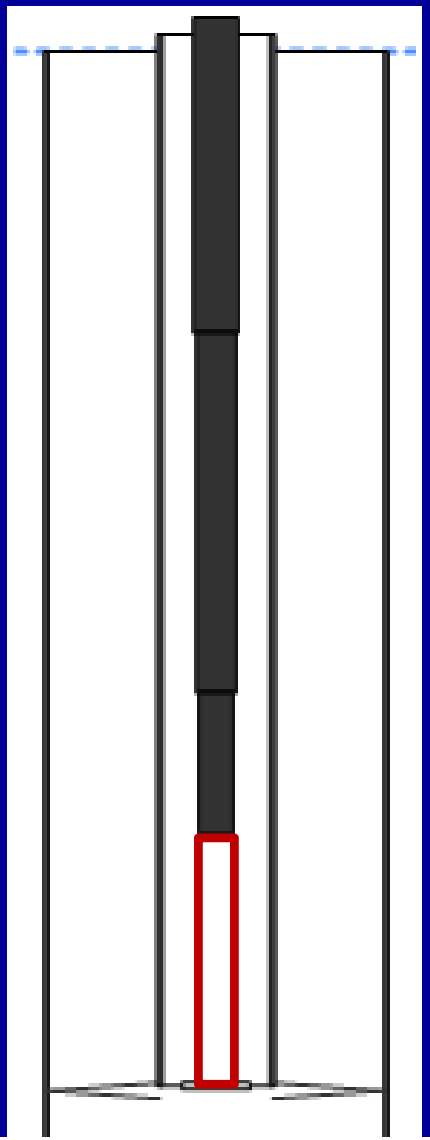
Rod parted at a depth of 5365 feet results in 3536 lbs missing weight of rods in fluid.

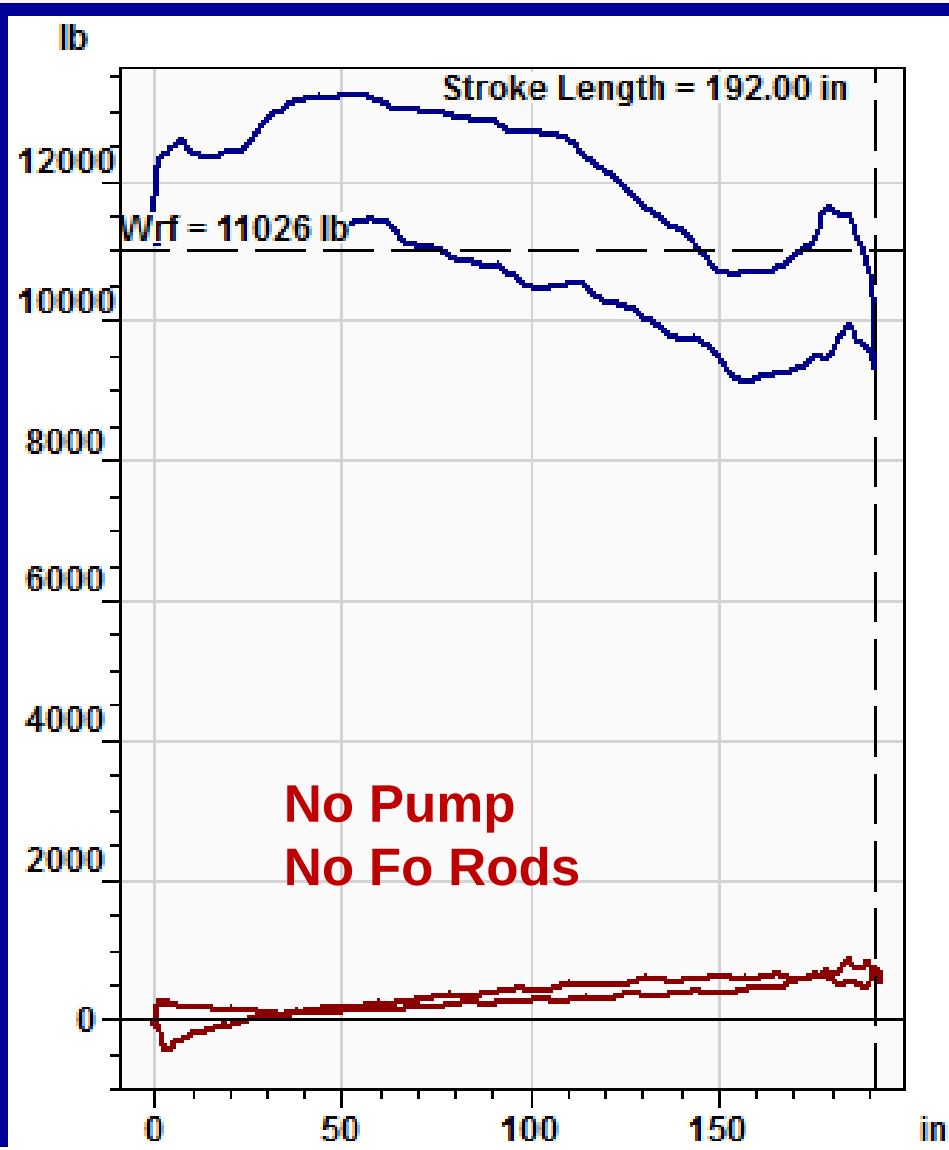
	Top Taper	Taper 2	Taper 3	Taper 4
Rod Type	D	D	D	SB
Length	1927.00	2475.00	2350.00	275.00
Diameter	1.000	0.875	0.750	1.500
Weight	5573.3	5474.7	3815.1	1795.7

Annotations 2020_08 : RodPart_5365

37 Rods Missing Parted @ 5365'

	Top Taper	Taper 2	Taper 3	Taper 4
Rod Type	D	D	D	NONE
Length	1927.00	2475.00	963.00	
Diameter	1.000	0.875	0.750	
Weight	5573.3	5474.7	1563.4	





Adjusted Rod Length to Equal 5365 Ft, Corrected Rod Weight Now Pump Card Sets on Zero Load Line

Location of Pump Card with Respect to Basic Loads are Critical to Analysis

1) Location of Pump Load can be Used to Identify and Troubleshoot Problem in the Well.
2) Pump card that plots as a flat line could be:

TV Stuck Open	**Tubing Dry**
Deep Rod Part	**SV Stuck Open**
Shallow Rod Part	

3) OK Pump Card should plot between Zero Load Line and Fo from Fluid Level Line
4) If Polished Rod Transducer used to acquire dynamometer data ***<u>and pump card is flat</u>***
   - Difficult to identify problem
   - All of the loads plot on the zero load line.