Users' Group Conference 2018

Compressor Analysis Special Circumstances

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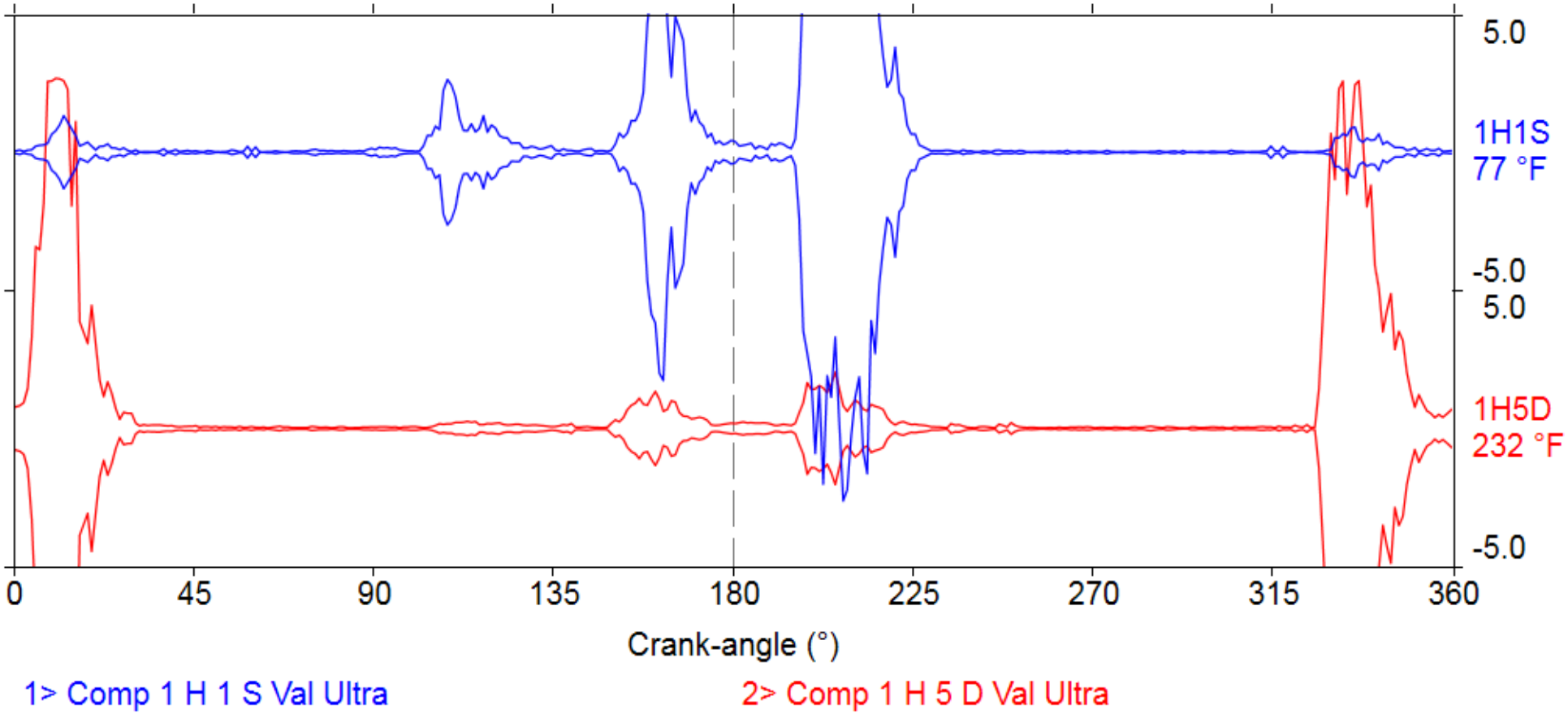
Topics, top compressor questions

- Ultrasound Baseline
- Cat Eyes
- Leak Index
- VE Correction
- Toe Pressure and Slope Checks
- TDC
- Raw Sensor Points Backups
- Theoretical PV Models
- Clearance Calculation Models

Ultrasound Traces, how about some definition to the baselines



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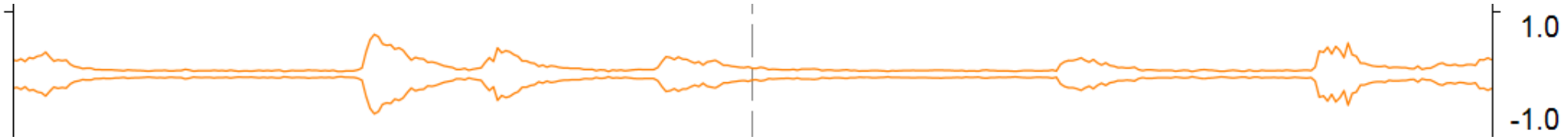
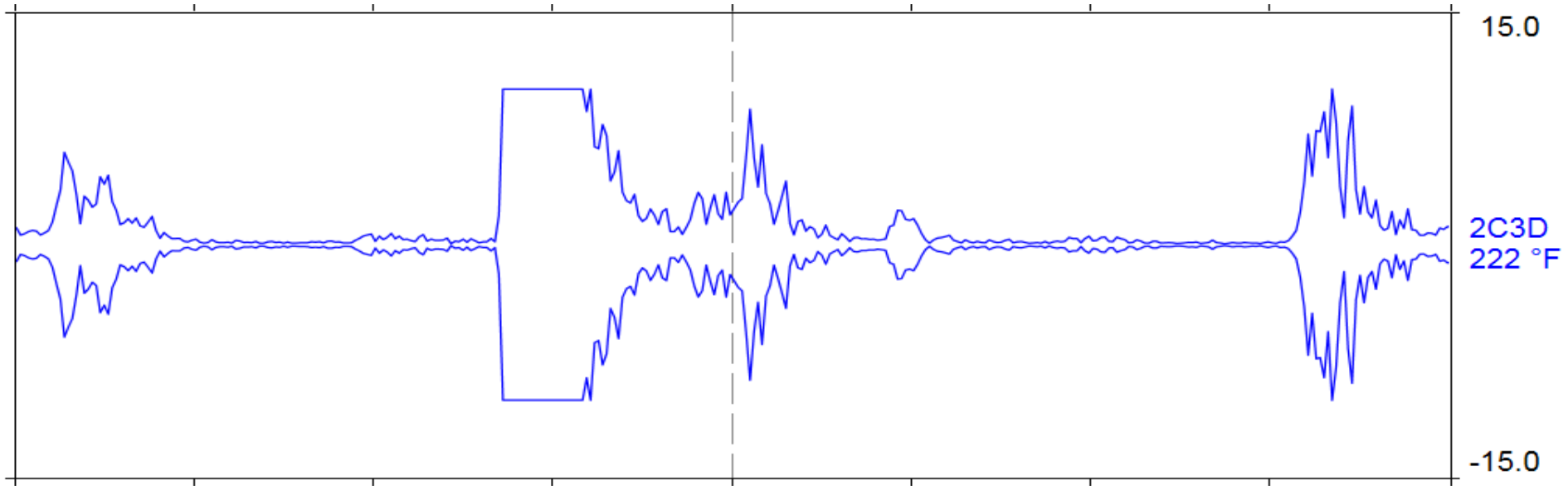
The Problem with a flat baseline?

- Leakage pattern may be missed.
  - A flat line could indicate the gain was too low.
  - Increasing the scale with a flat line baseline will sometimes only display a larger flat line.
  - Stacking ult traces on a group plot will shrink the scale



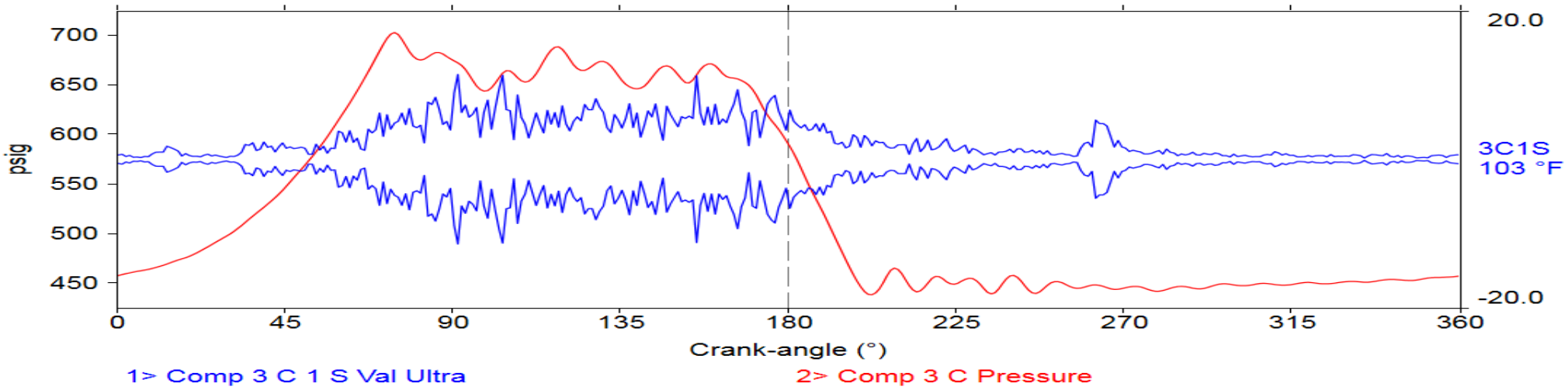
Increase the Gain

- Increasing the gain may clip the peaks of the valve opening and closing.
  - Clipping the peaks of the acoustic response is ok because it is not measuring the impacting of the valve opening or closing.



Valve Leaks While It Is Closed

- Some ultrasound traces can be very noisy in this area.
- The tapering of the baseline during compression and expansion can sometimes help detect leakage



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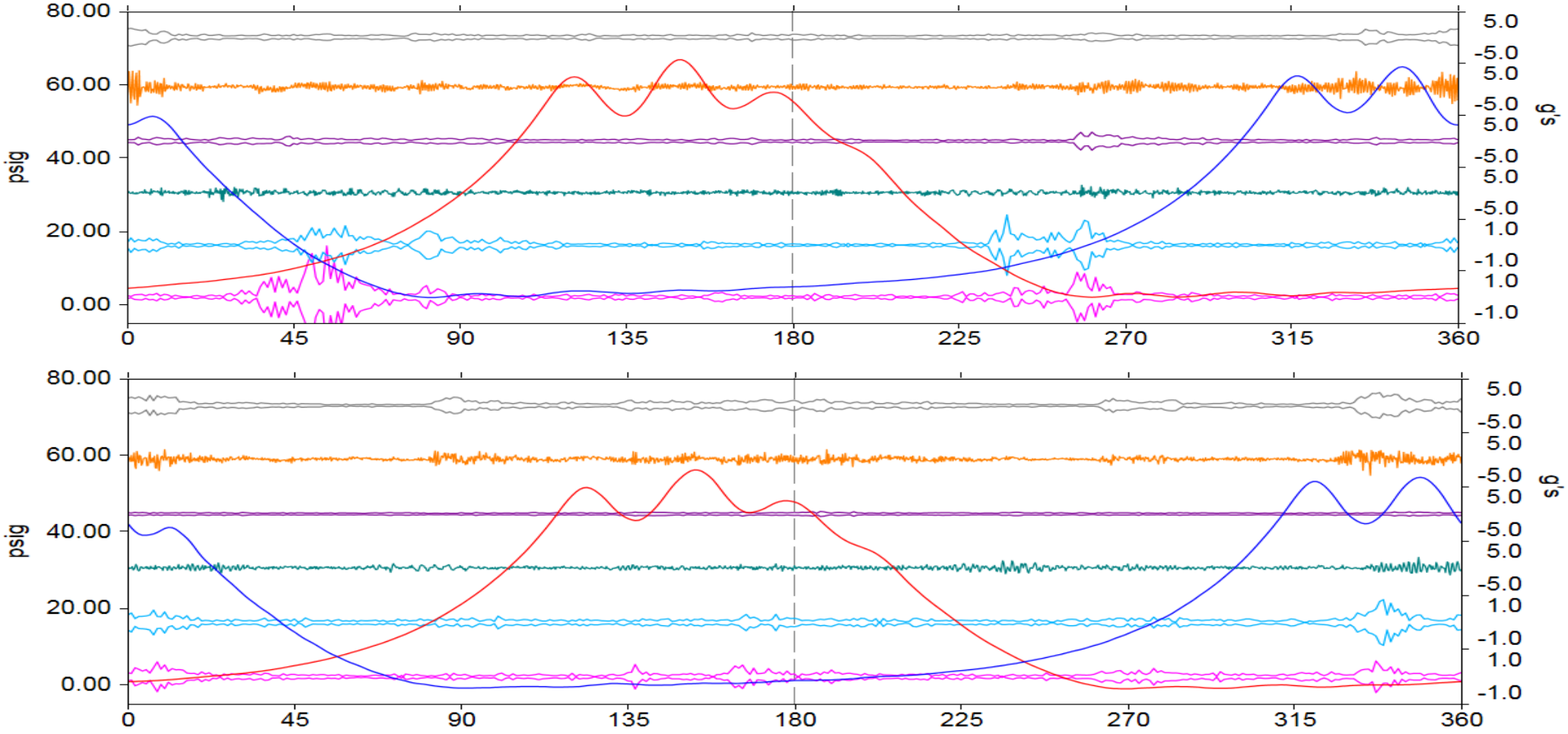
Cat Eyes

- Named from the ultrasound pattern it can make on a PT/VT plot
  - Can look like two cat eyes on the PT
- Acoustic response from gas passing by the rings
- Occurs at pressure reversal
  - Quiet area
- Sometimes it is the only indicator of damage to the piston rings
- Best seen if collected on cylinder ends but can be seen on valve cap ultrasounds sensor points

Cat Eyes, with and without



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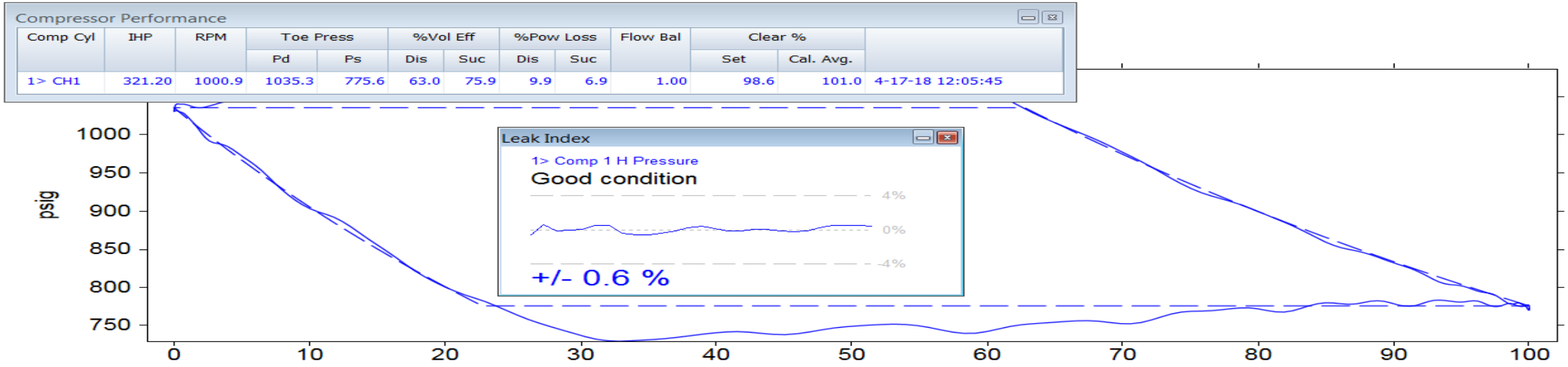
Leak Index, making MD work for you!

- Leak Index is the indexing of the compression and expansion lines on the PV at the similar pressures
  - The points created from the indexing will generate a curve
- If the compression line and expansion line do not have leakage then the curve will be a straight and flat line



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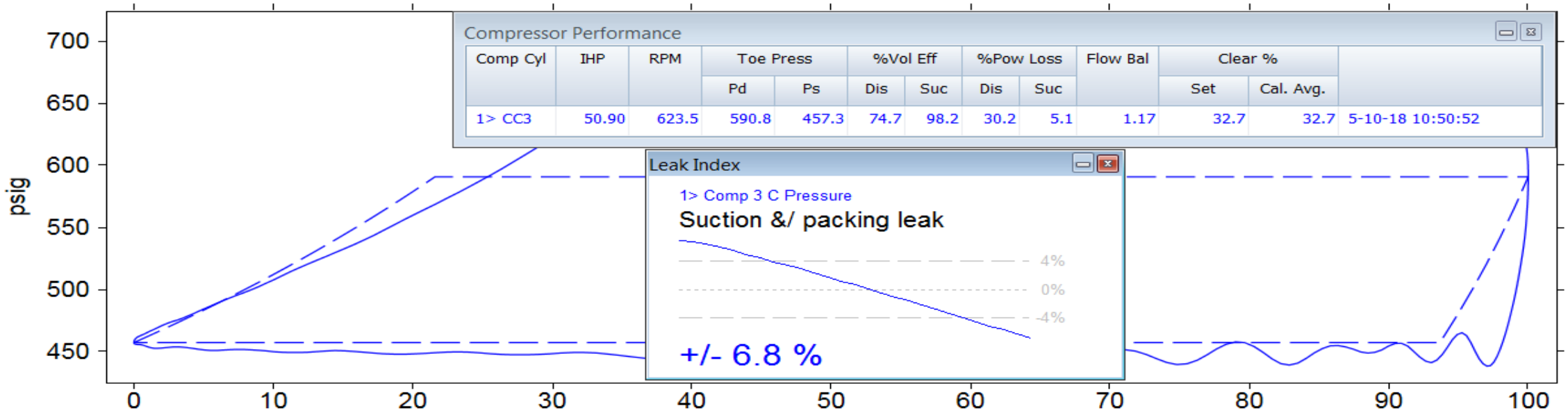
Leak Index With Suction Leakage

- Suction leakage will cause the straight flat line to rise past zero on the left side and fall past zero on the right side
- The percentage number is an indicator of severity
  - It is the percentage the line is off of zero



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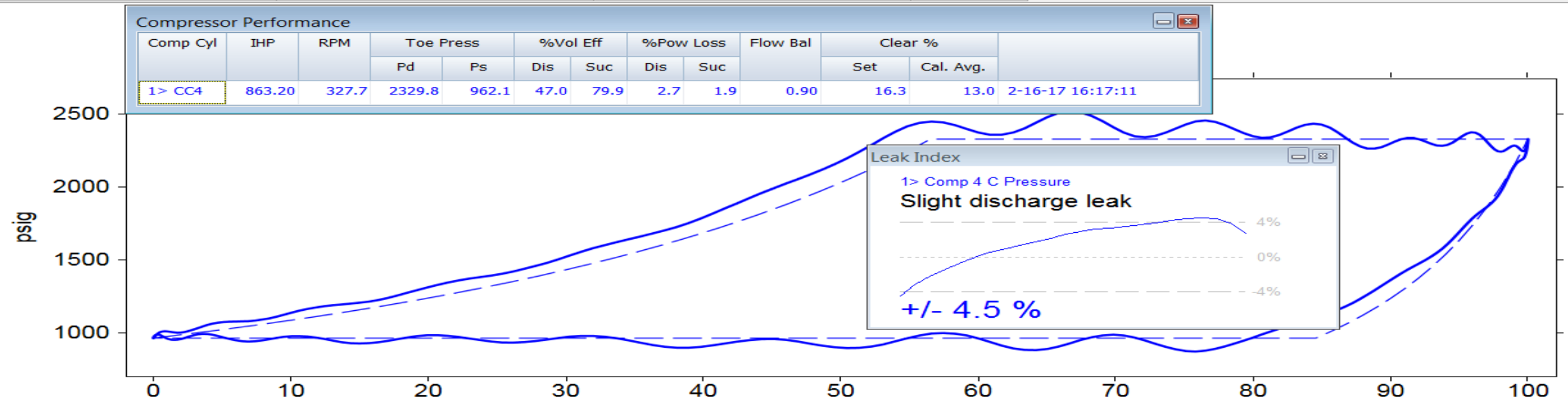
Leak Index With Discharge Leakage

- Discharge leakage will cause the straight flat line to fall past zero on the left side and rise past zero on the right side
- The percentage number is an indicator of severity
  - It is the percentage the line is off of zero



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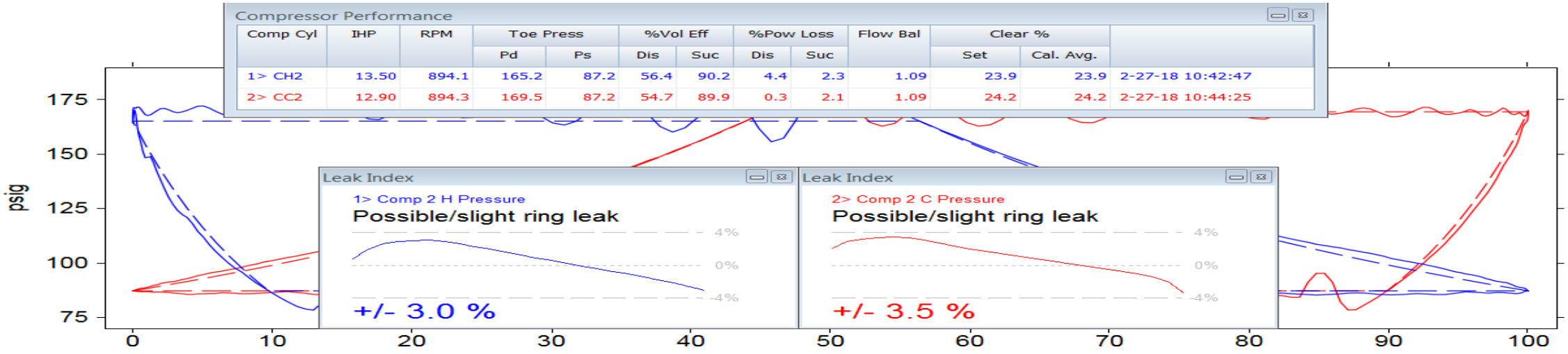
Leak Index With Piston Ring Leakage

- Piston Ring leakage will cause a curved (hooked) line to rise past zero on the left side and fall past zero on the right side
- The percentage number is an indicator of severity for suction leakage
  - It is the percentage the line is off of zero



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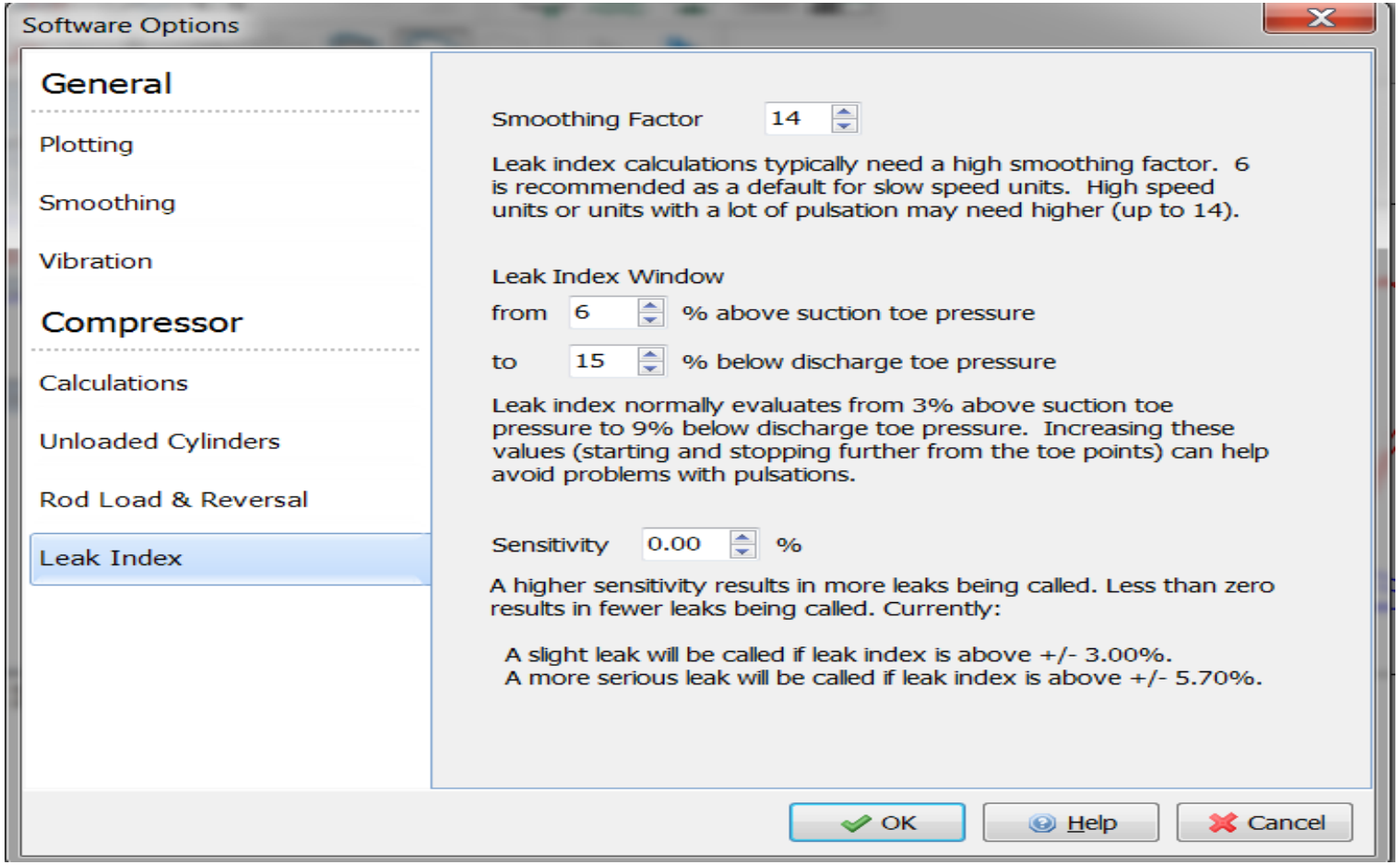
Leak Index Diagnostics

- The Leak Index is how MD will make suction, discharge and piston ring leakage diagnostic calls
- Due to a very high number variables the analyst has to careful control three aspects of the Leak Index
  - Smoothing of the Leak Index curve
  - The percentage of the compression and expansion line it uses to make the curve
  - The sensitivity of the warnings and alarms

Leak Index Software Options

- These changes can be made under the software setup tab
- High speed units will need up to 14 for smoothing
- Window is % away from the toe pressure



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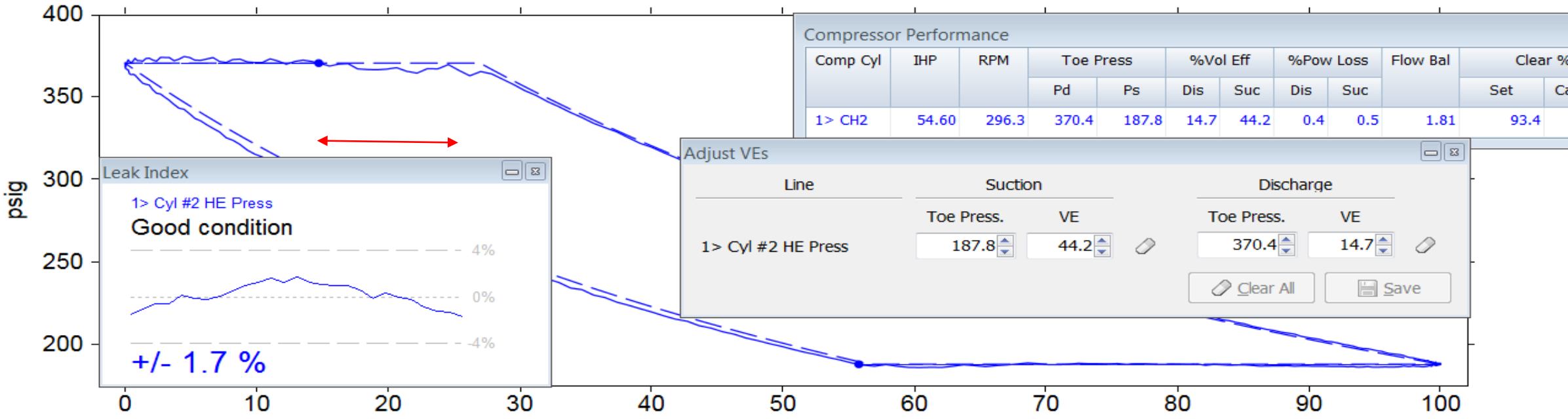
VE Correction, Rules to the Nuclear Option

- I call it the nuclear option because it is the last thing you should do when you are validating your data
  - VE Correction can affect the integrity of the data
- VE Correction is for adjusting toe pressure, compensating for skinny VEs and adjusting VEs due to pulsation and inaccurate compression/expansion picks
  - Channel Resonance
  - Restriction between transducer and internal cylinder pressure
  - High Speed delay

Rule #1, stay on the slope

- The slope of the compression and expansion line needs to be followed
  - If pulsation has physically moved the line of the slope then you should follow where the slope should be



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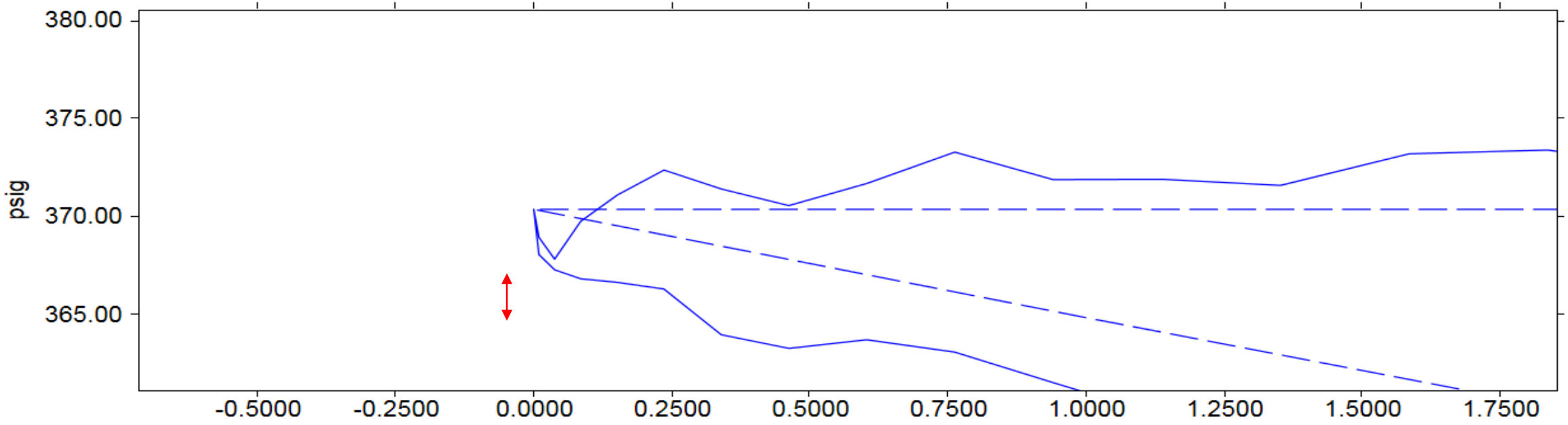
Rule #2, stay on the toe

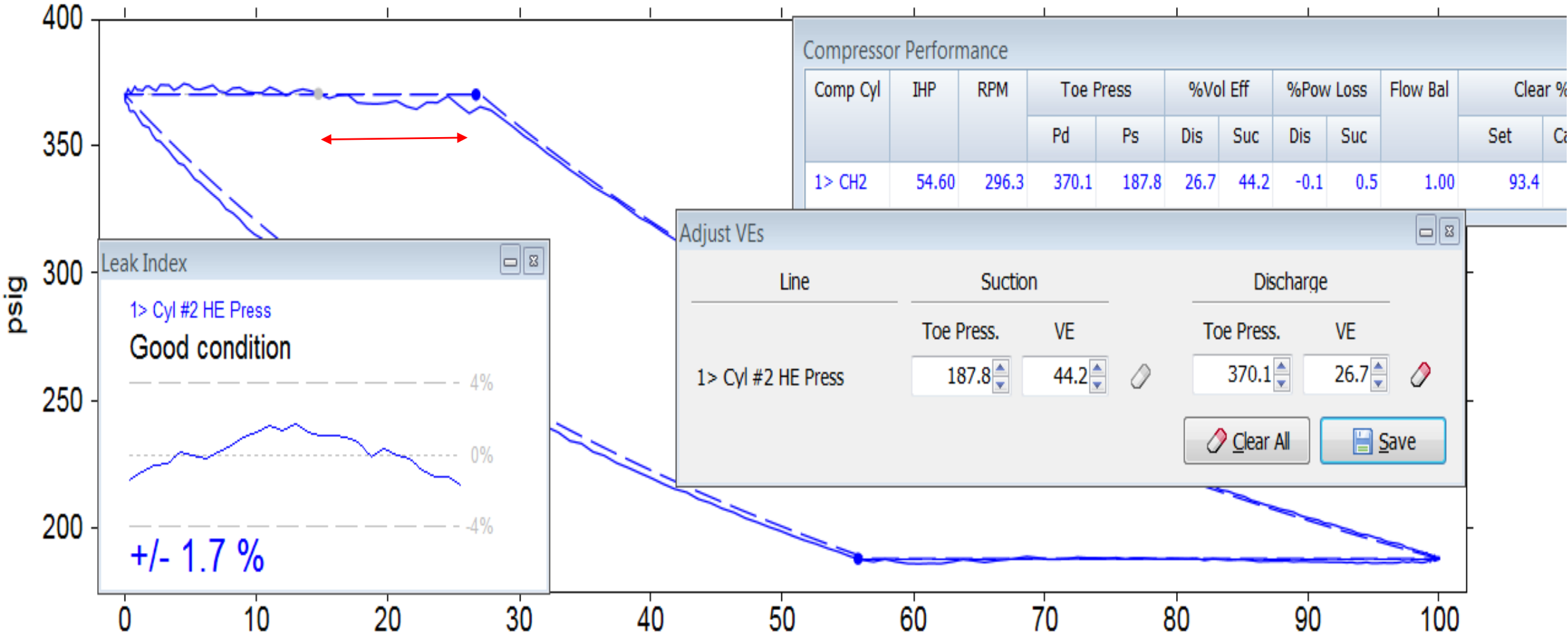
- The toe pressure at 0 and 100% swept volume in some cases may cover a wide range of pressure
- Try to follow it to the opposite side and use both pressures



Rule #3, Check yourself before you…

- The calculator and adjust clearance windows should be brought up at the same time you are moving the VEs
  - This allows you to check to see if the data is making sense with flow balance and the suction\discharge clearance calculations
- Previous data, slopes of the theoretical compression and expansion and panel suction and discharge pressure are just a few things you can use

VE Corrected!



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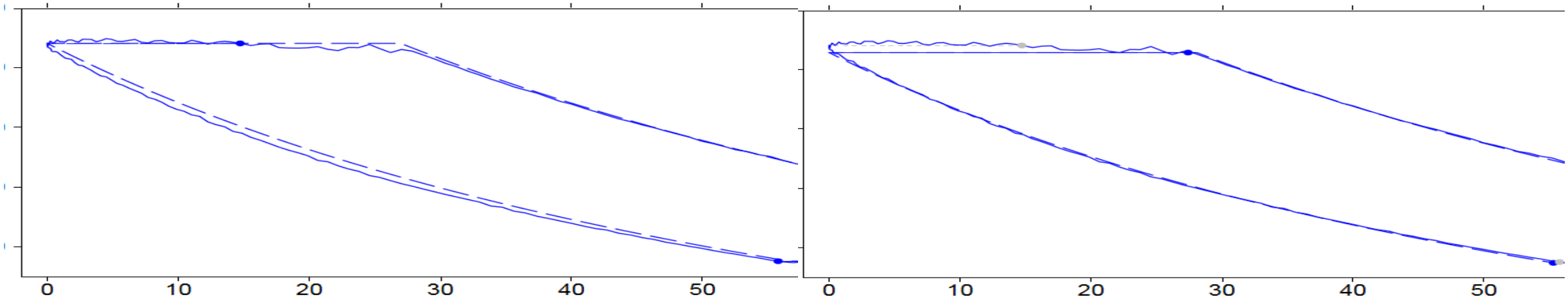
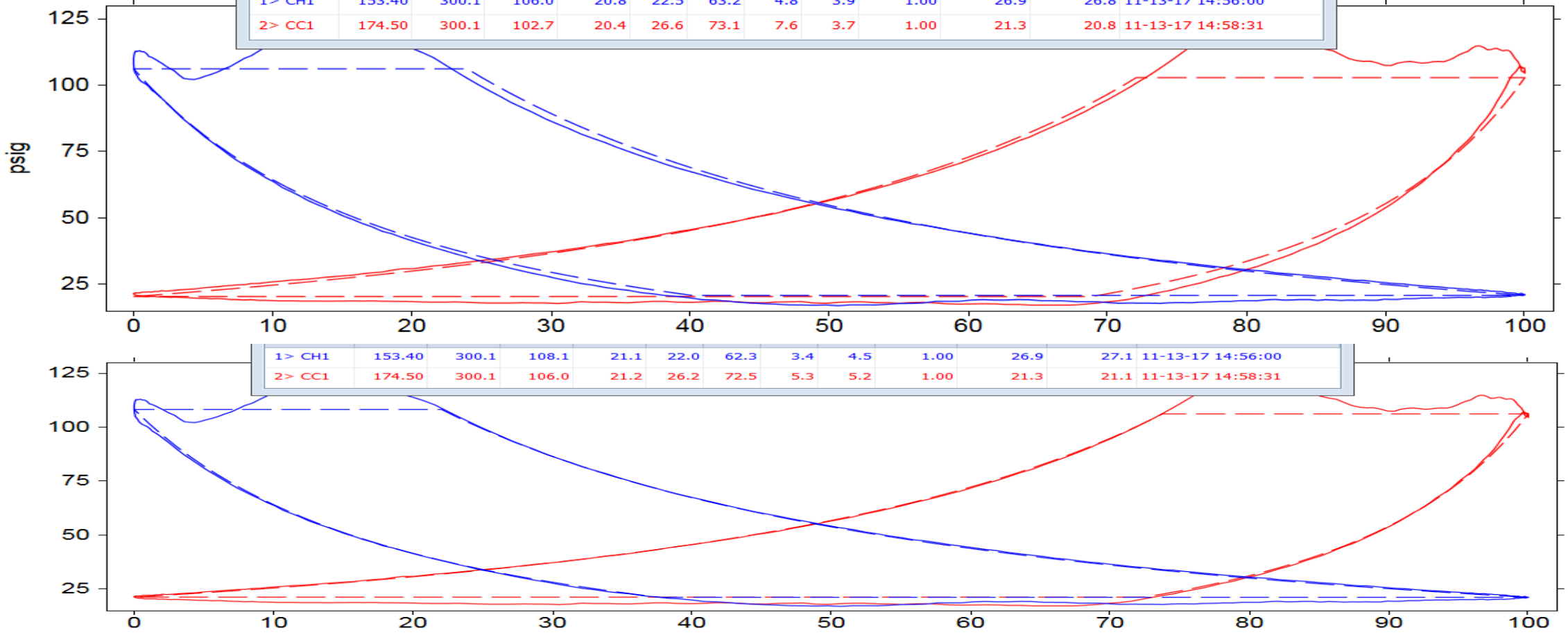
Toe Pressure and Slope Checks

- Toe and slope checks can be used to check for the correct theoretical model, the correct clearance and for general data validation and comparison
- The slope as a whole will typically be more accurate than the toe pressure



Equation of State (K) vs N Base, Top is K and bottom is N Base

Comp Cyl	IHP	RPM	Toe Press		%Vol Eff		%Pow Loss		Flow Bal	Clear %		
			Pd	Ps	Dis	Suc	Dis	Suc		Set	Cal. Avg.	
1> CH1	153.40	300.1	106.0	20.8	22.5	63.2	4.8	3.9	1.00	26.9	26.8	11-13-17 14:56:00
2> CC1	174.50	300.1	102.7	20.4	26.6	73.1	7.6	3.7	1.00	21.3	20.8	11-13-17 14:58:31



1> CH1	153.40	300.1	108.1	21.1	22.0	62.3	3.4	4.5	1.00	26.9	27.1	11-13-17 14:56:00
2> CC1	174.50	300.1	106.0	21.2	26.2	72.5	5.3	5.2	1.00	21.3	21.1	11-13-17 14:58:31

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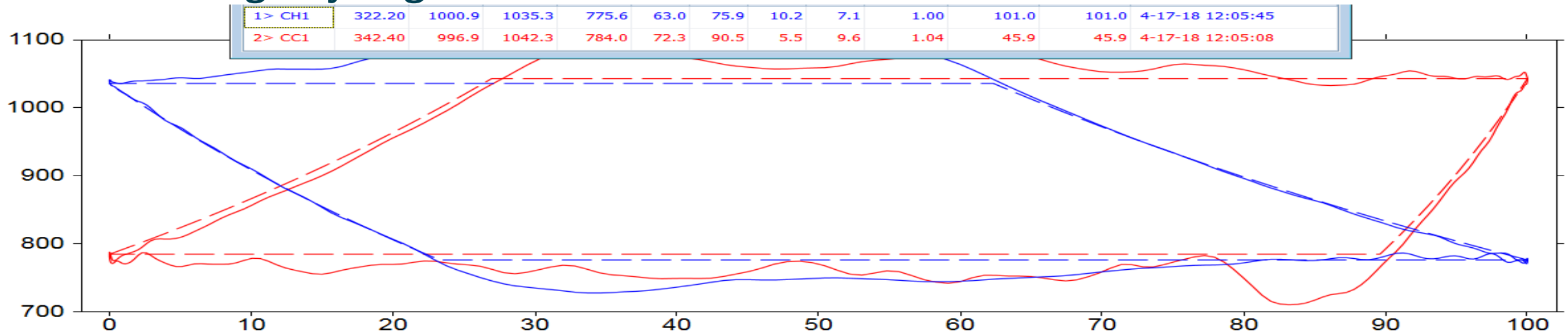
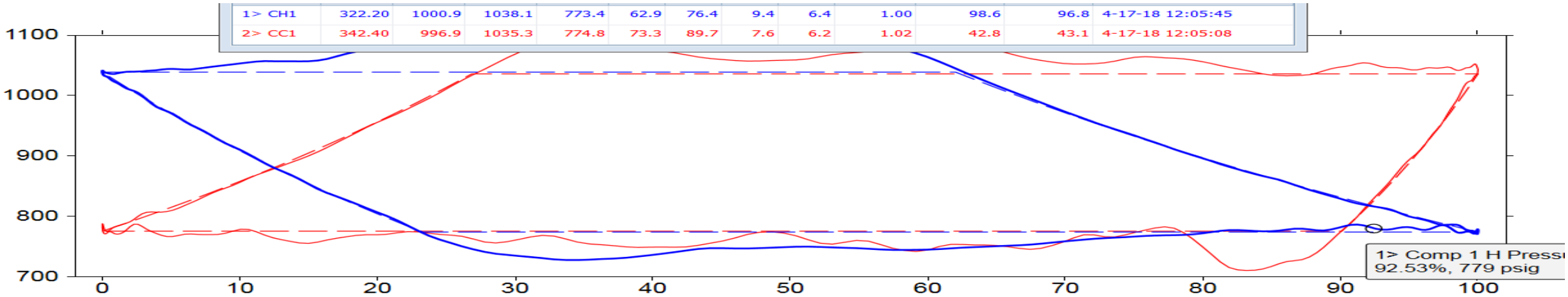
Smooth Less & Adjust Toes, top CE suction toe pressure slightly high





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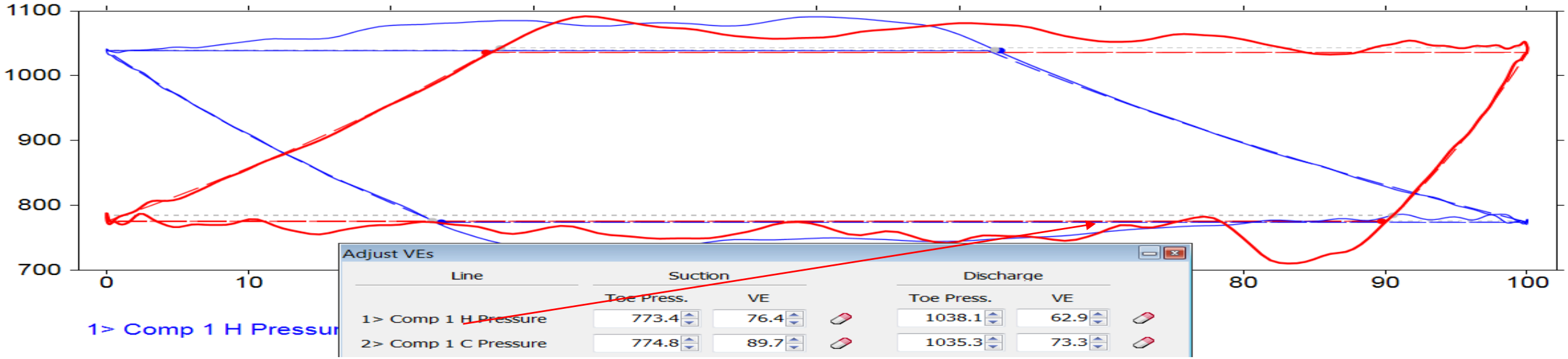
Lessons Learn

- VE being moved can shift/control the theoretical compression or expansion line on the opposite side of the PV
- If you move the VE then you need to adjust clearances
- Some bugs still remain, Windrock is working them



TDC, the three big indicators

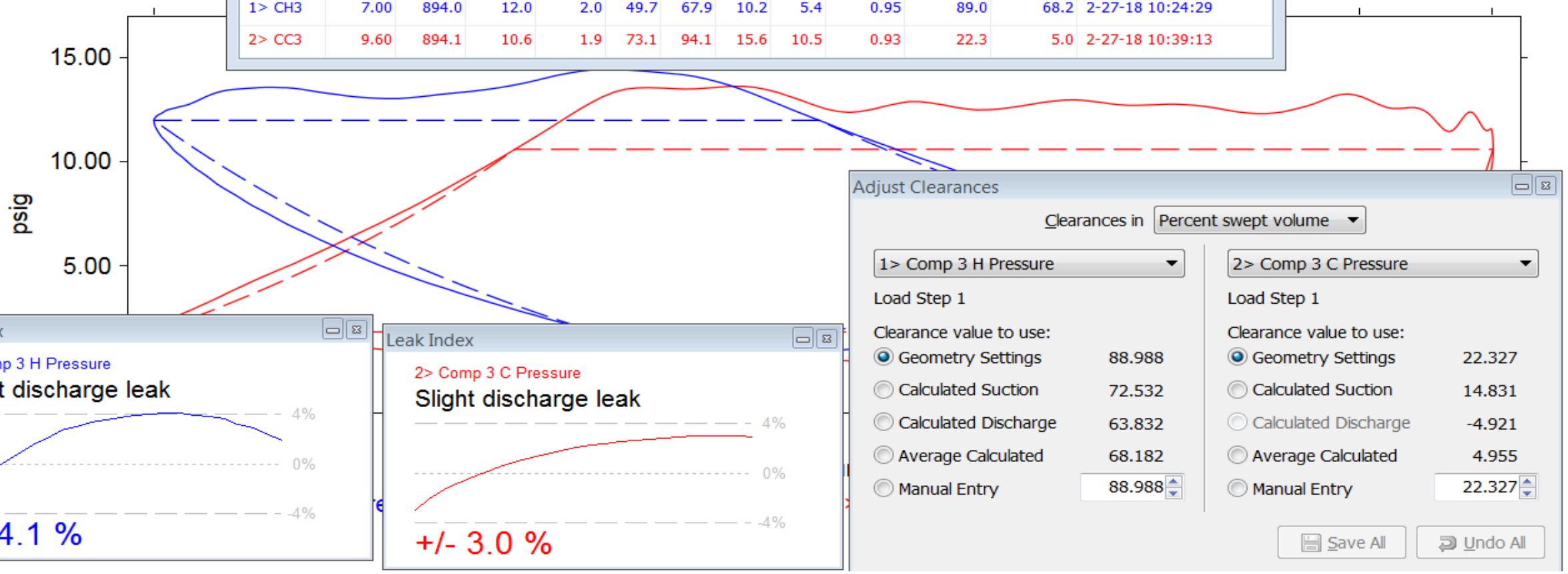
- Flow Balance
  - Are all of the Flow Balances above 1 or below it?
- Leak Index
  - How flat is the Leak Index
- Adjust Clearance Window
  - The difference between the calculated suction and calculated discharge

TDC Confirmation Pitfalls

- Unhealthy cylinders
- Too much smoothing
  - May have to stop smoothing significantly before yellow indicator
- All cylinder's data should make sense with the new TDC
  - Must be able to explain why the indicators are abnormal
- Bad geometry and/or gas analysis
- Wrong models
- Bad data
  - Restriction and high speed delay

TDC -10 Degrees, note discharge toe pressure

Comp Cyl	IHP	RPM	Toe Press		%Vol Eff		%Pow Loss		Flow Bal	Clear %		
			Pd	Ps	Dis	Suc	Dis	Suc		Set	Cal. Avg.	
1> CH3	7.00	894.0	12.0	2.0	49.7	67.9	10.2	5.4	0.95	89.0	68.2	2-27-18 10:24:29
2> CC3	9.60	894.1	10.6	1.9	73.1	94.1	15.6	10.5	0.93	22.3	5.0	2-27-18 10:39:13



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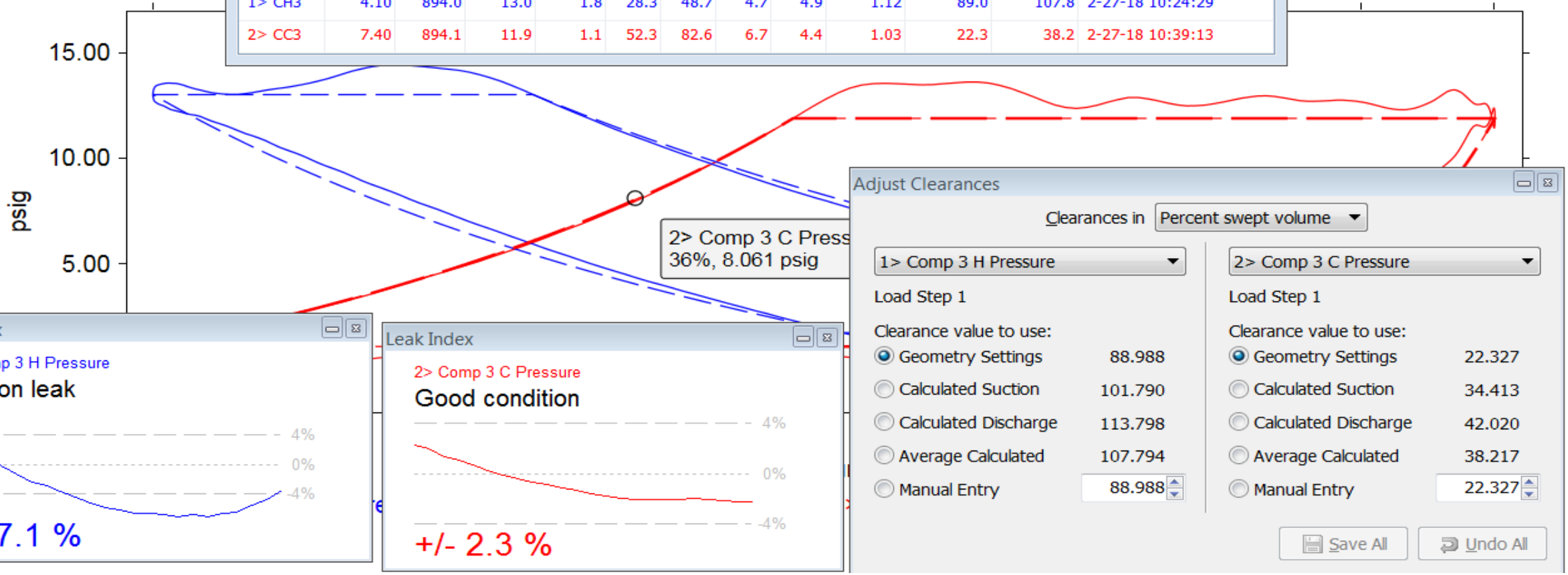
TDC +10 Degrees, note discharge toe pressure

Comp Cyl	IHP	RPM	Toe Press		%Vol Eff		%Pow Loss		Flow Bal	Clear %		
			Pd	Ps	Dis	Suc	Dis	Suc		Set	Cal. Avg.	
1> CH3	4.10	894.0	13.0	1.8	28.3	48.7	4.7	4.9	1.12	89.0	107.8	2-27-18 10:24:29
2> CC3	7.40	894.1	11.9	1.1	52.3	82.6	6.7	4.4	1.03	22.3	38.2	2-27-18 10:39:13



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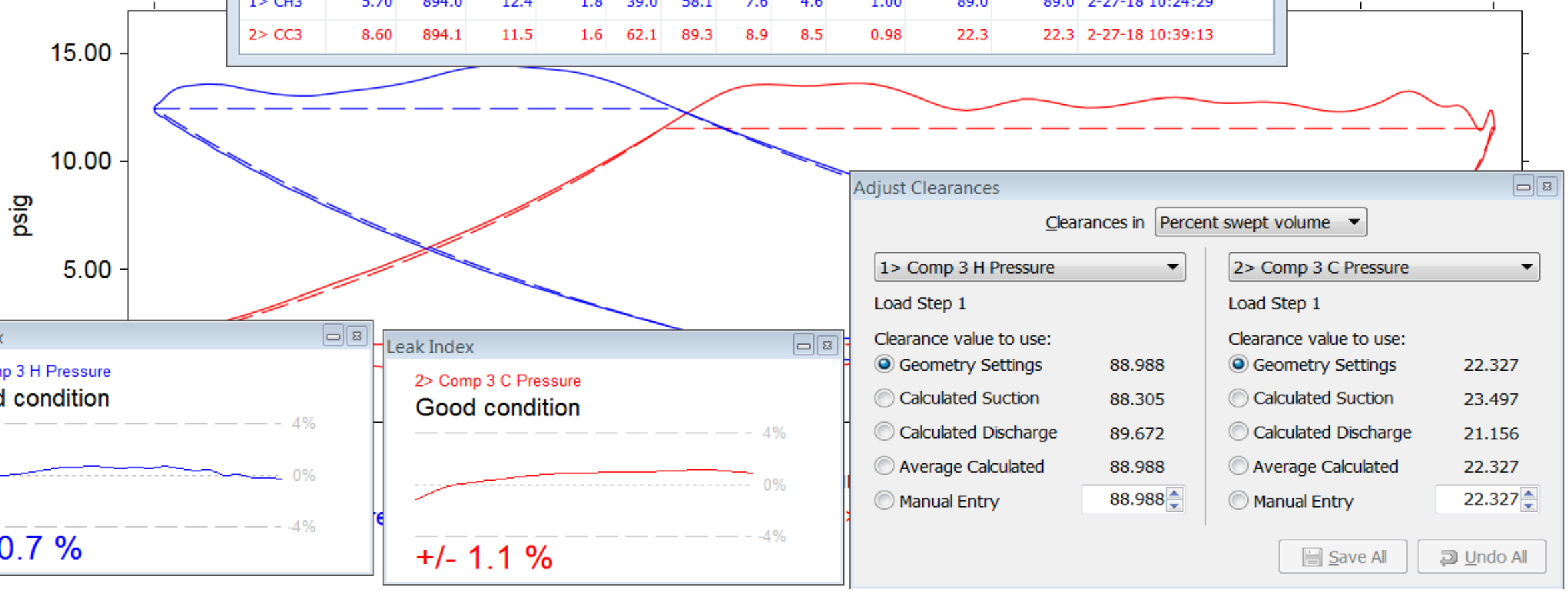
Correct TDC

Comp Cyl	IHP	RPM	Toe Press		%Vol Eff		%Pow Loss		Flow Bal	Clear %		
			Pd	Ps	Dis	Suc	Dis	Suc		Set	Cal. Avg.	
1> CH3	5.70	894.0	12.4	1.8	39.0	58.1	7.6	4.6	1.00	89.0	89.0	2-27-18 10:24:29
2> CC3	8.60	894.1	11.5	1.6	62.1	89.3	8.9	8.5	0.98	22.3	22.3	2-27-18 10:39:13



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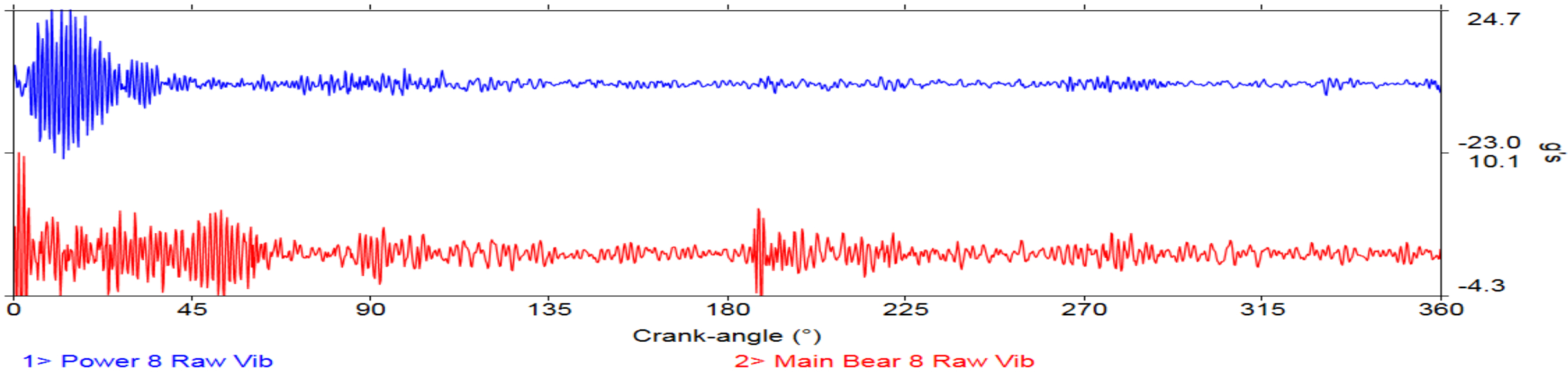
Raw Sensor Points Backups

- It has come to my attention that some Raw vibration sensor points, in special circumstances, are not displaying vibration impacts normally
- The reason appears to be from modulated vibration
  - Modulated impacts will make data interpretation difficult because it muffles the impacts
  - Modulated vibration signatures have only been documented in a few cases
  - These cases have been documented with setups that the user had used 4 samples per degree with medium to high speed compressors/engines.

Why is modulation a problem?

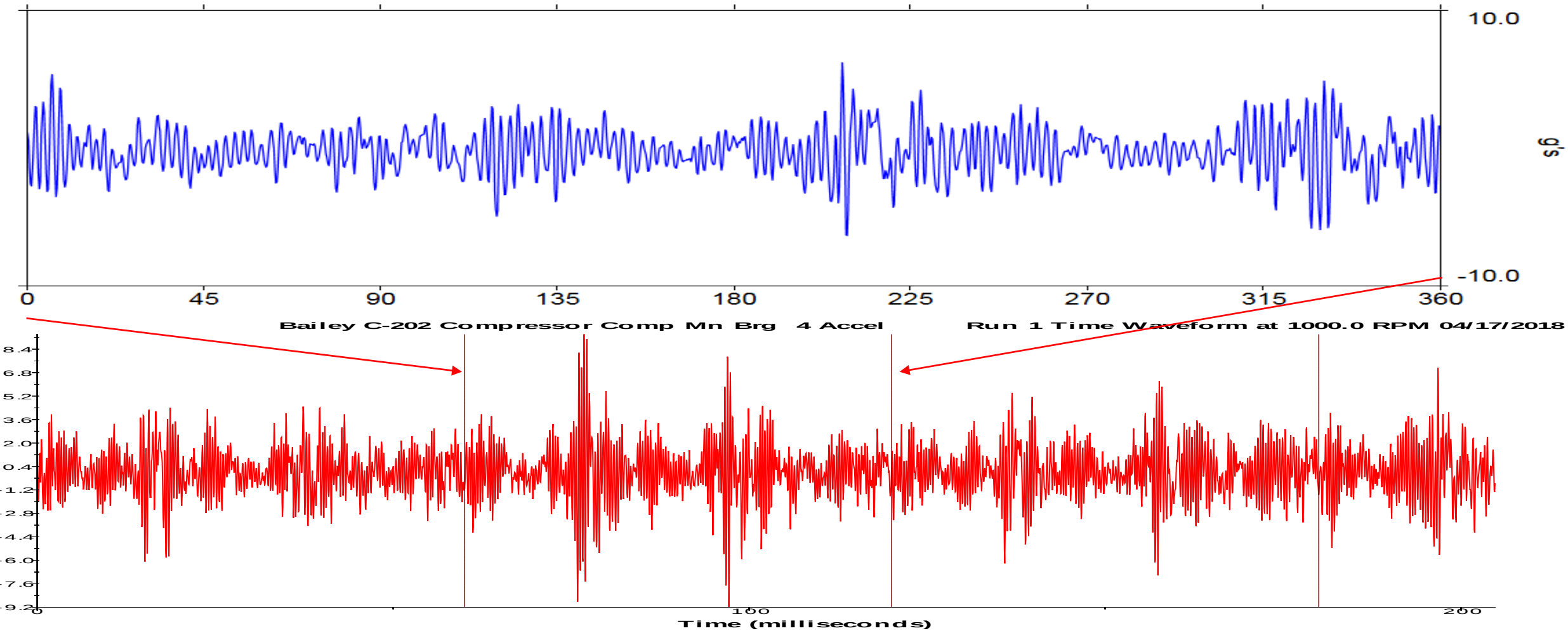
- Pattern interpretation is one of the 3 major techniques used for analysis
  - Slight differences like sharp points and a few degrees can be the difference between identifying a problem or missing it.



FFT to back it up

- I am recommending adding a FFT acceleration sensor point to backup every Raw sensor point
  - This is not for the FFT plot but to compare the time waveform to the Raw sensor point
- A Raw sensor point looks at 30 to 600,000 CPM
- Here is the setup I would recommend
  - Accelerometer with the units displayed in Gs and peak. The sensitivity still at 100 and the auto box checked. The source will be standard. Channel 1 is used. The averages should be about 10. 1600 lines, Hanning window and Fmax is at 600,000 CPM. Mode will be Linear + and TDC should also be selected.
- Setup would be very similar to a Raw sensor point but sampling less so less likely to have modulation

The Comparison, top is Raw and bottom is time waveform



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Navigating in WinTrans

- Click on FFT icon in MD
- Click on the Point Selection icon in WinTrans
  - Make sure to change the plot from FFT to time waveform
- Scroll through the list and find the correct sensor point
- The time waveform length will be too long to see impacts
  - Right key click on plot to adjust X axis
  - Change “to” number to about 100-200 milliseconds, so that only a few dotted line are in the time waveform
  - Dotted lines are TDC marks

Other Things…

- Reducing your Raw sensor points to 2 samples per degree with medium and high speed units
- Using the flat magnet in place of the rail magnet for Raw sensor points
  - Both of these things are to reduce the mounting resonance frequency vibration which may play a part in the possible issue.
- Document all cases with major discrepancies between the Raw and acceleration time waveforms sensor points

Theoretical PV Models

- Windrock offers 4 theoretical PV models
  - Specific Heats (Equation of State Model K Temperature)
  - K Based (Adiabatic)
  - N Based
  - Averaged N Based

- The Specific Heats is the default and the most widely used

Facts Jack

- You don’t need to know your compressor’s thermodynamic process but the more you understand them the better your analysis will be
  - Isothermal, Adiabatic or Polytrophic
  - All compressors have variations of all of these thermodynamic processes and they can change
  - Liquids dropping out, water jackets plugged up, significant gas makeup change and ambient heating or just a few things that can modify the thermodynamic process
- You do have to know which theoretical model will work best for your data

So Which One Do I Use?

- The answer is that you use the one that gives you the best results
  - Theoretical model lines up with the actual data
  - Has the best analysis capabilities
- Purpose is to see leakage
- An accurate gas analysis, good data and the correct geometry will make the Equation of State Model K Temperature model work well enough to do your analysis on most compressors

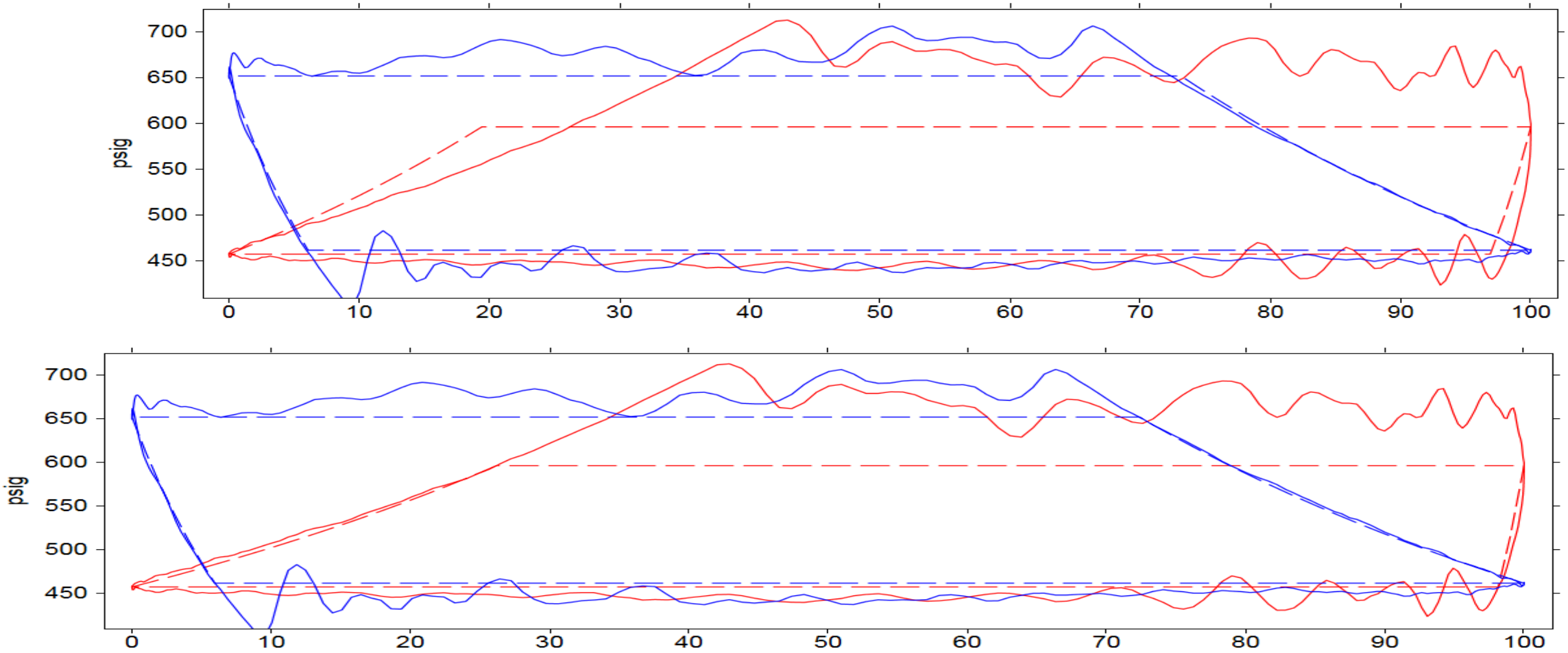
What Makes The Models Tic?

- The models are based off of the actual PV data
- K base models use the gas analysis
- N base models do not use gas analysis
  - Bad gas analysis
  - Gas composition changes frequently like flare gas units
  - Gas behaves differently at high pressures like CO2
- All of them use the set clearance to a degree
- Models do not change the slope of the compression and expansion, they change the VE which changes the slopes

The Down Side to N Based

- PV pattern interpretation of a leaking cylinder will change
  - Some cases leakage that can be easily seen with K based models will not show up at all using the N models
- N based models force the model to fit the PV at the VE area
  - Leakage can only be seen between the toes if it can be seen at all
- Should not use N models to set clearances
- And the Bug
  - If N base models are used then changing the group plots will only show K base models unless you make it calculate.
  - You can make it calculate by toggling the VE adjustment or Theoretical icon. However, changing the group plot will make it start over again.

Example #1 (Short & Fat PV)



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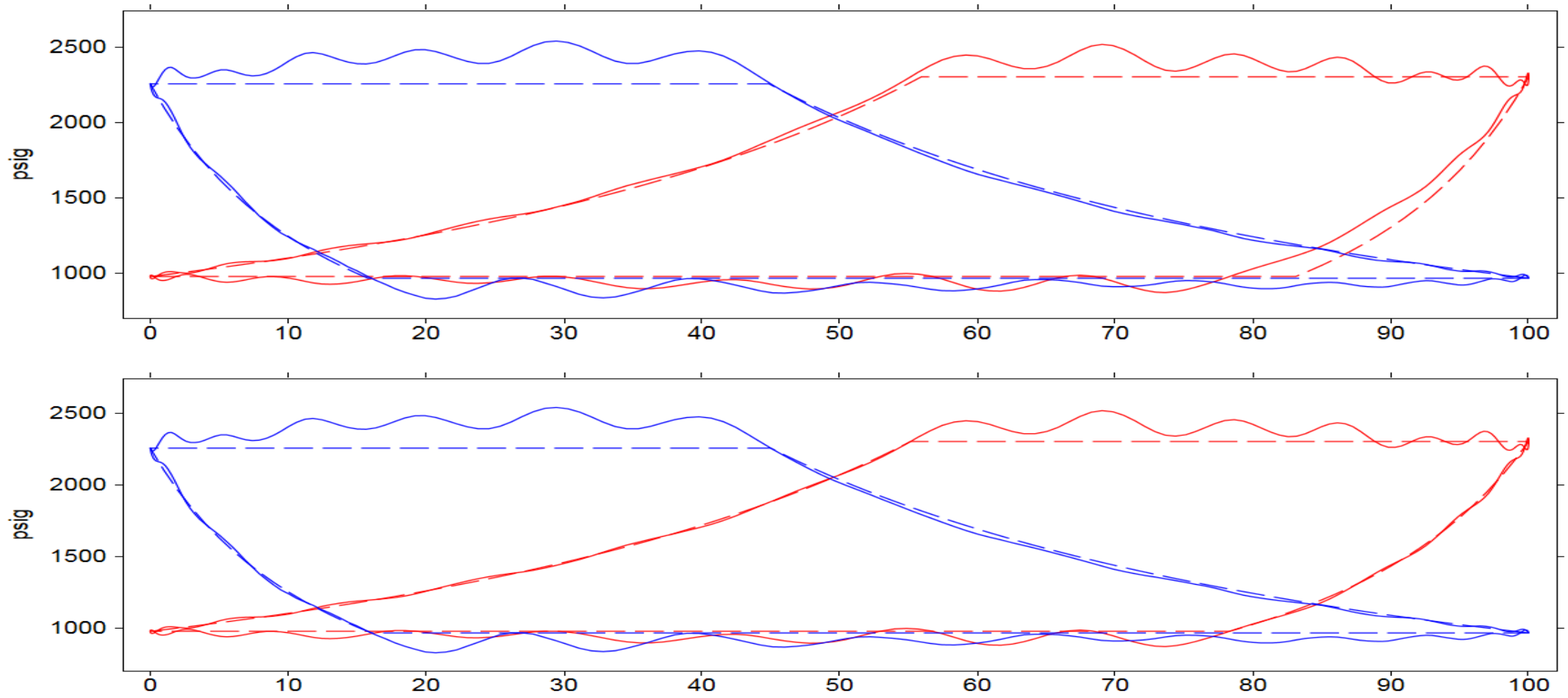
Example #2 (Medium and Average)



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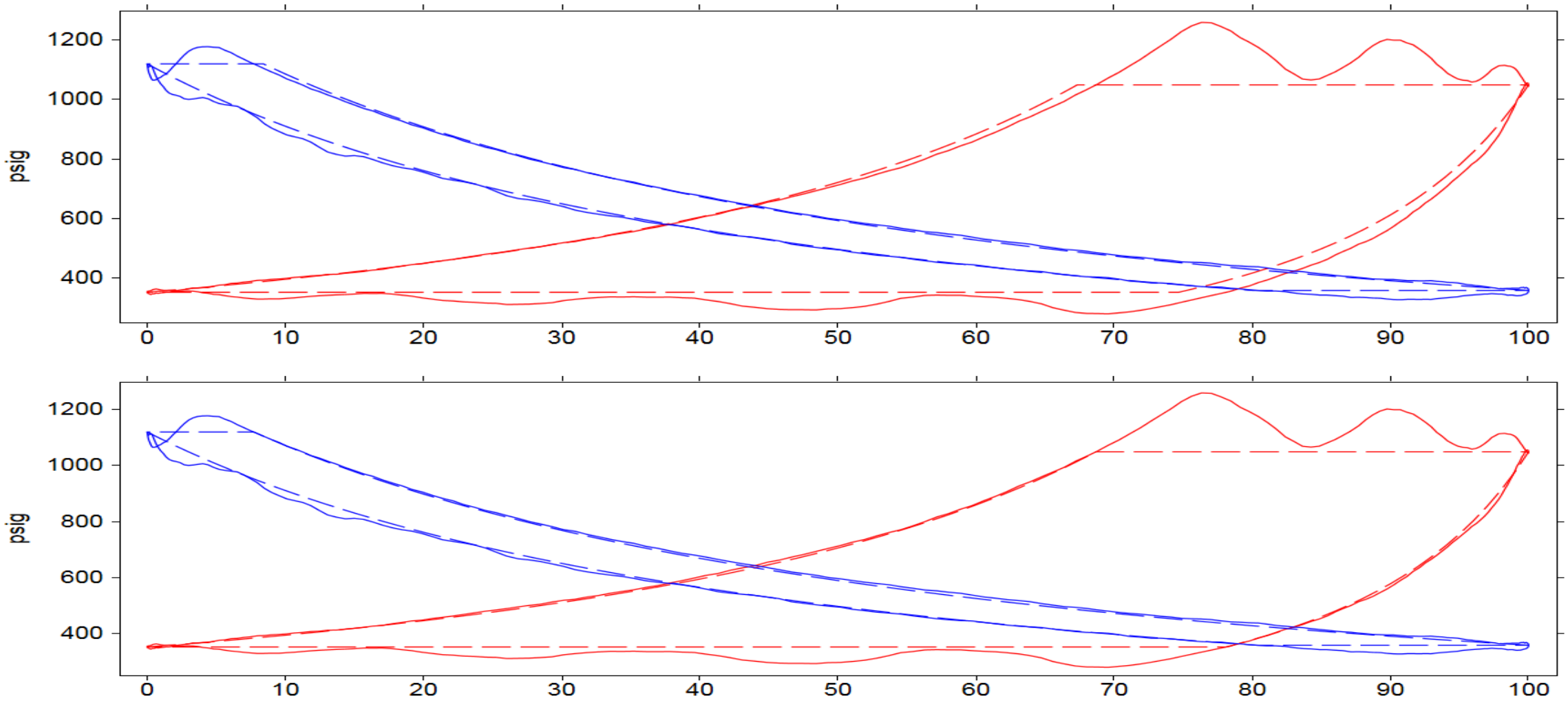
Example #3 (Tall and Skinny PV)



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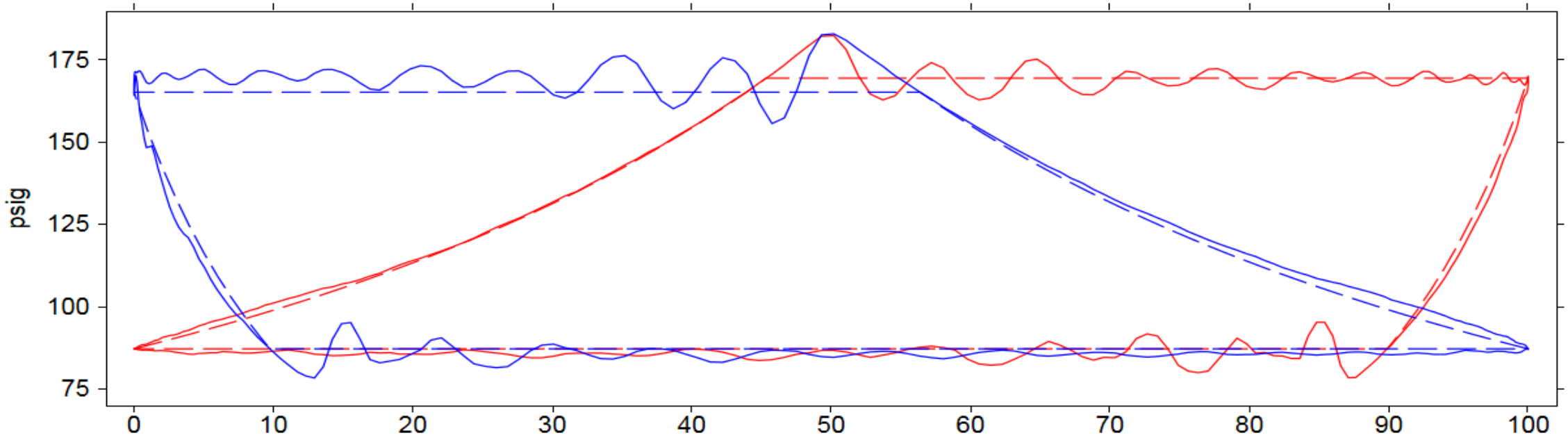
The Point

- N Base Theoretical will bend your theoretical PV in way which you will not see valve leakage
- Leaking piston rings can still be seen because of the curve



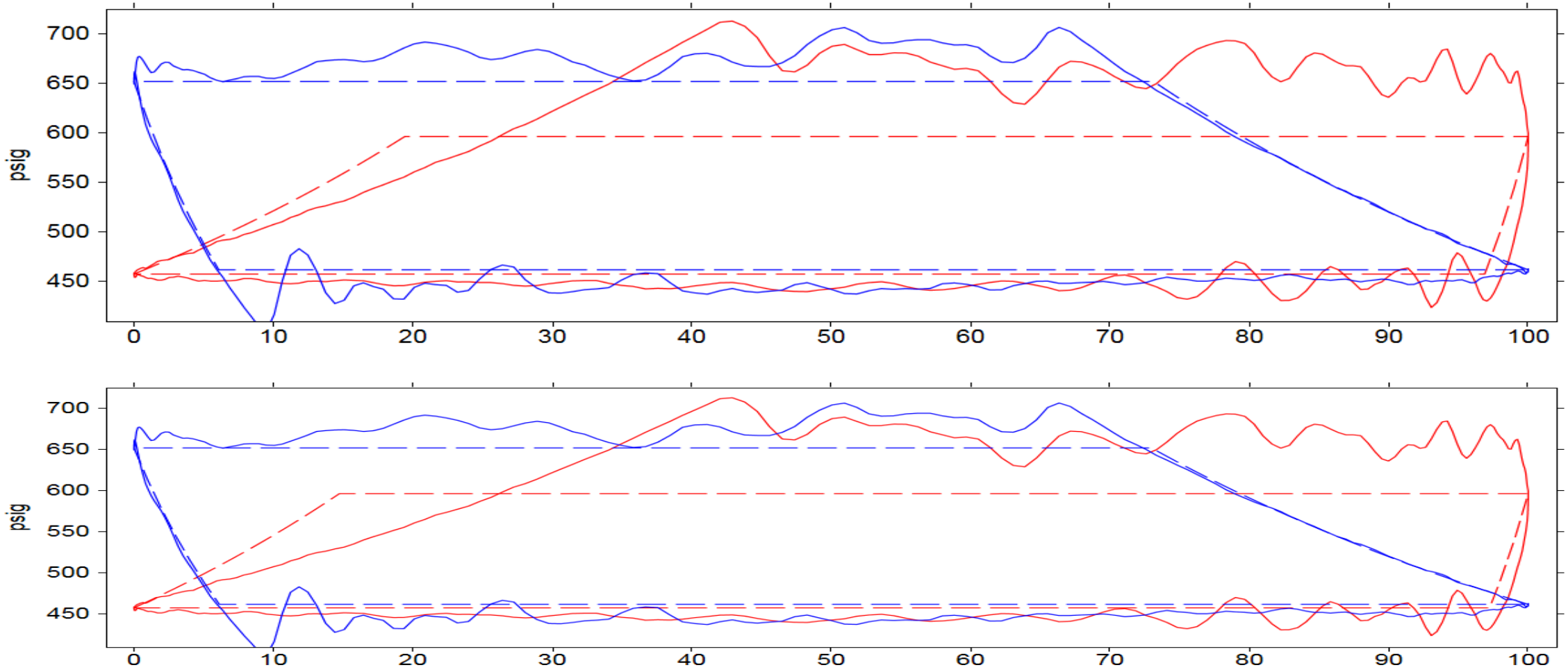
That's A Plus

- The N Base Theoretical model
  - Nonlinear curve from piston ring leakage will show up
  - Can be used to verify gas analysis
  - Can be used to verify TDC with compressor where the K base models fall short
  - Can be used to finally make that theoretical model fit that PV. (For show only)

Average N Base To The Rescue

- The point to the Average N Base model is for the benefits of the N Base model but to still see that valve leakage
- Works just like the N Base model but the VE placement is average out so you can see the valve leakage
- The correct clearance calculation is critical
  - However, if you are using the Adjust Clearance Window, the Average Clearance method or doing any verification then you should change your model to the specific heats model until the verification is completed and clearances are set
- It can exaggerate valve leakage (just like the average K)

Example #1 (Short and Fat PV), top is K and bottom is Average N



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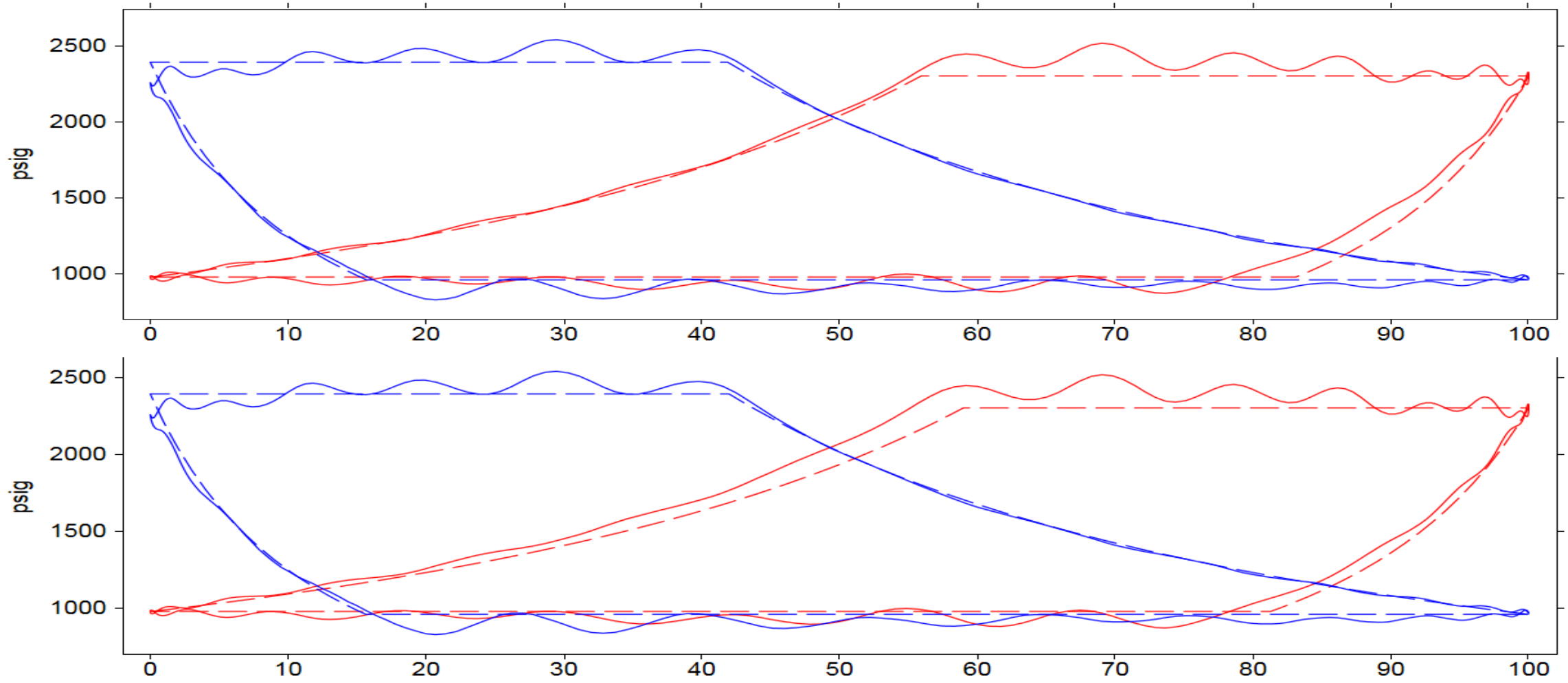
Example #2 (Medium and Average) bottom is the average N



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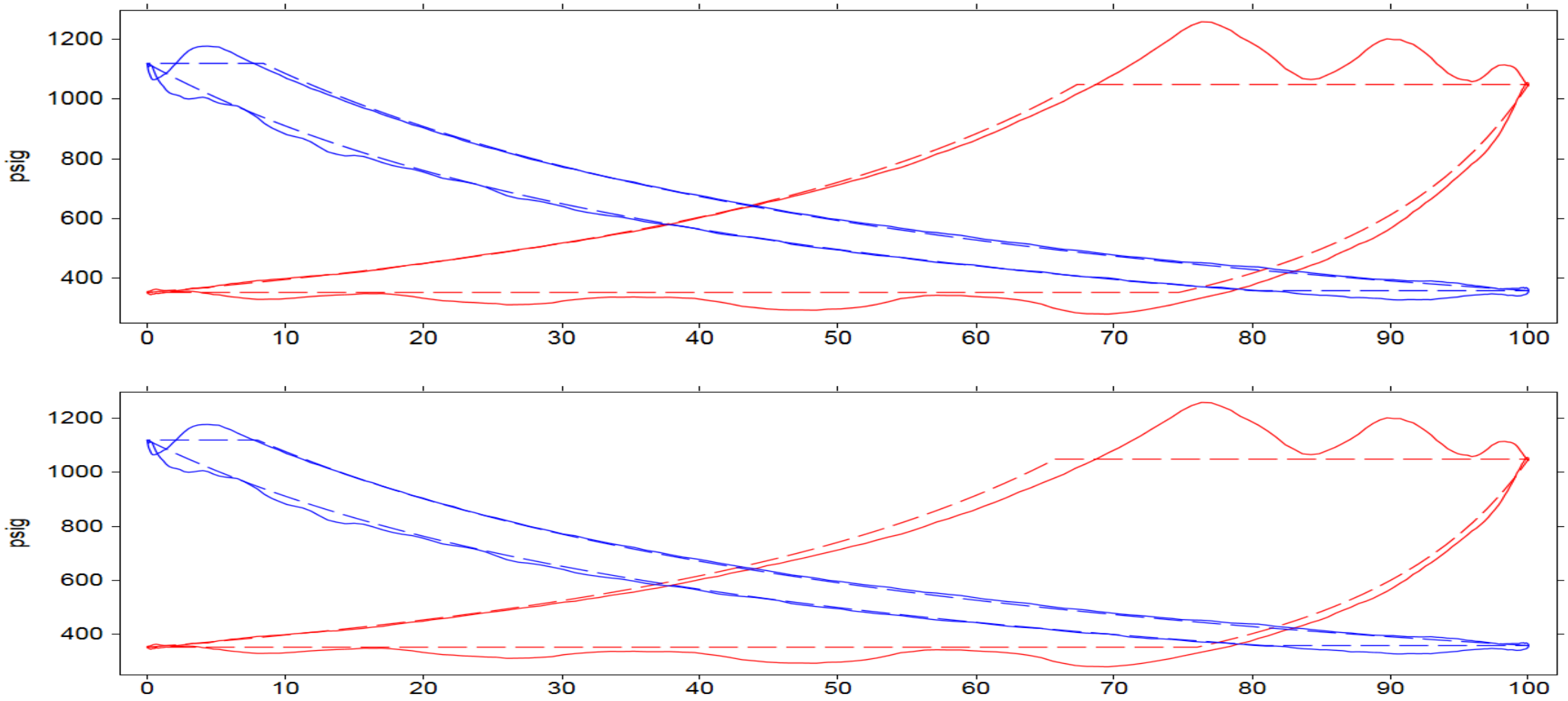
Example #3 (Tall and Skinny PV), bottom is average N



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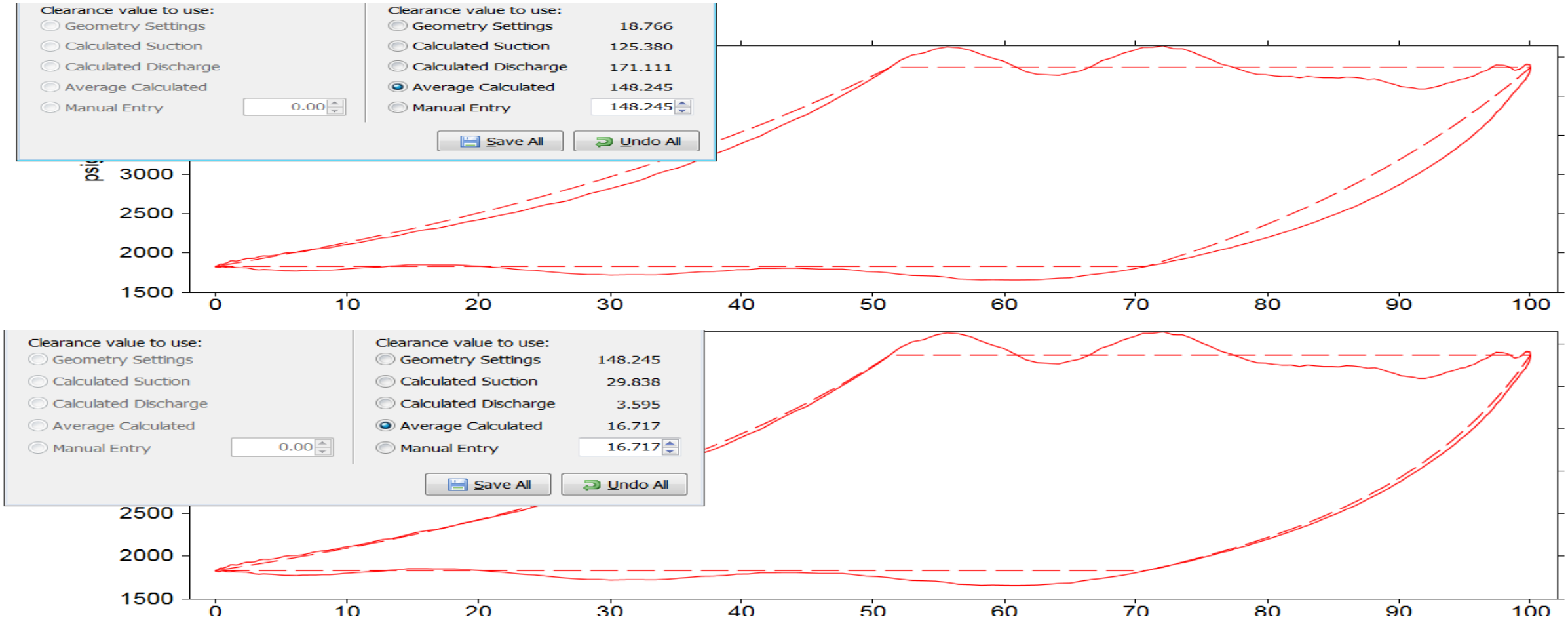
Sum It Up

- Try to use the specific heats model
  - Definitely use it to do most of your validation and to set clearances
- If you have a good gas analysis and the specific heats model is not showing valve leakage well then try the K Average
- If your gas analysis is suspect or the gas is constantly changing then try the N Average
- Watch out for late closing valves
  - Windrock software does not know how to handle it
  - Can affect TDC validation and clearance validation which is a domino effect

Clearance Calculation Models

- Windrock offers 2 models
  - GPSA – Calculations from the GPSA Engineering Data Book
    - Calculations include the ratio of the suction Z value to the discharge Z value.
  - 84-10a based – Calculations from the Southwest Research Institute's Technical Report 84-10a.
    - Calculations do not include Z ratio. However, K valves are used
    - Works well in cases of unusual compression like CO2

How Does It Work On CO2? 84-10a is bottom



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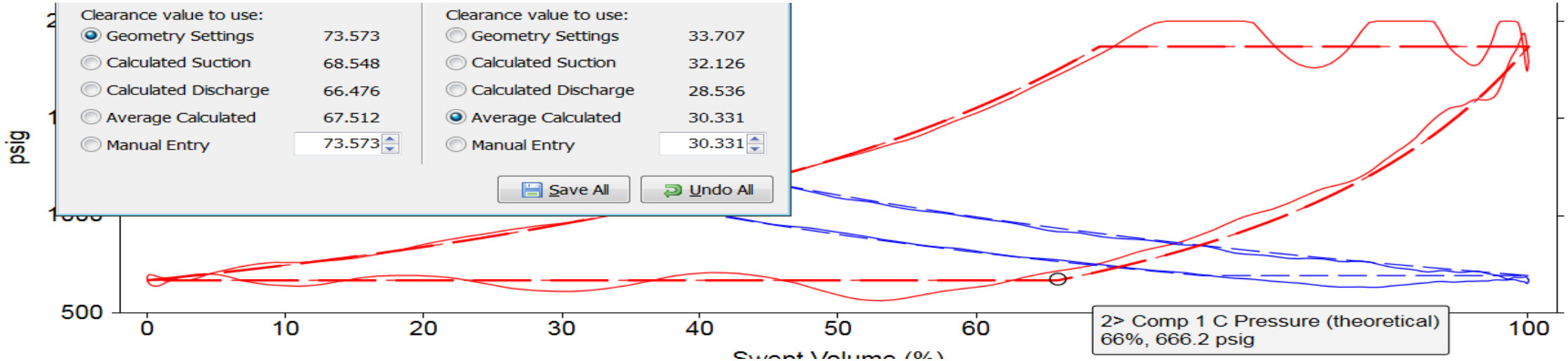
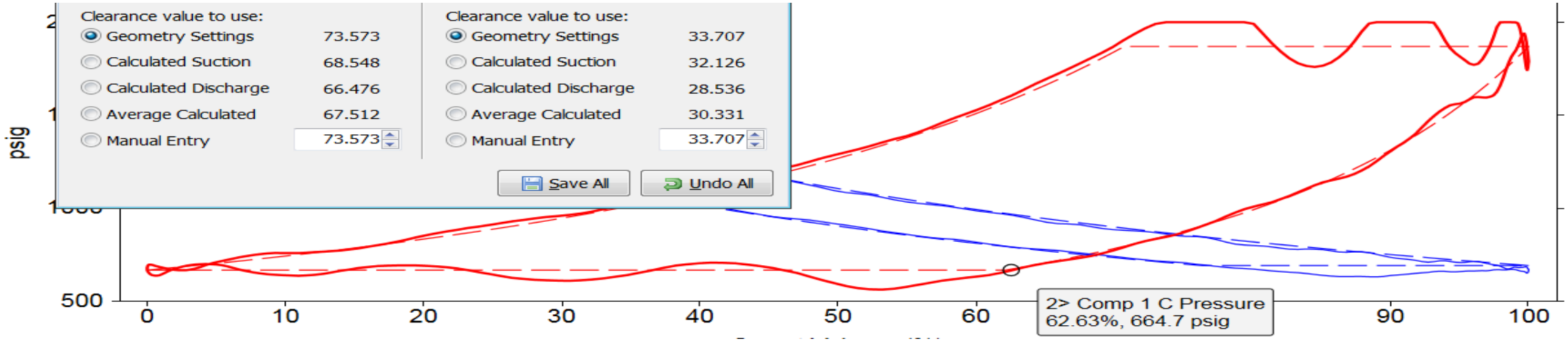
Which One Should I Use?

- Before deciding which calculation to use
  - Validate TDC, data and temperatures
  - Choose the highest pressure cylinder that does not have leakage or need much VE Correction
  - VERIFY that valves are not closing late and no piston rings are leaking
  - Turn Smoothing down the lowest setting you can without significantly changing the toe pressure or the slopes.
- Use both methods
  - Watch how the average moves the theoretical towards or away from the PV

Magic, GPSA was the winner! Time for the icing on the cake.





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Thank You
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