Monitoring Reciprocating Compressors

for the Vibration Institute
Piedmont Chapter
September 18th

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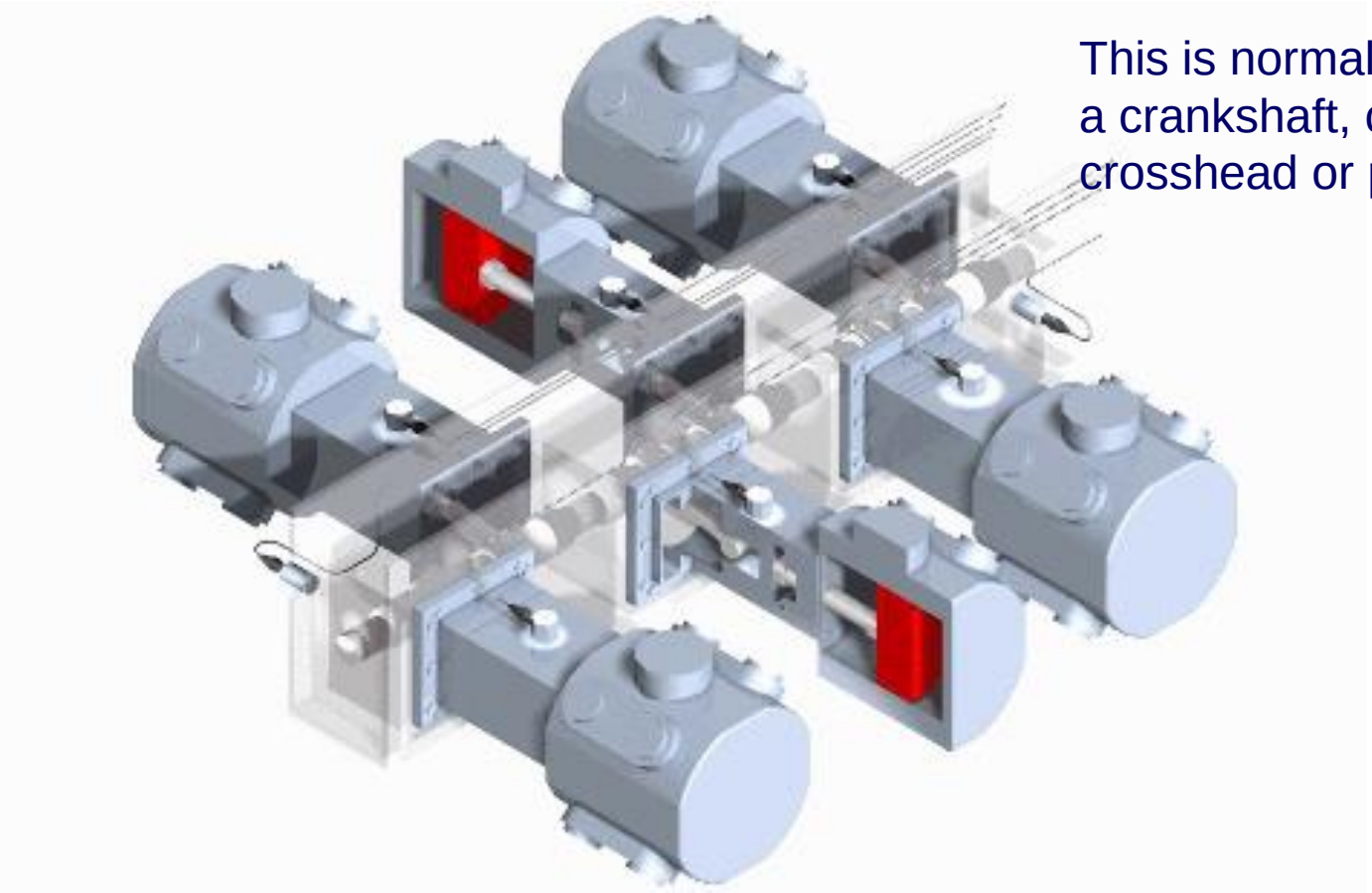
- Degree in Computer Science from the University of Tennessee
- Worked for CSI 1988 to 1996
- Worked for MachineXpert 1996 – 2002
- Worked for PCB Piezotronics 2002 – End 2012
- Worked for Windrock Beginning of 2013 to Present

What is a Reciprocating machine?

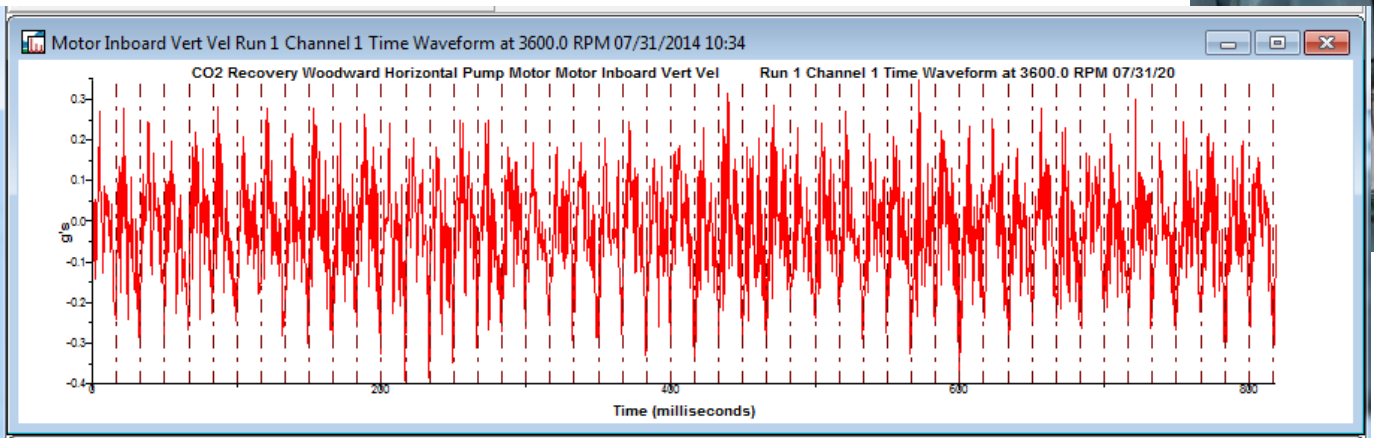
A reciprocating machine is one which rotational movement is turned into reciprocating motion

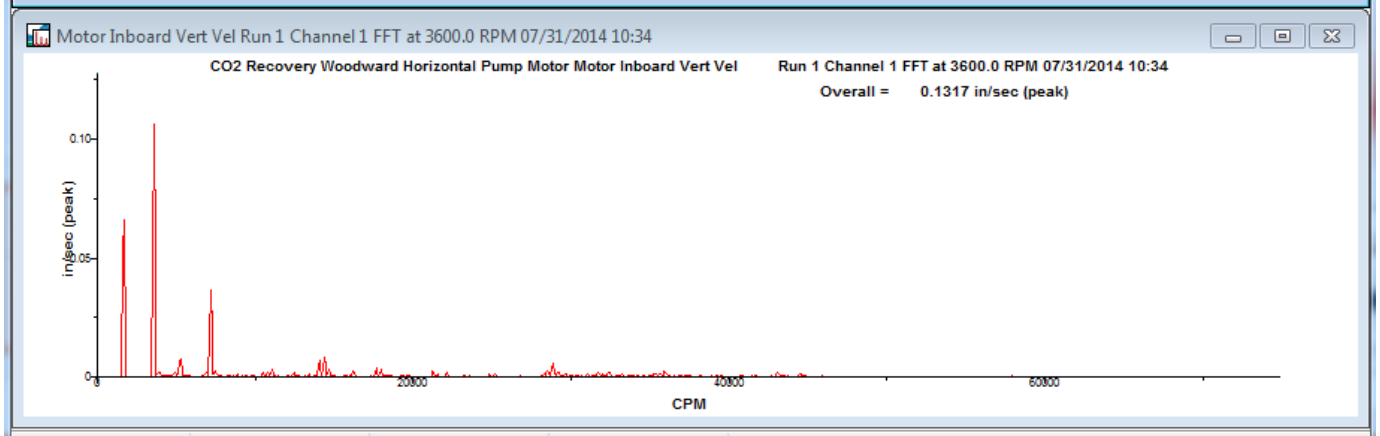
This is normally done with the use of a crankshaft, connecting rod and crosshead or piston



FFT Monitoring for Rotating Equipment

- **Components that PdM personal use to get FFT data:**
  - Accelerometer
  - Cable
  - Data Collector



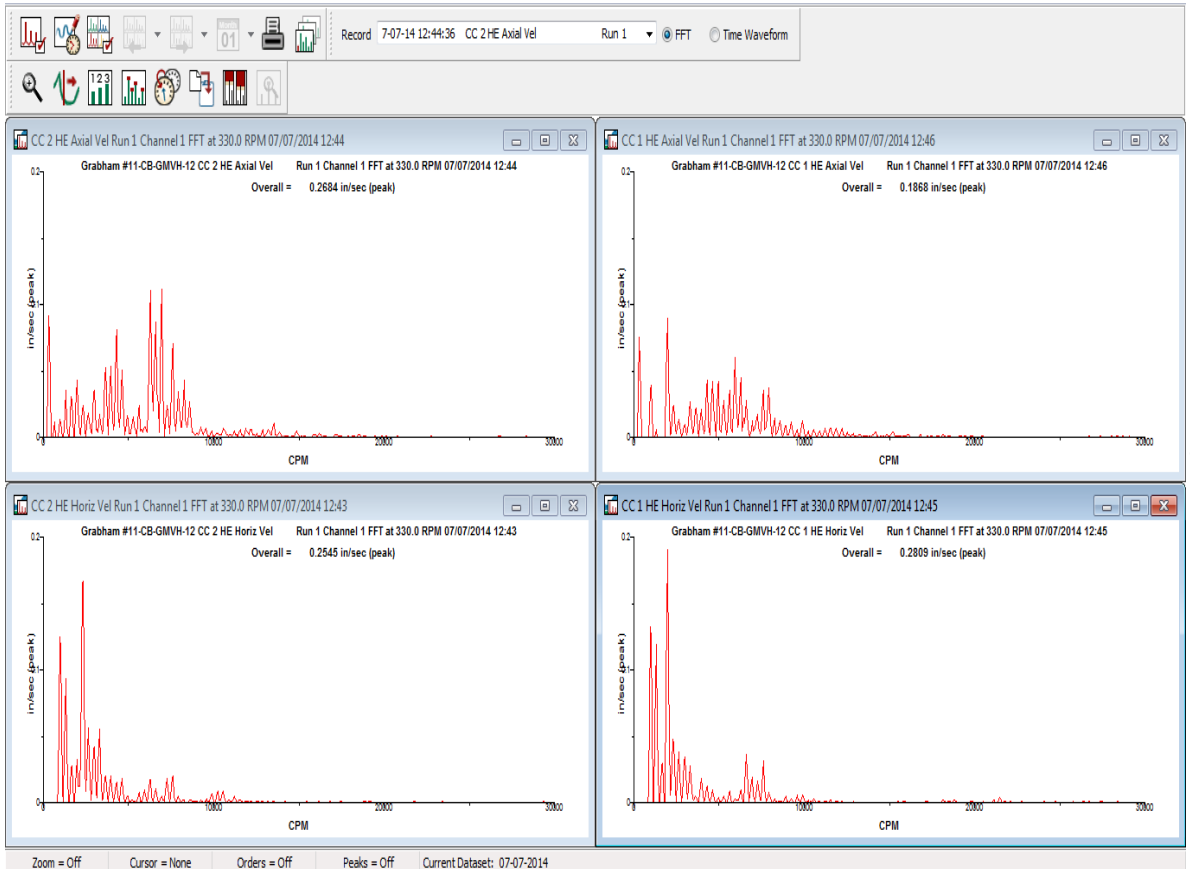


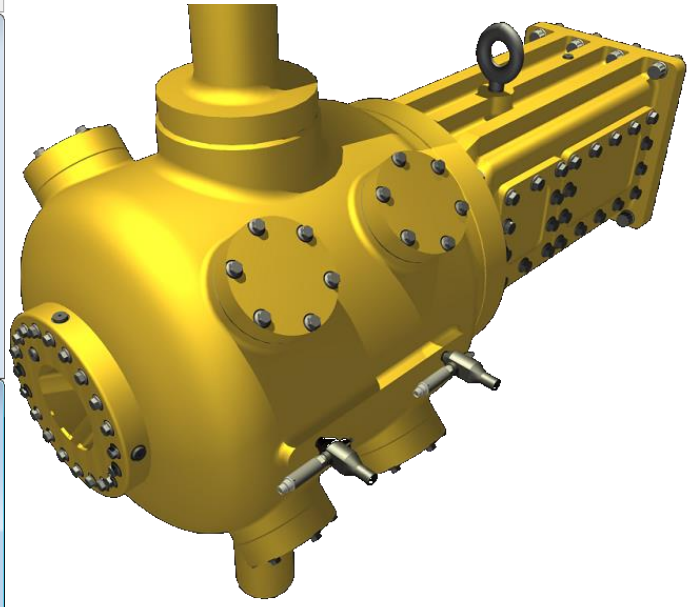
Vibration measured as a function of time but also as a function of frequency or phase

FFT Example on a reciprocating Compressor

Normal Horizontal and Axial readings on end of cylinder

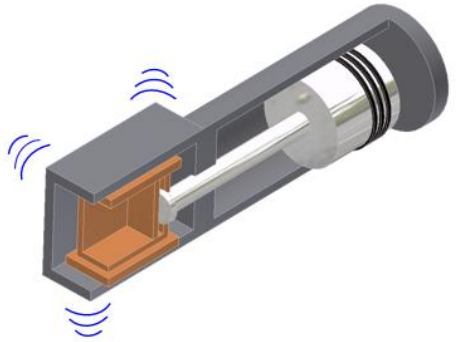
Lots of energy related to running speed could make it hard to determine issues

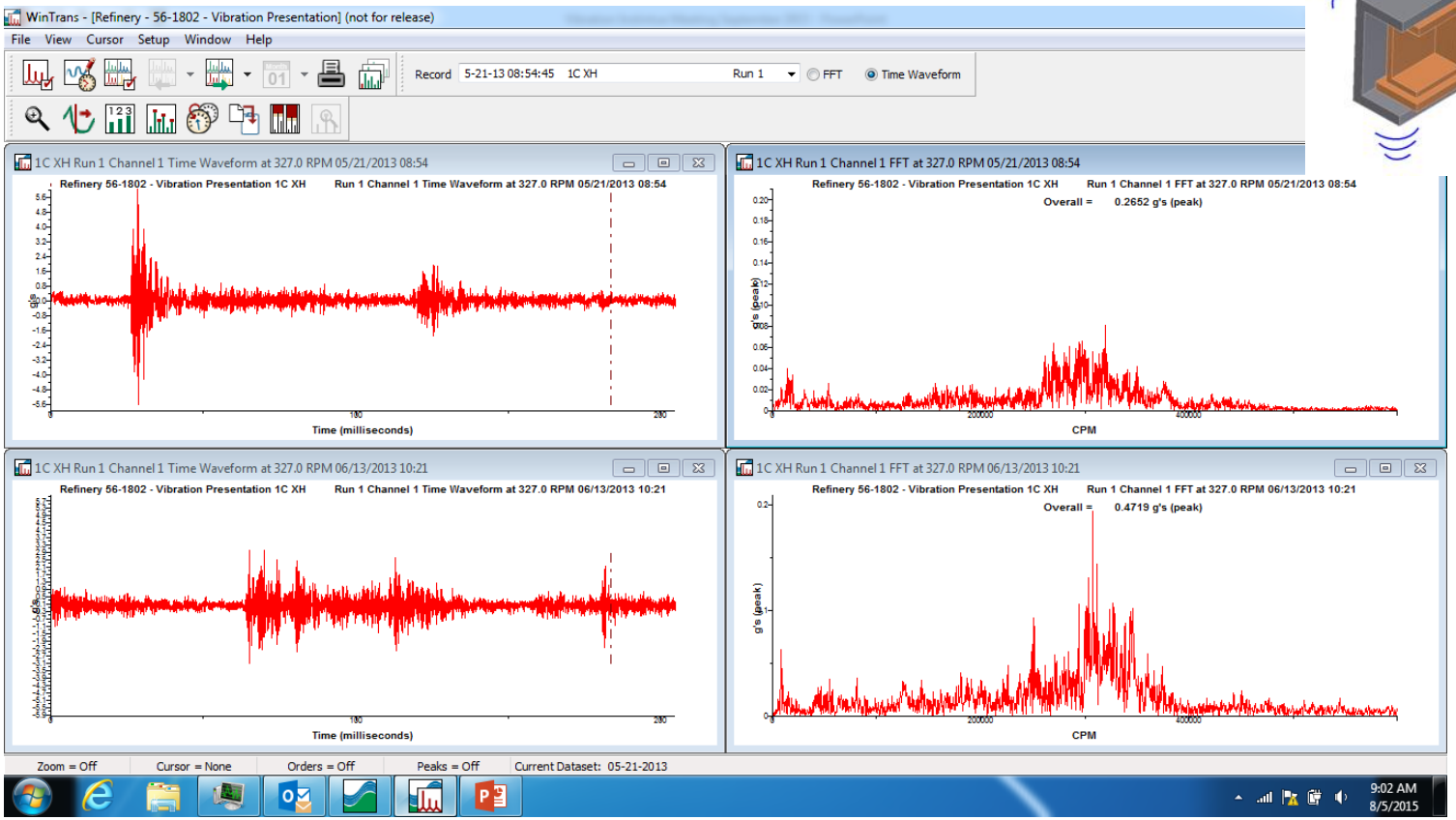




Vibration on the cross head of a compressor Throw

- **An Example of the limitations of Waveform/FFT analysis on a reciprocating compressor**

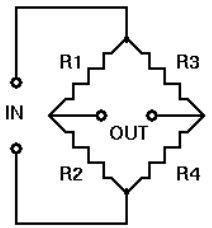




You Know something is wrong but what is the problem? Stay tune till the end of the presentation to find out.

Portable Reciprocating Monitoring Tool

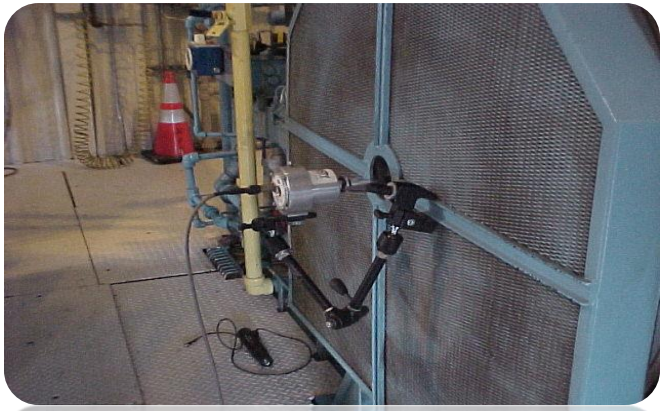
- **A Predictive Tool**
  - Reciprocating Machinery Analysis
    - Engines
    - Compressors
  - Data Typically Collected
    - In Cylinder Pressure
    - Temperatures
    - Vibration
    - Ultrasonics



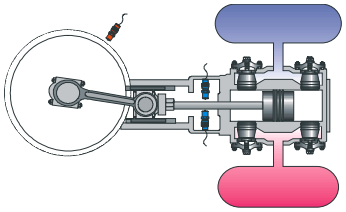
Key Component of Crank Angle Analysis

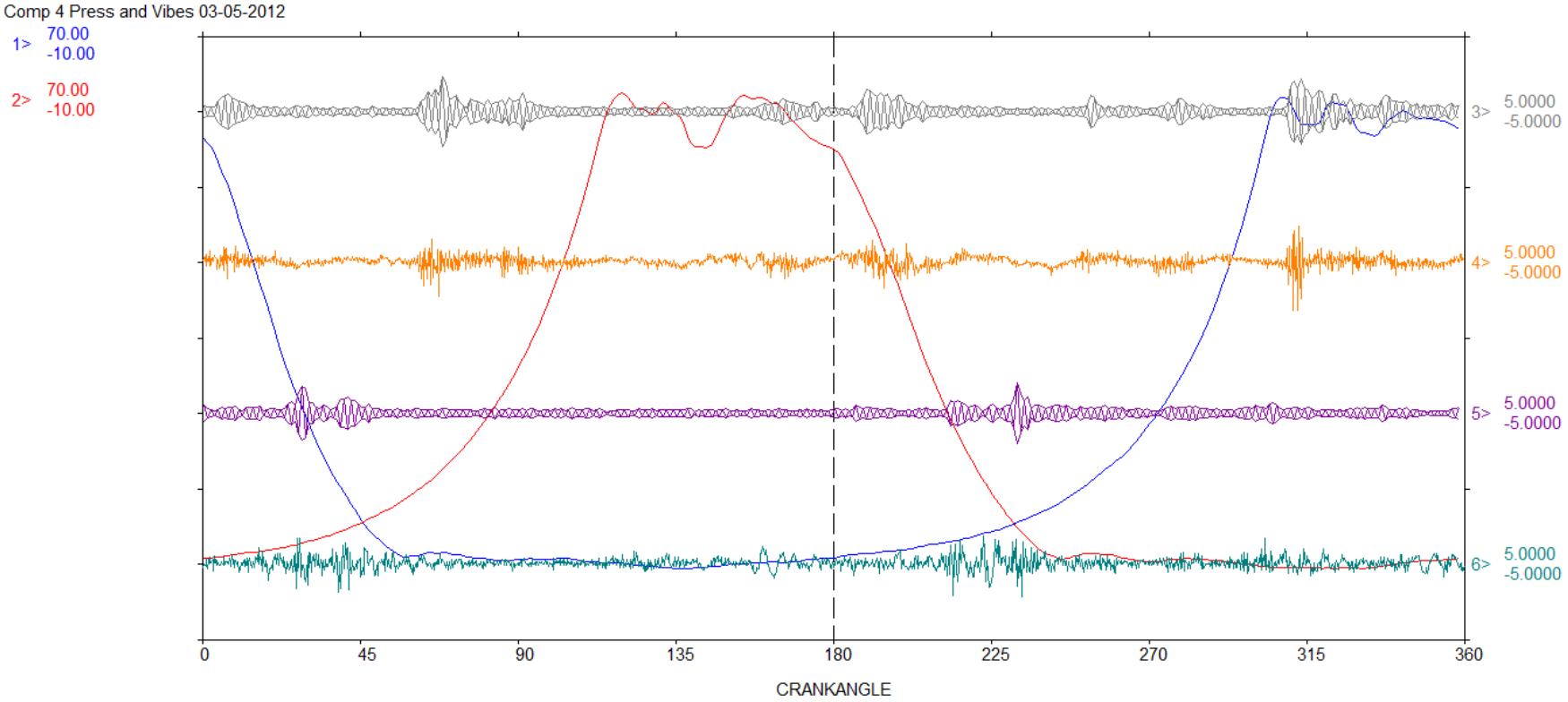
- **Pressure, Vibration, Ultrasonic Data is referenced to <u>crank shaft position</u>**
  - This is Not FFT or Spectrum Data Vibration Data
  - Band Filtered, Envelope Detected Vibration
  - Frequency Ranges specific to Reciprocating machines

- **Cylinder Top Dead Center (TDC) Synchronized to Analyzer**



Crank Angle Vibration on Compressor





Performance data on Compressors

- *Horsepower*
- Volumetric efficiency (suction and discharge)
- *Flow*
- Leak Index & Flow balance
- *Valve/nozzle HP loss – suction and discharge*
- Clearance volume
- Toe pressures
- Theoretical vs. actual discharge temperature
- *Rod load – compression and tension*
- Rod reversal

Mechanical defects on Compressors

- Vibration vs. Crankangle
  - Loose rod on piston/crosshead – by looking at the vibration pattern vs. rod load, you can zero in on the cause.
  - Abnormal impacts on valves, unloading devices
  - Crosshead looseness
  - Bearing defects

- FFT Vibration
  - Coupling misalignment
  - Imbalance
  - Foundation problems
  - Pulsation problems
  - Broken frame bolting

Common Problems picked up with portable

- **Engines**
  - Valve Leakage
  - Valve Train Problems
  - Ignition Issues
  - External leaks
  - Piston / Cylinder Issues
  - Bearings
  - Accessories like Oil Pump, Water Pump

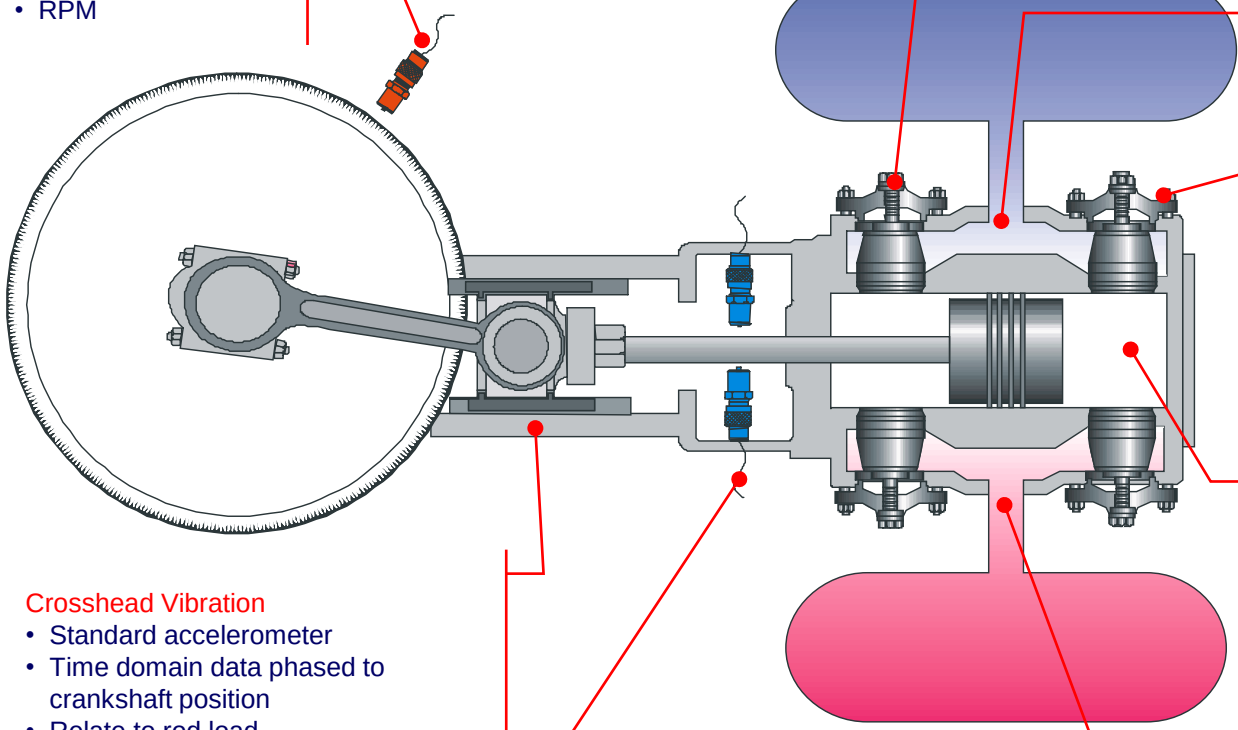
- **Compressor**
  - Suction/Discharge Valve
  - Leaking Valves
  - Leaking Rings
  - Malfunctioned Unloaders
  - Rod Load / Rod Reversal
    - Snap shot in time
  - Load / Flow
  - Vibration Issues
  - Pulsation
  - Rider Band / Cross Head Wear

Benefits of monitoring reciprocating compressors

- Defer Calendar Based Maintenance
- Performance Optimization
- Machinery Throughput Improvement
- Avoid Catastrophic Failures
- Reduce unscheduled downtime
- Reduce Machinery Abuse
- Quality Assurance of the New Installations and Overhaul Equipment
- Planning and Scheduling
- Extend the run time between overhauls
- Prioritize Maintenance Expenditures

Profit = Totalized throughput – (Energy cost + Maintenance Cost + Operating Cost + Analyzer Department Cost)

Compressor Data



TDC Reference
- Shaft encoder
- Magnetic pickup
- Phased data
- RPM

Valve cap temperatures
- Infrared temperature wand

Suction/discharge temperatures
- Infrared temperature wand
- thermocouples, RTDs

Suction/discharge valve vibration
Compressor ring leak vibration
Liner scoring
- Ultrasonic microphone
- Standard accelerometer
- Time domain data phased to crankshaft position

Head/crank end pressure
- Pressure transducer
- Time domain data phased to crankshaft position
- Multi-period sampling statistics

Crosshead Vibration
- Standard accelerometer
- Time domain data phased to crankshaft position
- Relate to rod load

Rod Motion
- Proximity probes
- Time-domain data phased to crankshaft position
- Rod displacement trends

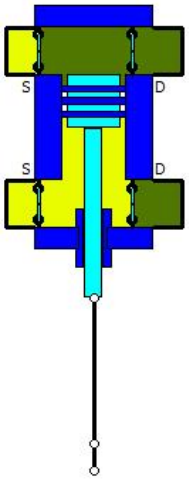
Frame vibration (displacement)
- Tri-axial accelerometer (H, V, A) taken at opposite corners of engine frae
- Frequency domain data

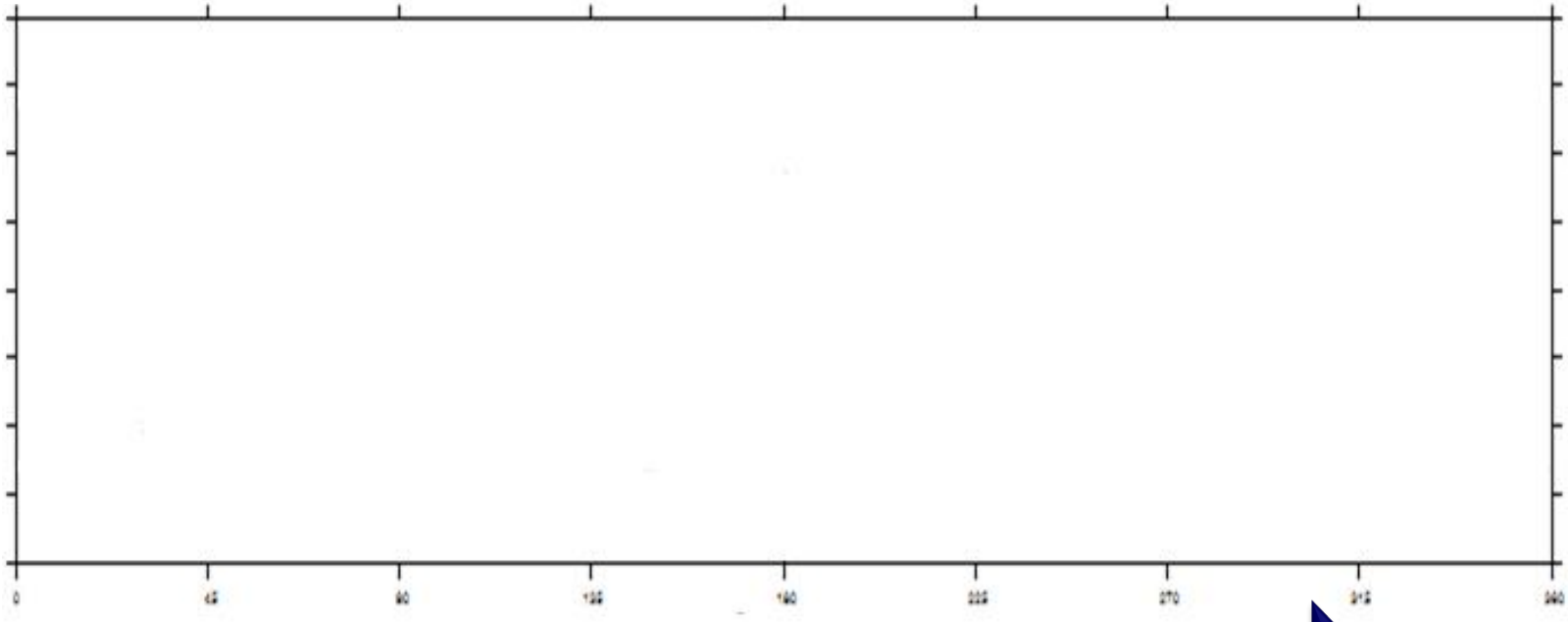
Suction/discharge nozzle pressure
- Pressure transducer
- Time domain data phased to crankshaft position (valve/passage loss calculations)
- Frequency domain (pulsation spectrum)
- Multi-period sampling statistics

Pressure Readings

Head and Crank End Pressure Sensors

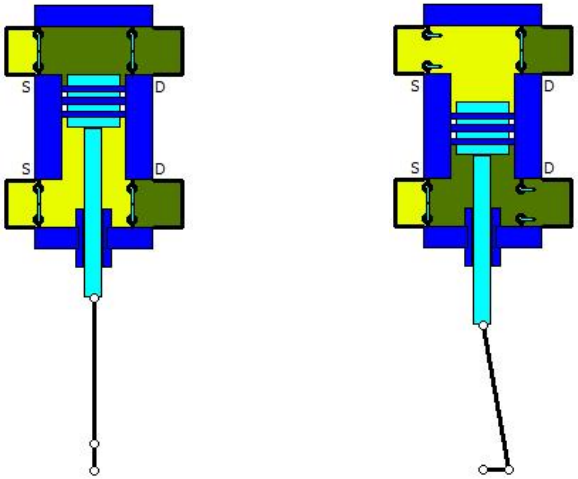
Pressure Traces– Reciprocating

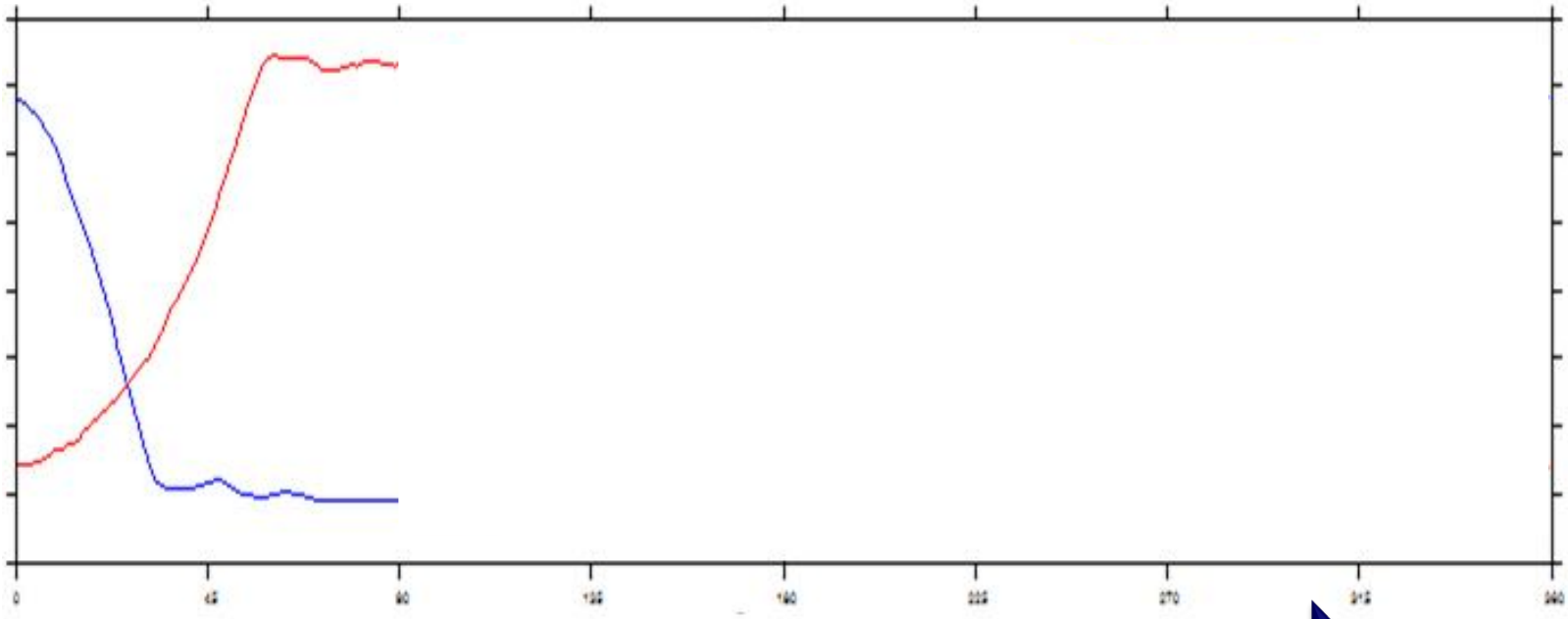




Crankangle Degree

Pressure Traces– Reciprocating





Crankangle Degree

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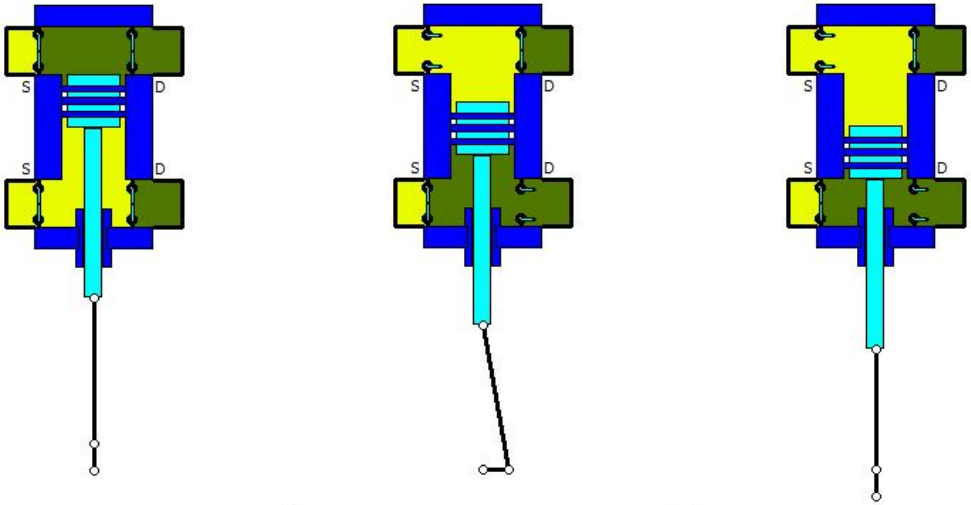
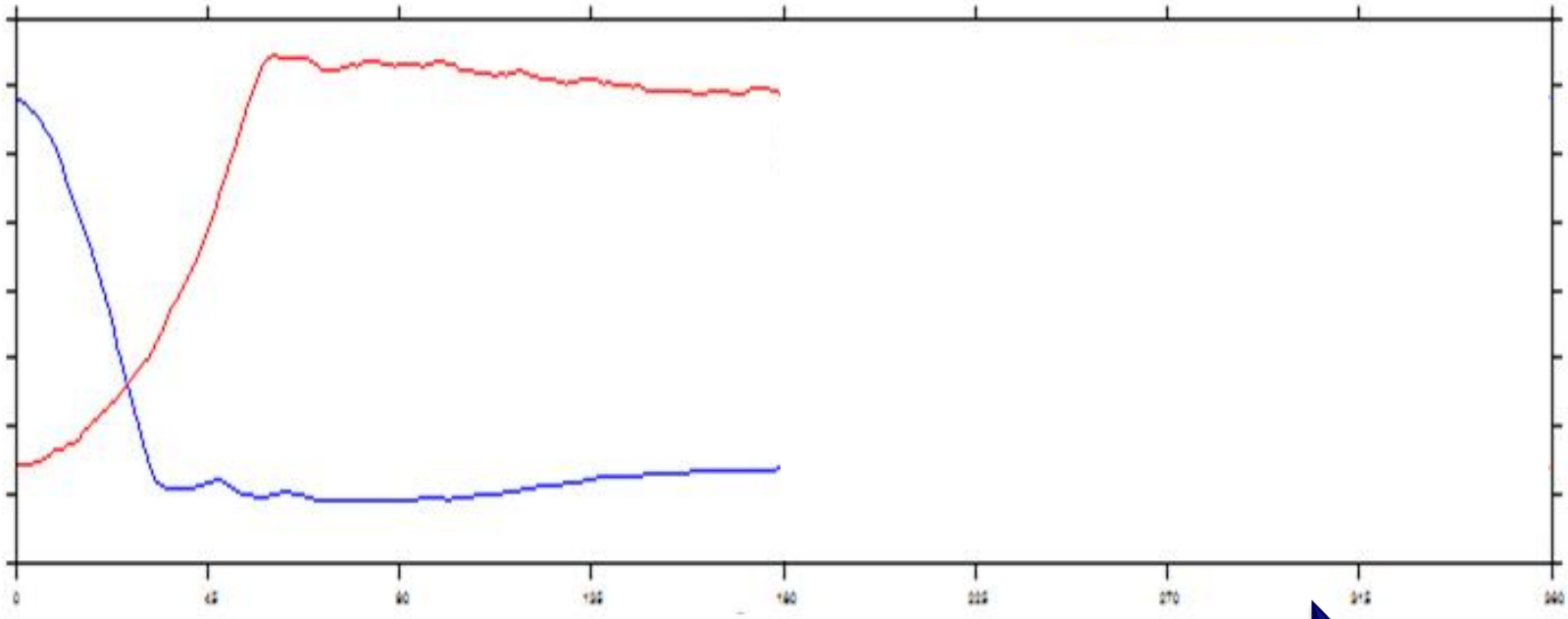
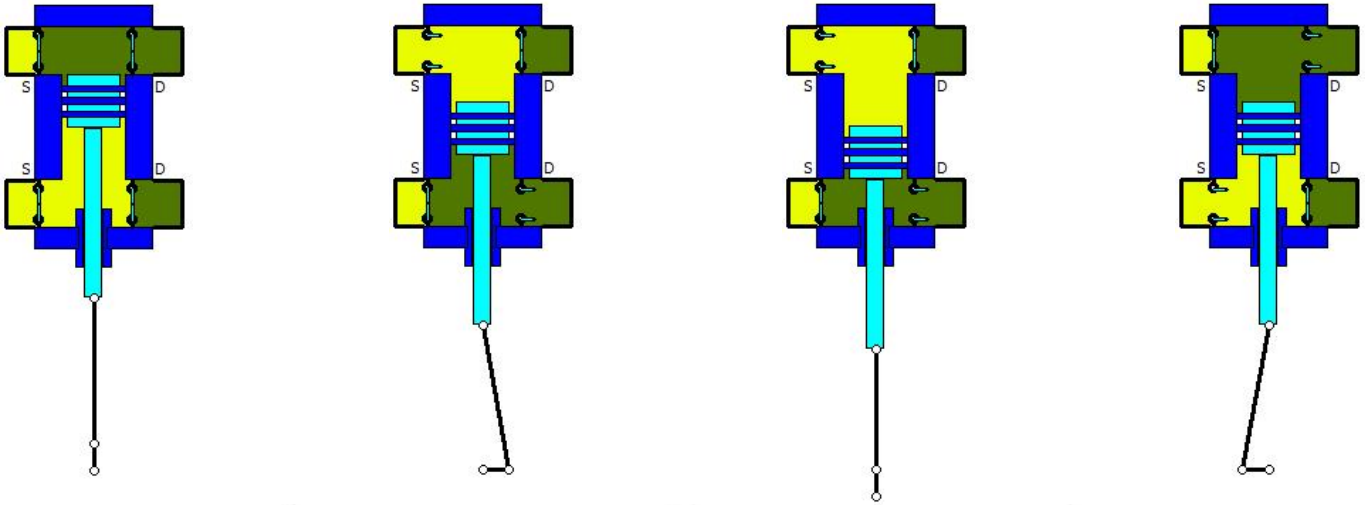
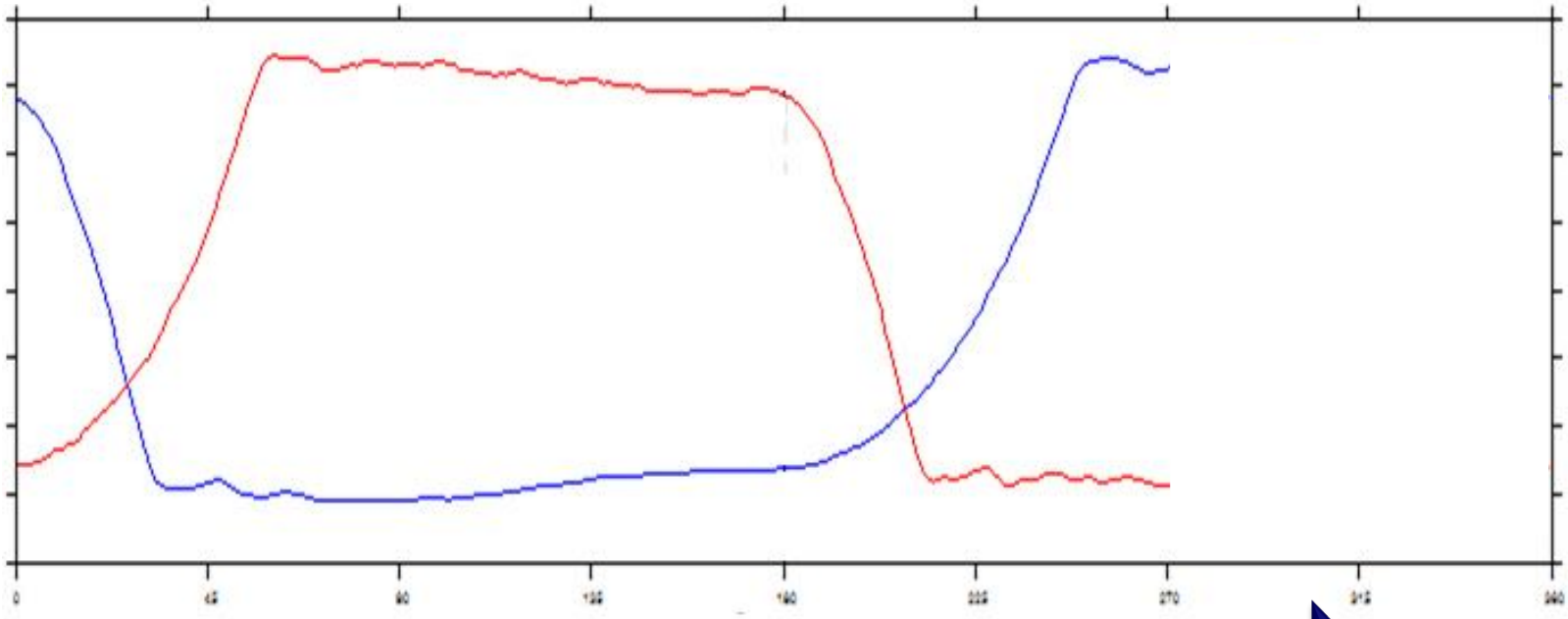




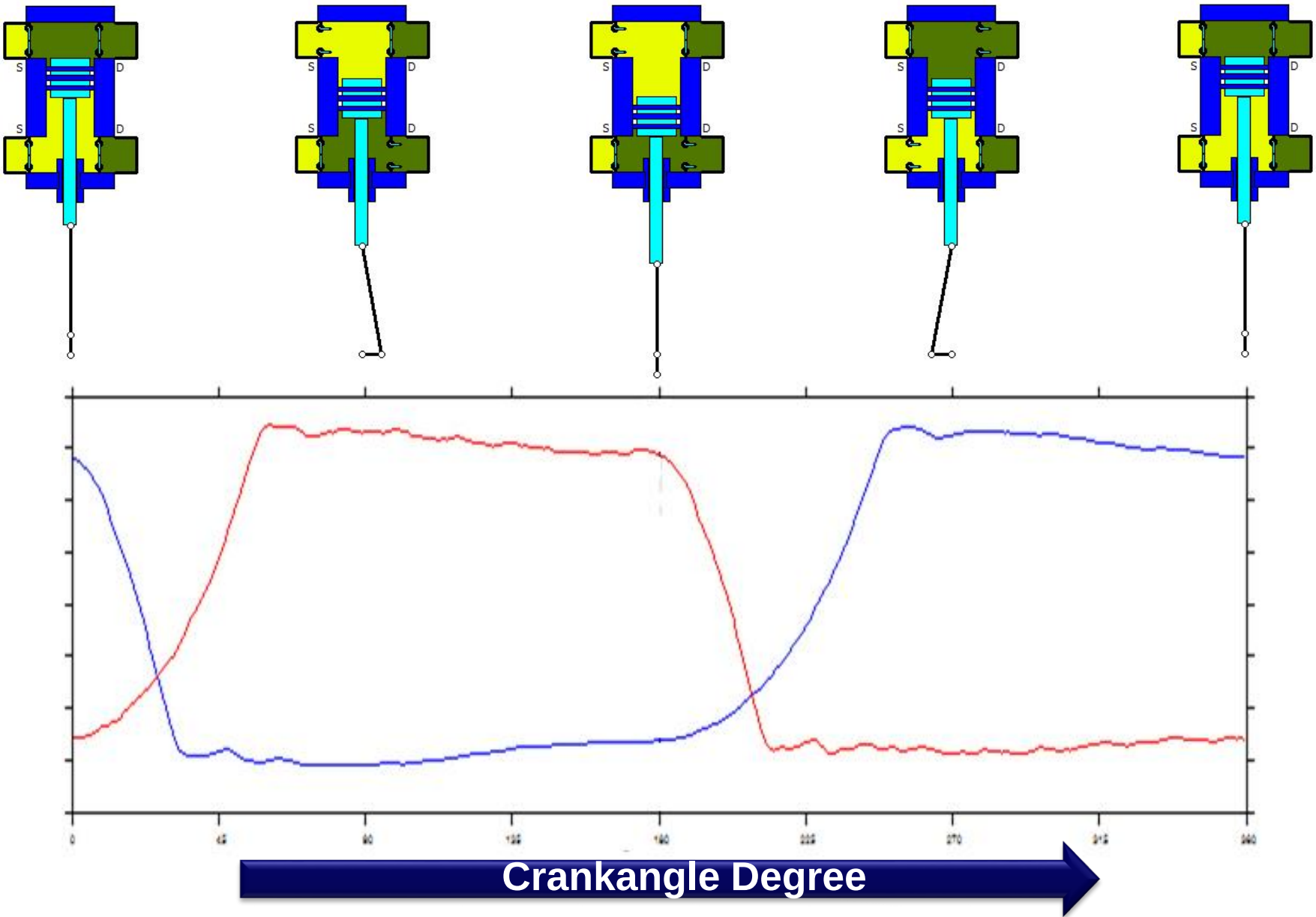
Pressure Traces– Reciprocating



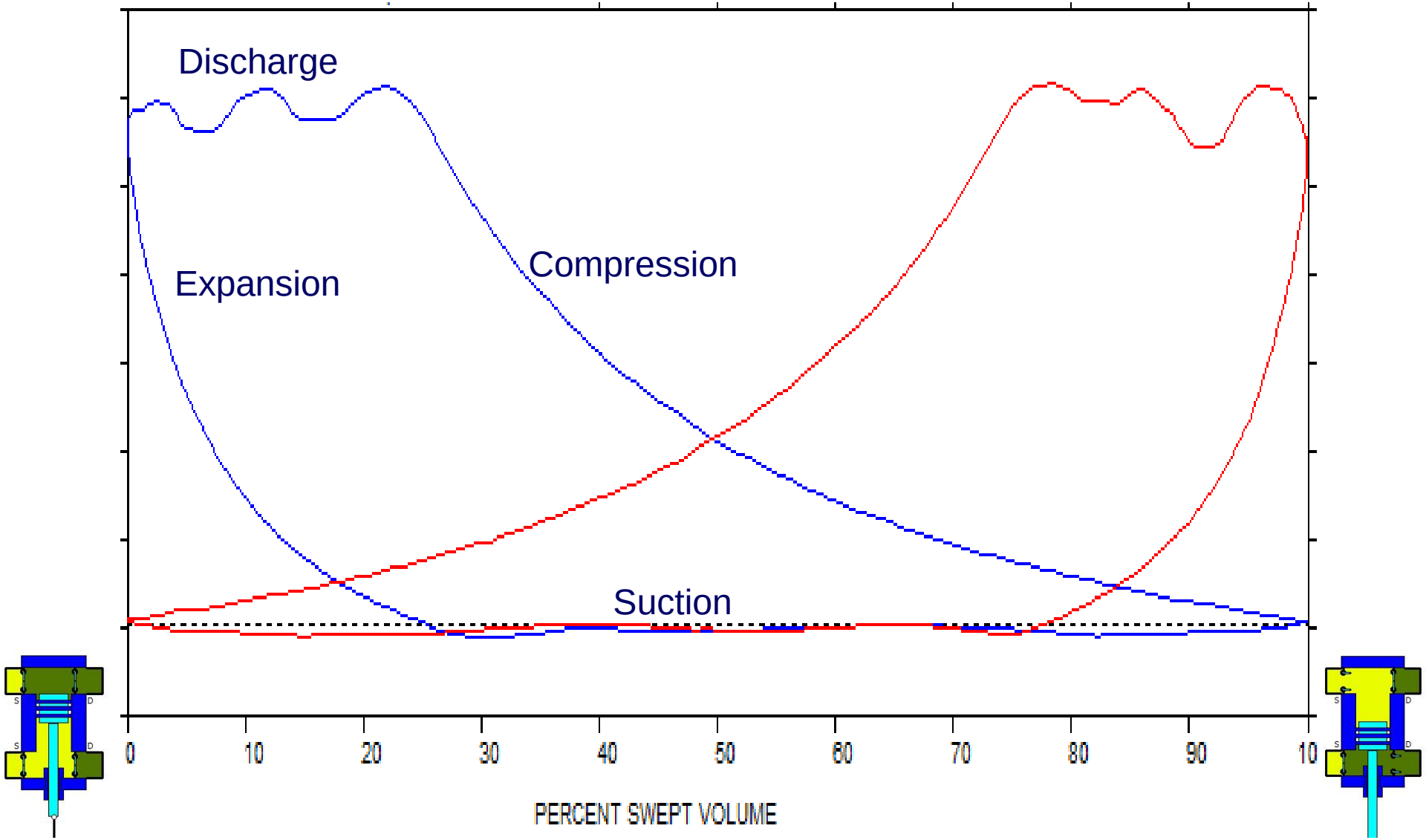


Crankangle Degree

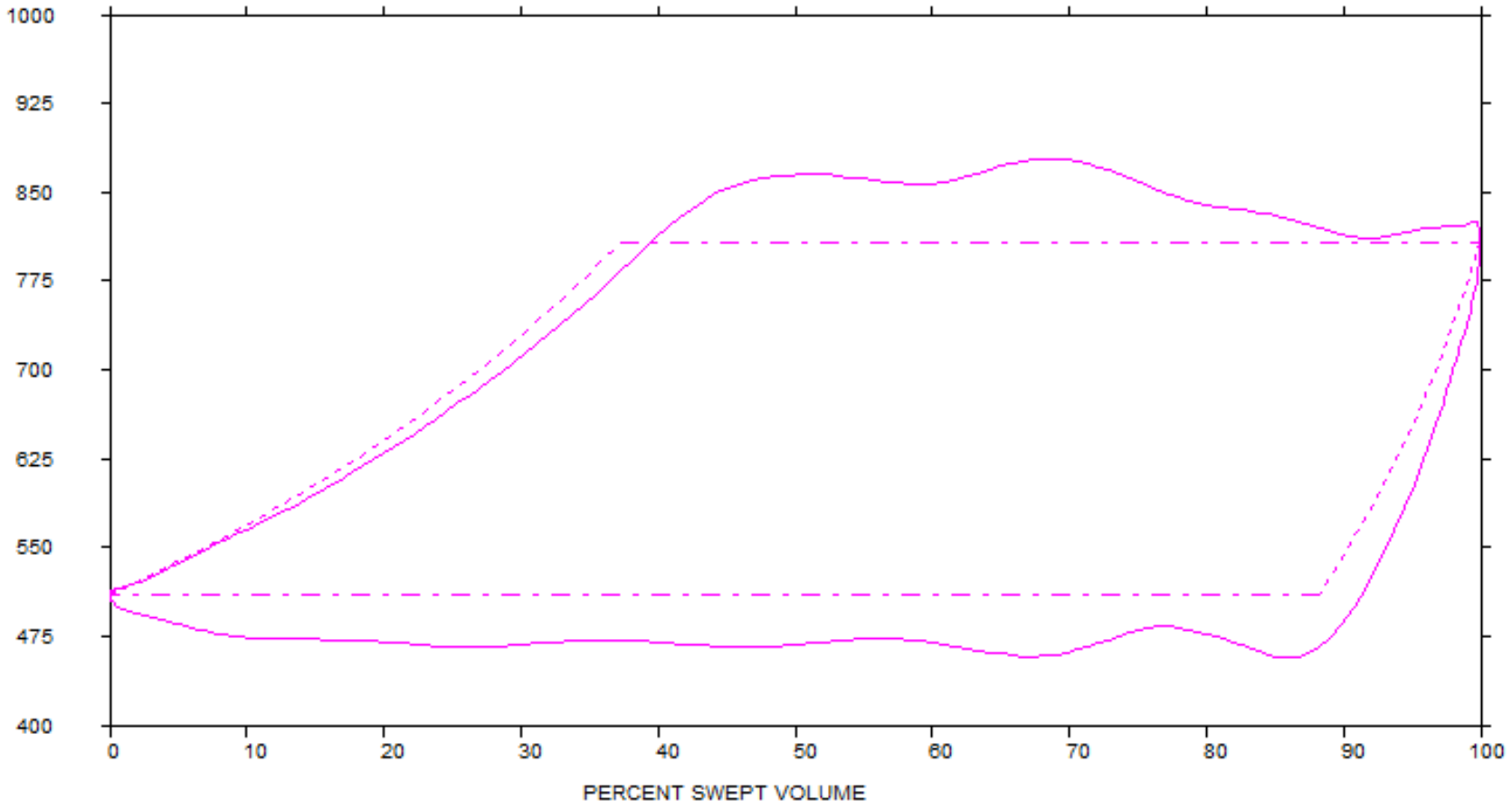
Pressure Traces– Reciprocating



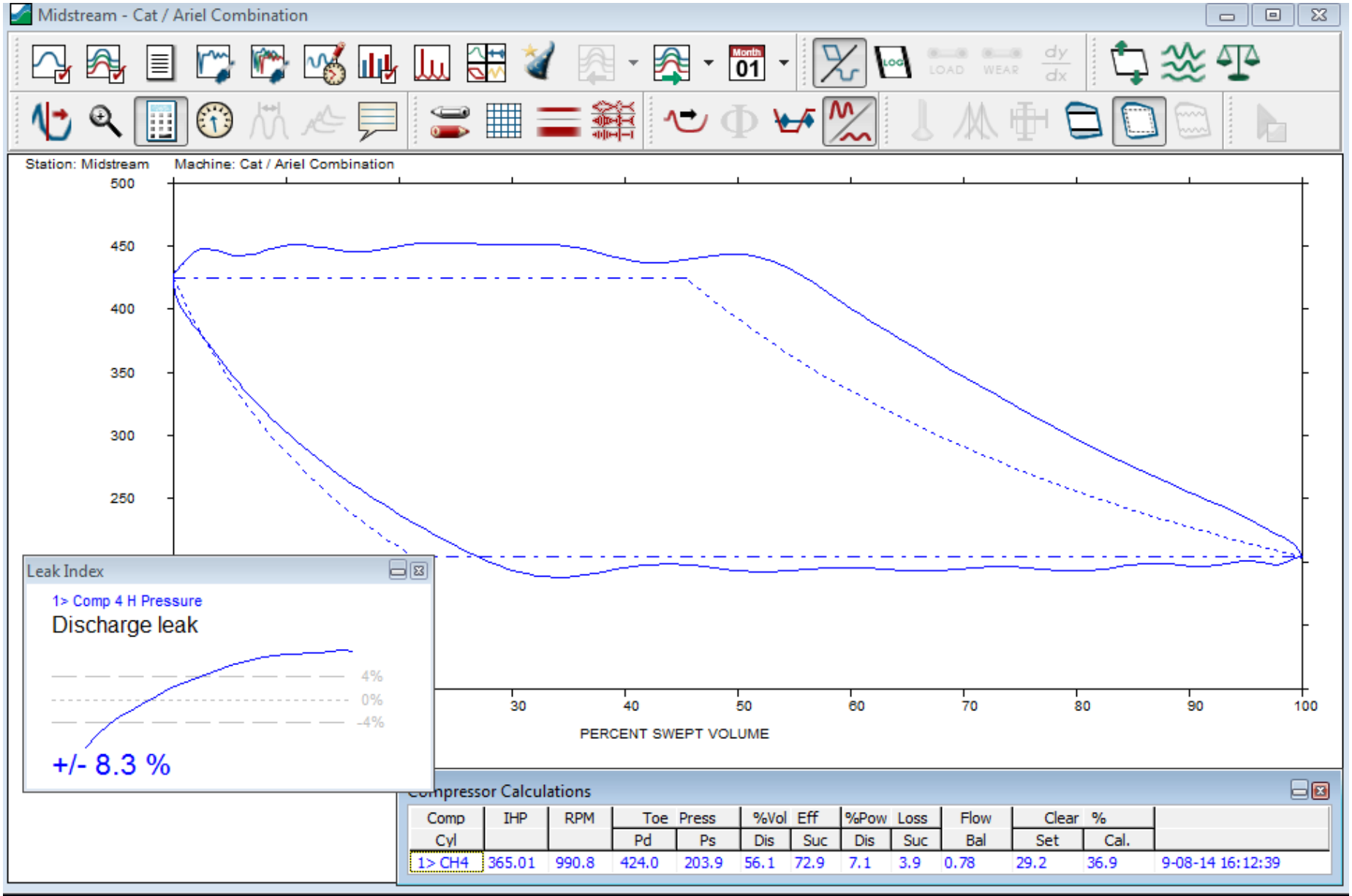
Pressure Volume Curves



Suction Valve Leakage

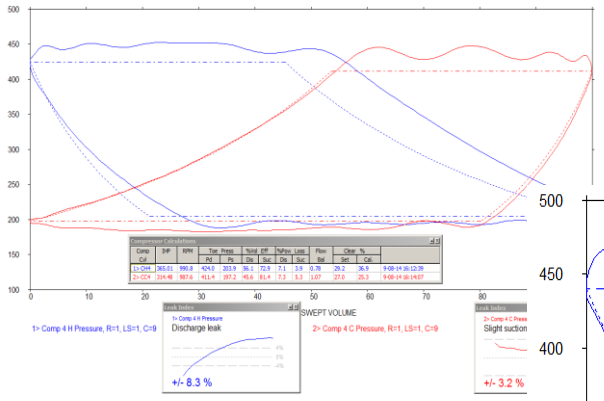


Discharge Valve Leakage

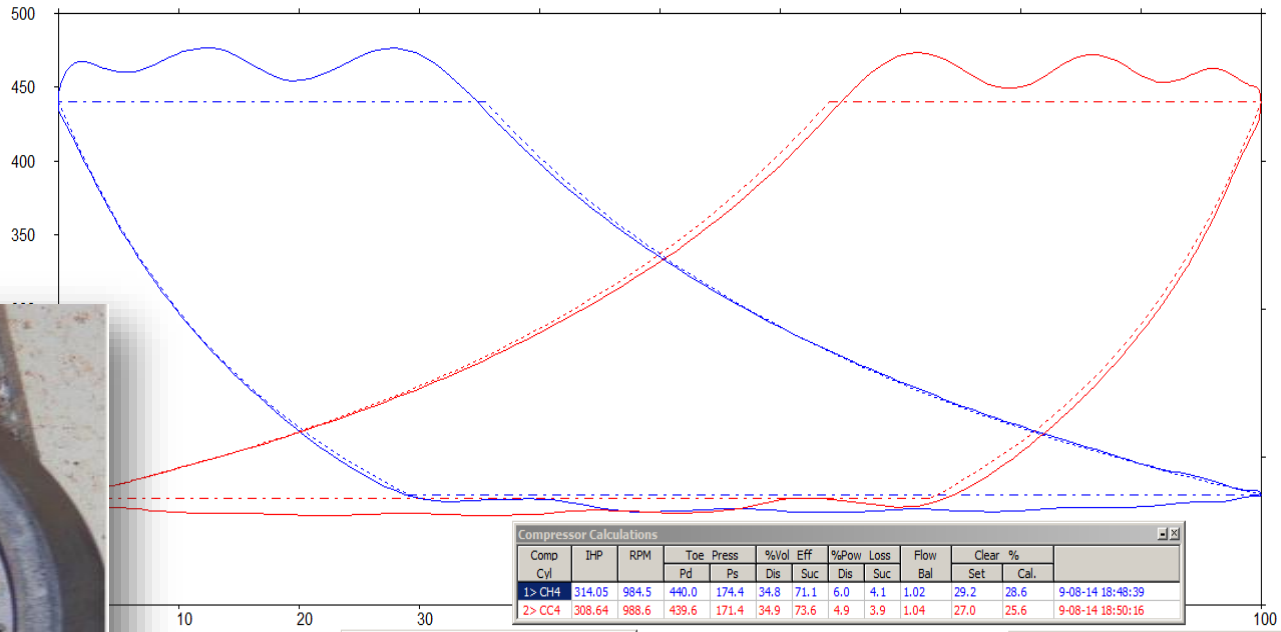


Repaired Discharge Valve

Before

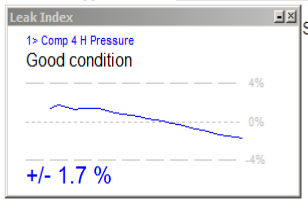


After Valve



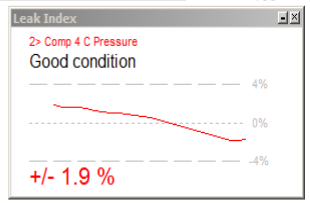
Compressor Calculations

Comp Cyl	IHP	RPM	Toe Press Pd	Toe Press Ps	%Vol Eff Dis	%Vol Eff Suc	%Pow Loss Dis	%Pow Loss Suc	Flow Bal	Clear % Set	Clear % Cal.	
1> CH4	314.05	984.5	440.0	174.4	34.8	71.1	6.0	4.1	1.02	29.2	28.6	9-08-14 18:48:39
2> CC4	308.64	988.6	439.6	171.4	34.9	73.6	4.9	3.9	1.04	27.0	25.6	9-08-14 18:50:16



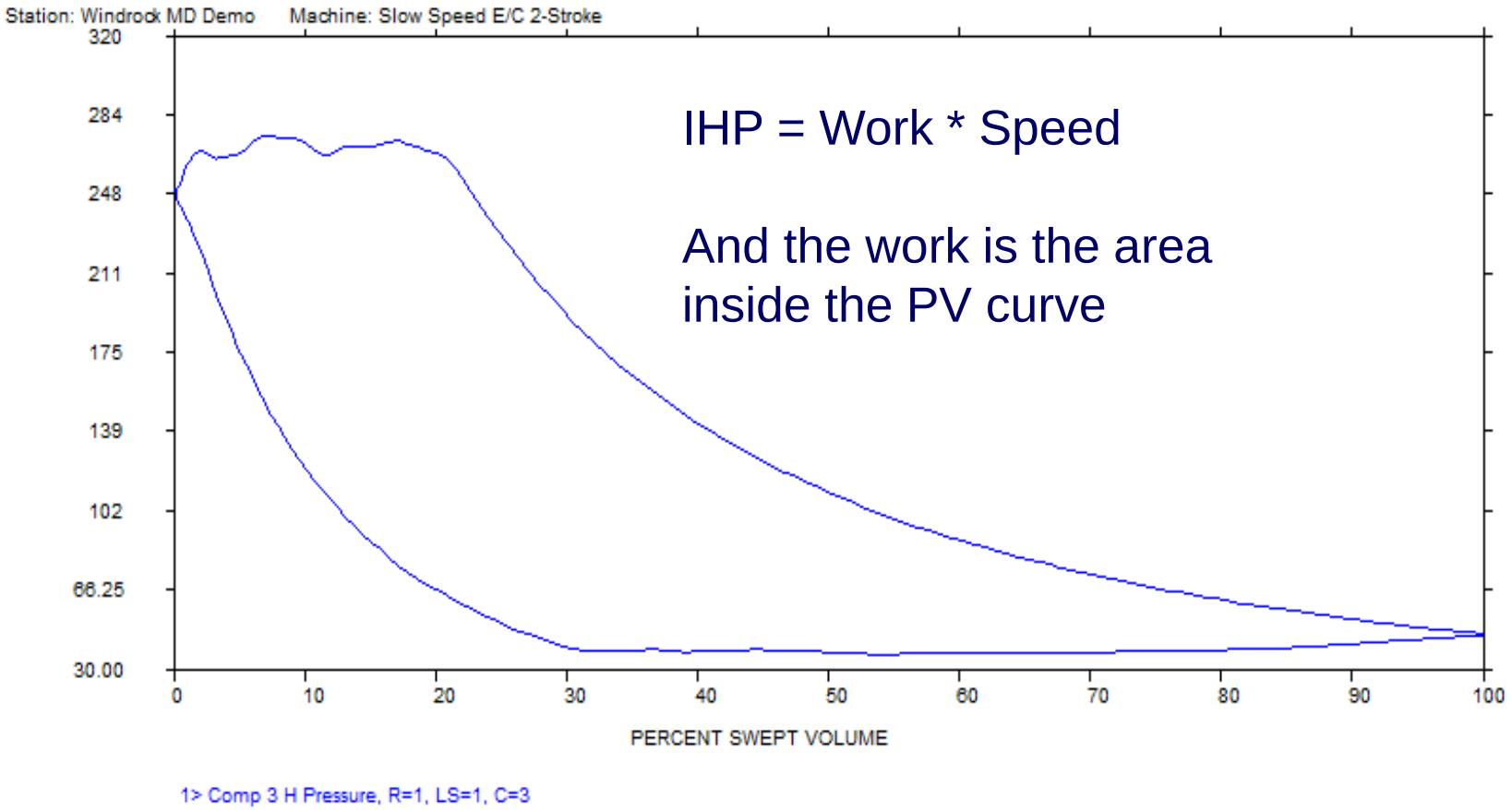
SWEPT VOLUME

2> Comp 4 C Pressure, R=2, LS=1, C=9
No Data Available

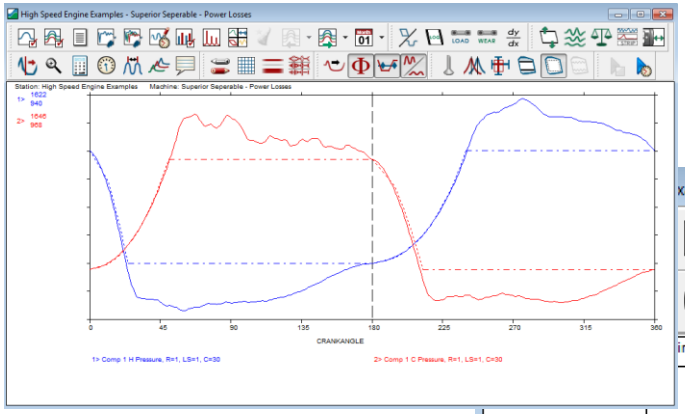


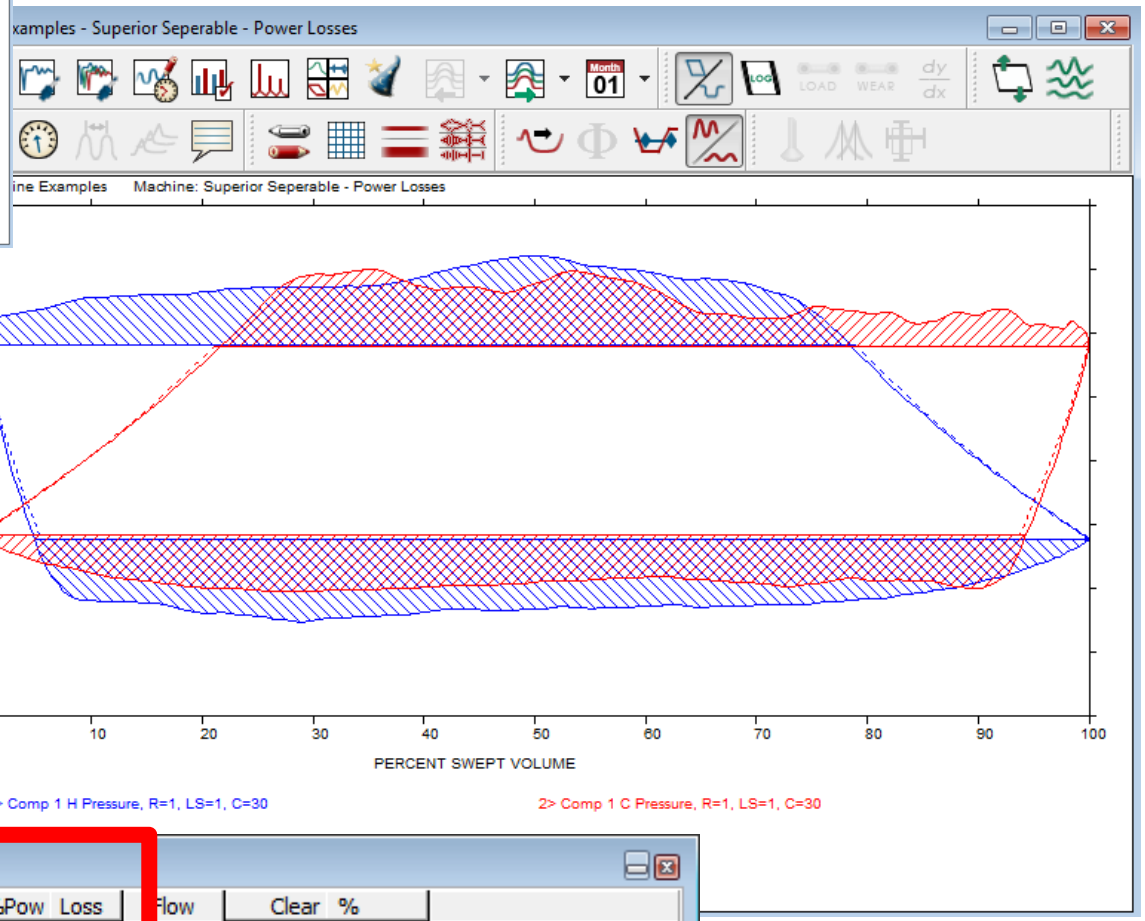
Calculating Horsepower

It takes work to transport gas through a pipe
That work is the area inside the PV curve
The rate of doing work is horsepower



Calculate Power Losses?



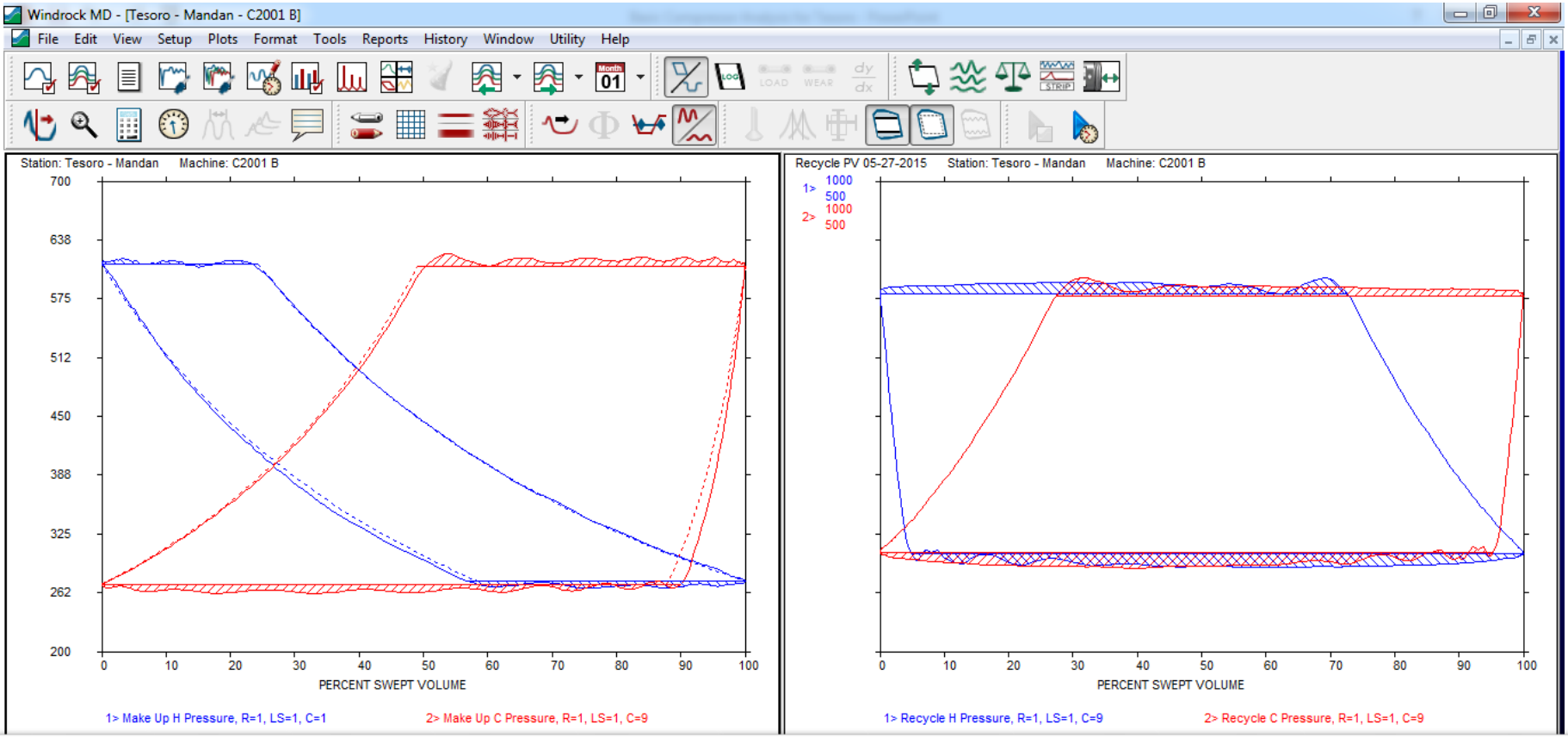


Why is this important?
By reducing valve losses you reduce Horse Power needed to flow gas. Less fuel / amps

Compressor Calculations

Comp Cyl	IHP	RPM	Toe Press Pd	Ps	%Vol Dis	Suc	%Pow Loss Dis	Suc	Flow Bal	Clear % Set	Cal.	
1> CH1	198.42	899.1	1453.7	1109.4	78.4	95.1	16.7	21.5	1.4	27.4	24.7	3-26-15 11:35:42
2> CC1	142.52	899.1	1450.3	1118.5	78.4	94.4	15.0	18.0	1.5	33.2	30.0	3-26-15 11:37:12

Valve Losses on C2001 B



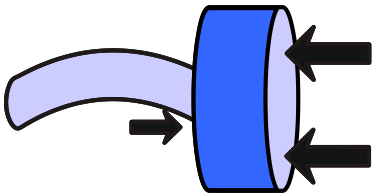
Compressor Calculations

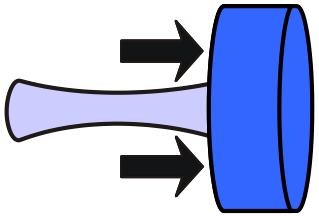
Comp Cyl	IHP	RPM	Toe Press Pd	Ps	%Vol Eff Dis	Su	%Pow Loss Dis	Suc	Flow Bal	Clear % Set	Cal.	
1> CH1	66.32	396.7	611.6	274.6	23.4	43.0	0.4	1.7	.08	81.4	79.4	5-27-15 10:10:57
2> CC1	130.93	396.8	609.7	271.1	49.6	90.0	1.4	2.1	.06	16.7	13.8	5-27-15 10:17:23

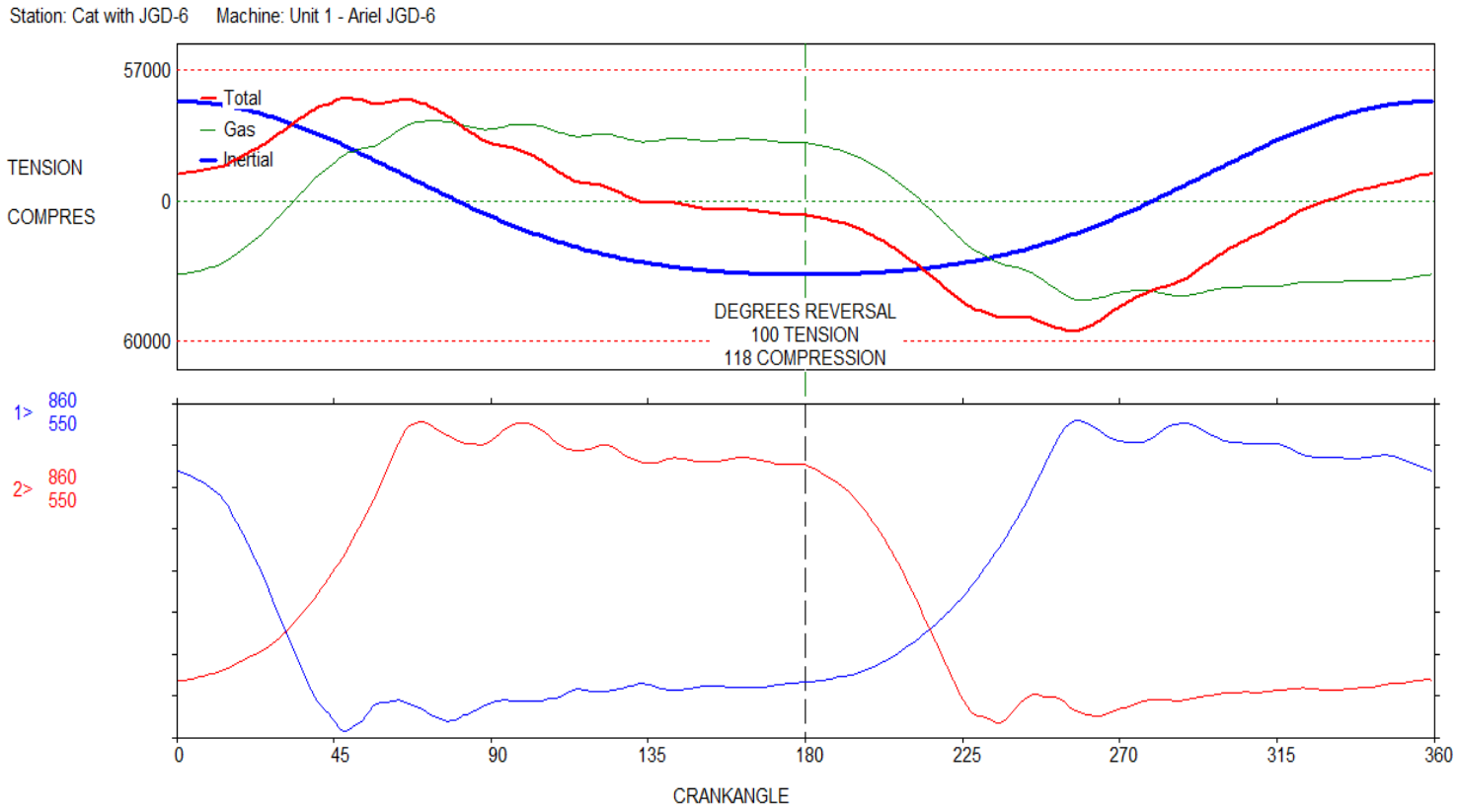
Dynamic Load - Combined

Static + Inertial = Dynamic (Total) Rod Load

Most of the time, inertial load reduces peaks of total load.





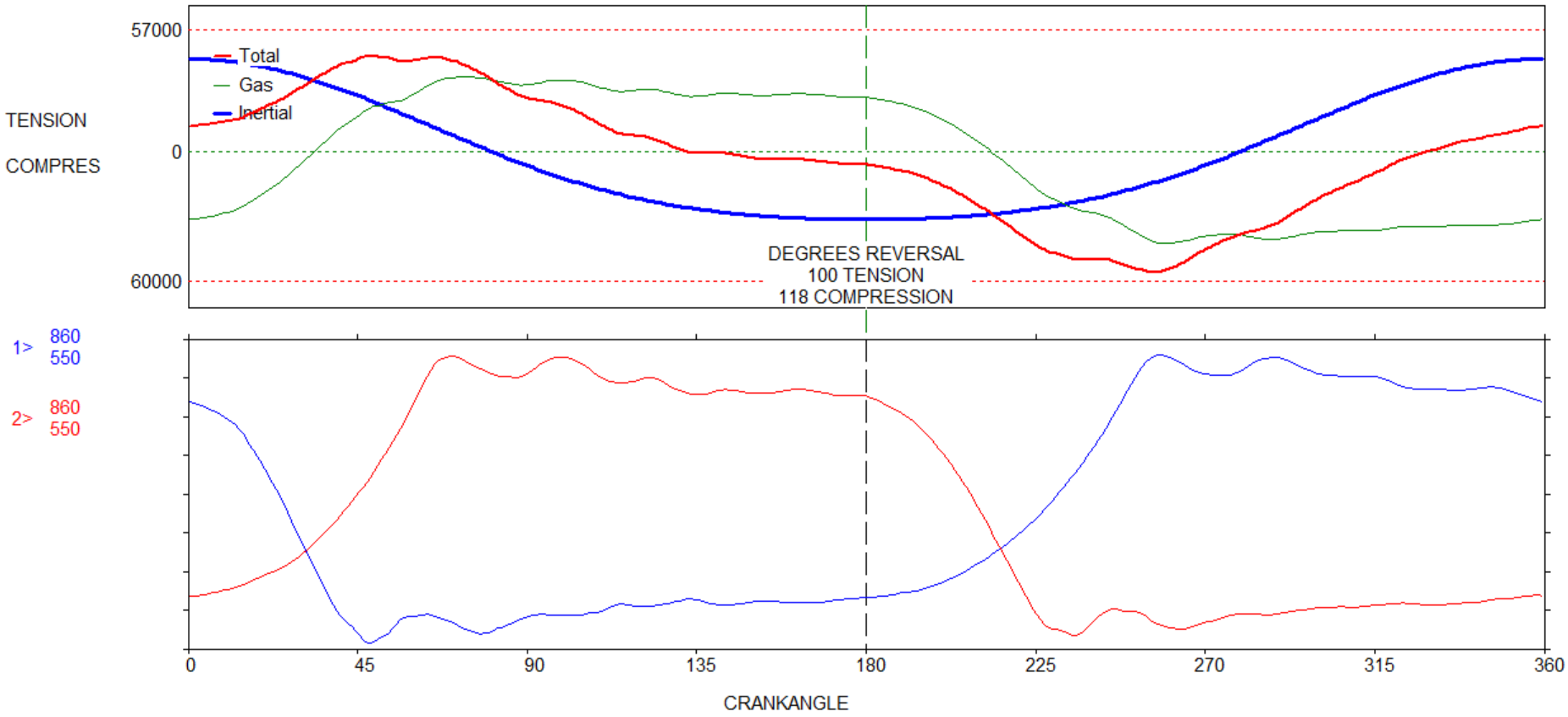


Within Rod Load Limits

Compressor Calculations

Comp Cyl	IHP	RPM	Toe Pd	Press Ps	%Vol Dis	Eff Suc	%Pow Dis	Loss Suc	Flow Bal	Clear % Set	Cal.	
1> CH5	392.11	002.6	796.9	601.4	72.3	88.1	9.0	6.5	1.01	42.0	53.0	5-19-09 11:25:33
2> CC5	369.51	000.7	803.1	603.1	71.1	88.7	7.9	6.1	1.03	44.0	49.3	5-19-09 11:26:40

Station: Cat with JGD-6 Machine: Unit 1 - Ariel JGD-6



1> Comp 5 H Pressure, R=1, LS=2, C=3

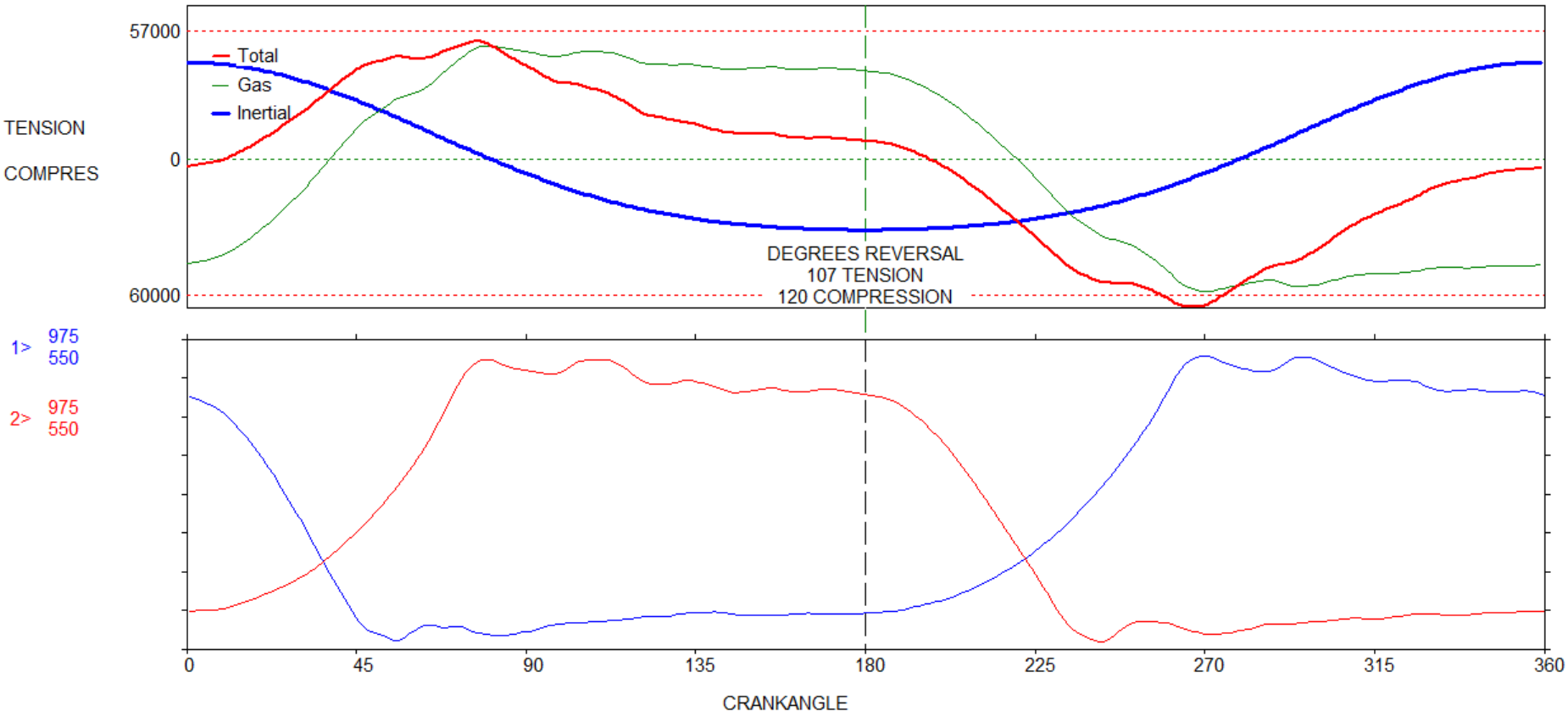
2> Comp 5 C Pressure, R=1, LS=2, C=3

Exceeding Rod Load

Compressor Calculations

Comp Cyl	IHP	RPM	Toe Pd	Press Ps	%Vol Dis	%Vol Suc	%Pow Dis	%Pow Suc	Loss Bal	Clear Set	Clear % Cal.	
1> CH5	508.29	000.0	897.5	601.9	63.1	84.1	7.1	4.6	1.02	46.3	47.5	5-19-09 14:24:53
2> CC5	579.16	200.0	899.0	601.7	62.8	83.7	6.0	4.3	1.02	46.6	48.2	5-19-09 14:25:12

Station: Cat with JGD-6 Machine: Unit 1 - Ariel JGD-6

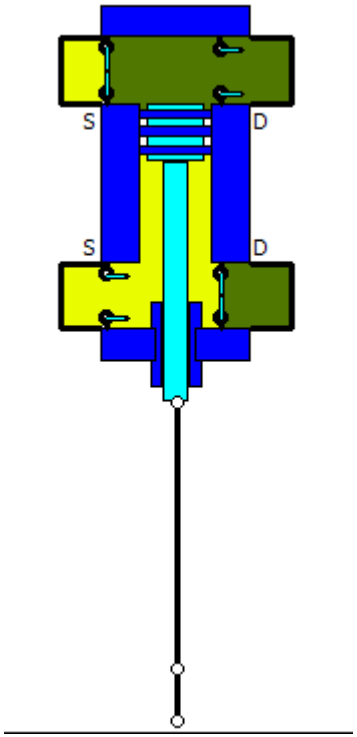


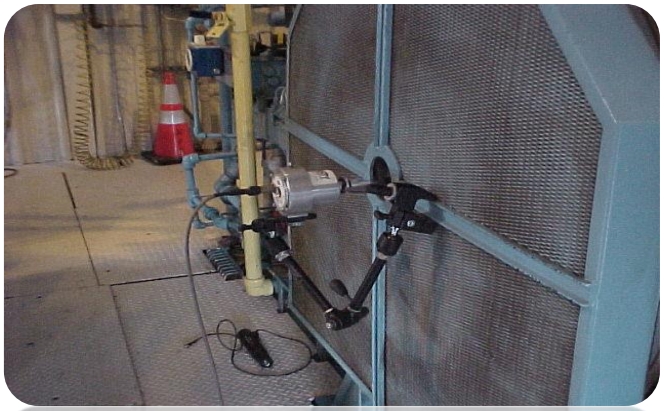
1> Comp 5 H Pressure, R=3, LS=5, C=2

2> Comp 5 C Pressure, R=3, LS=5, C=2

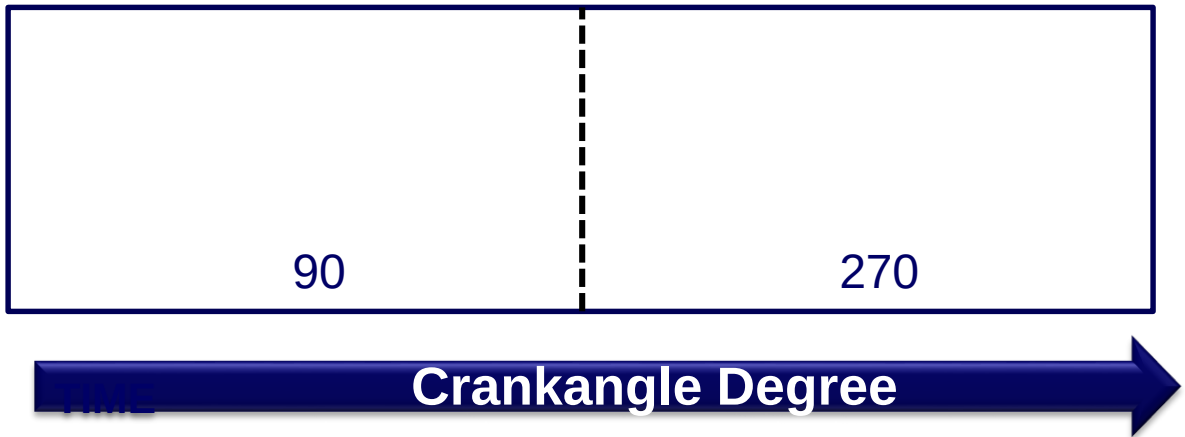
Vibration to Identify Mechanical Defects

Basic Vibration – Reciprocating

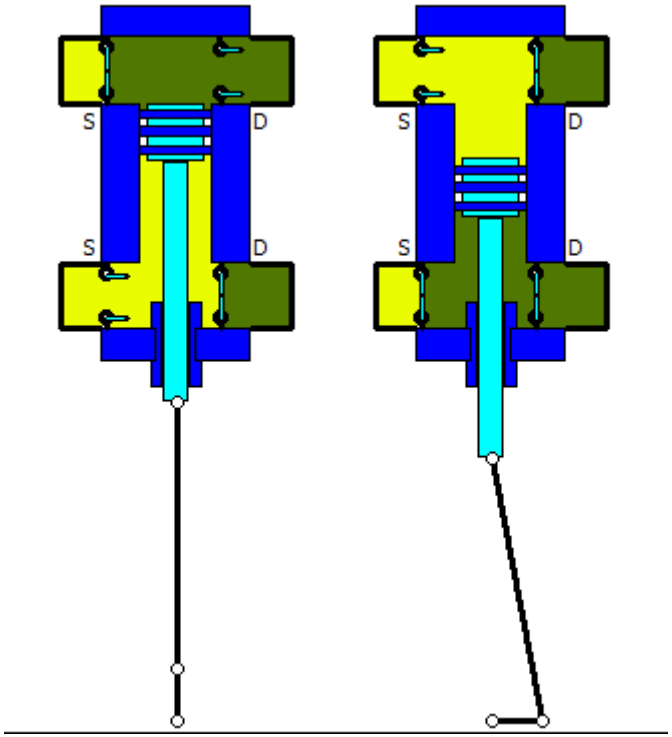


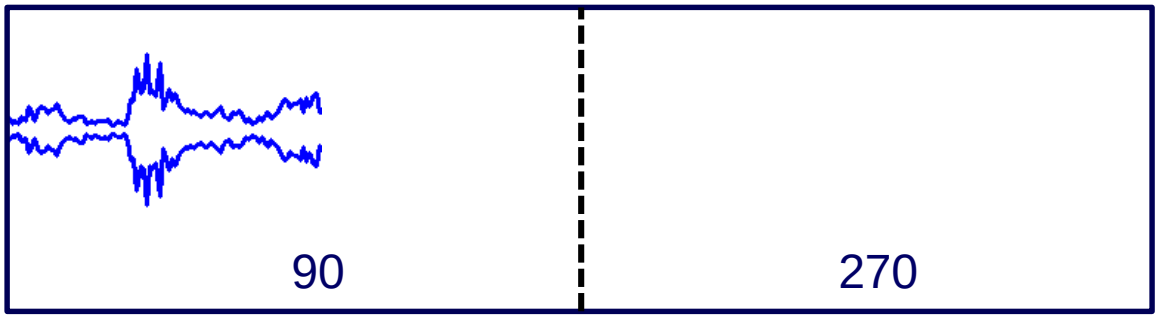


Vibration is taken in conjunction
With an encoder or mag pickup.



Basic Vibration – Reciprocating

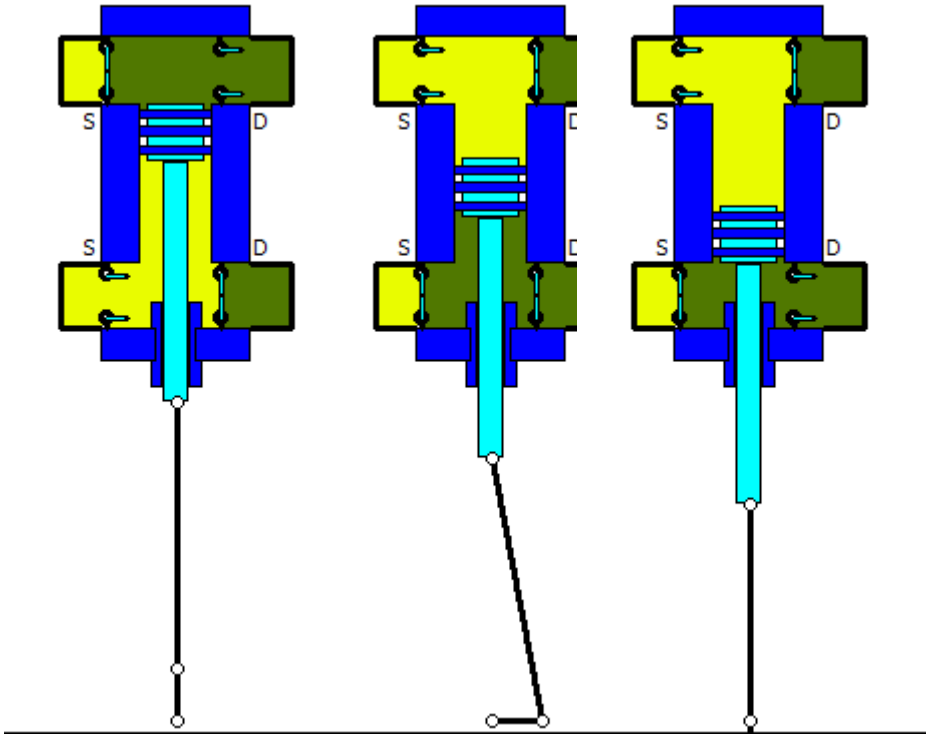


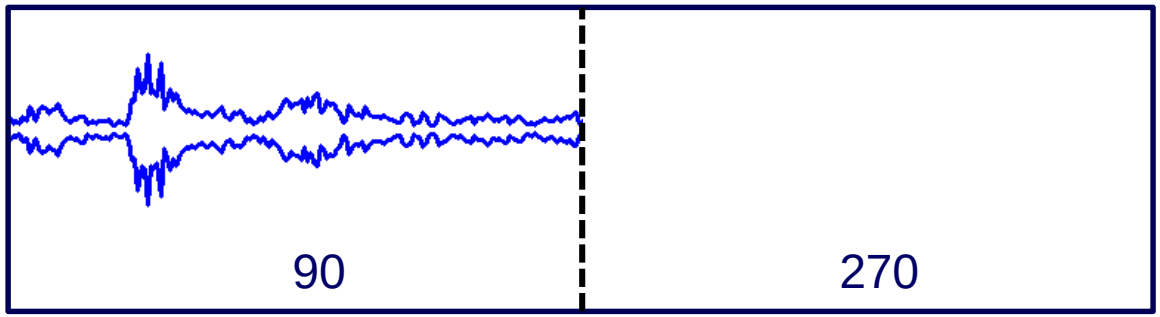


TIME

Crankangle Degree

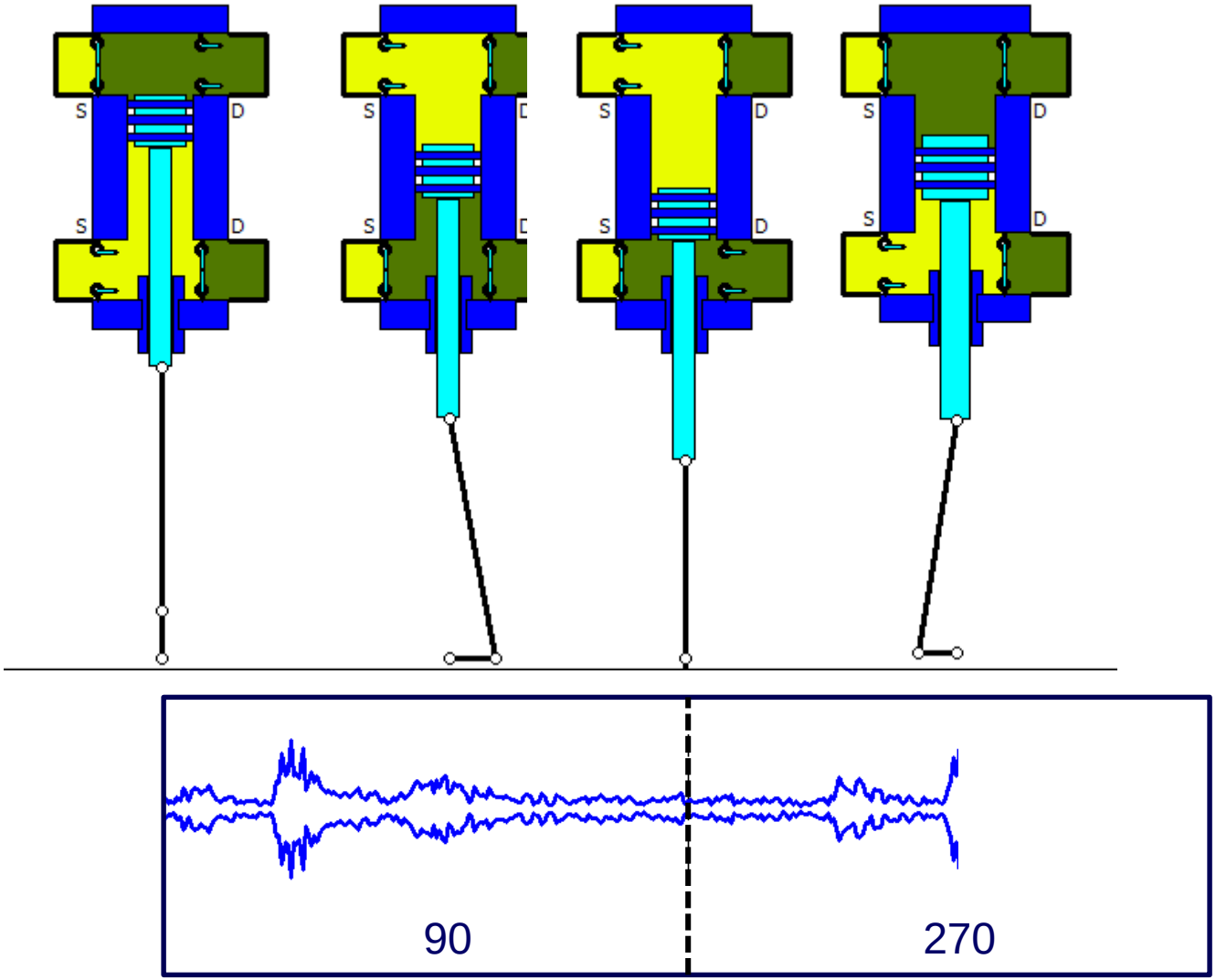
Basic Vibration – Reciprocating



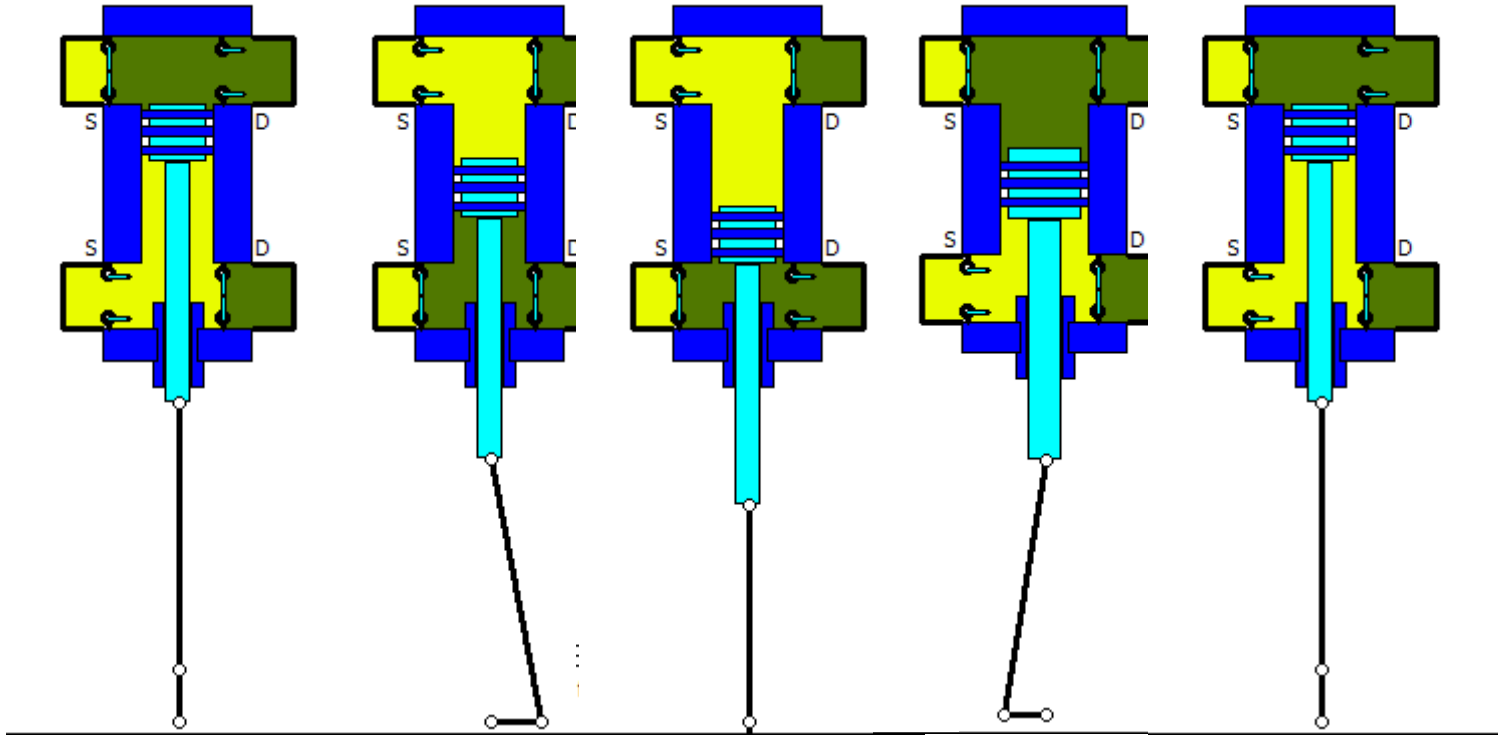


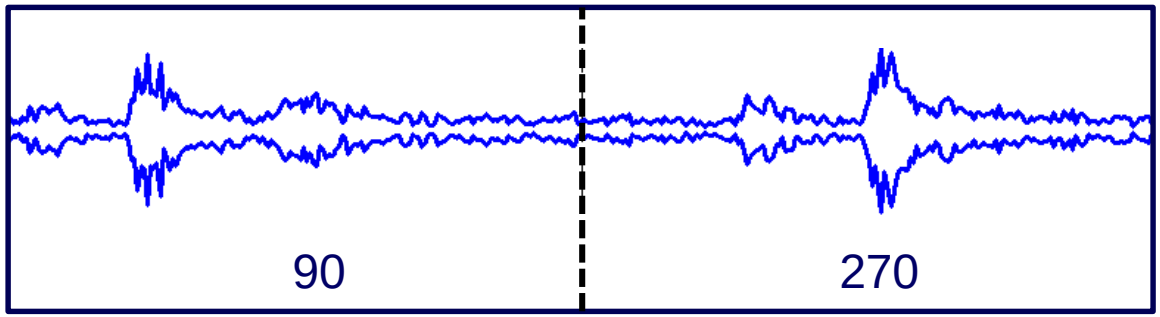
Crankangle Degree

Basic Vibration – Reciprocating



Basic Vibration – Reciprocating

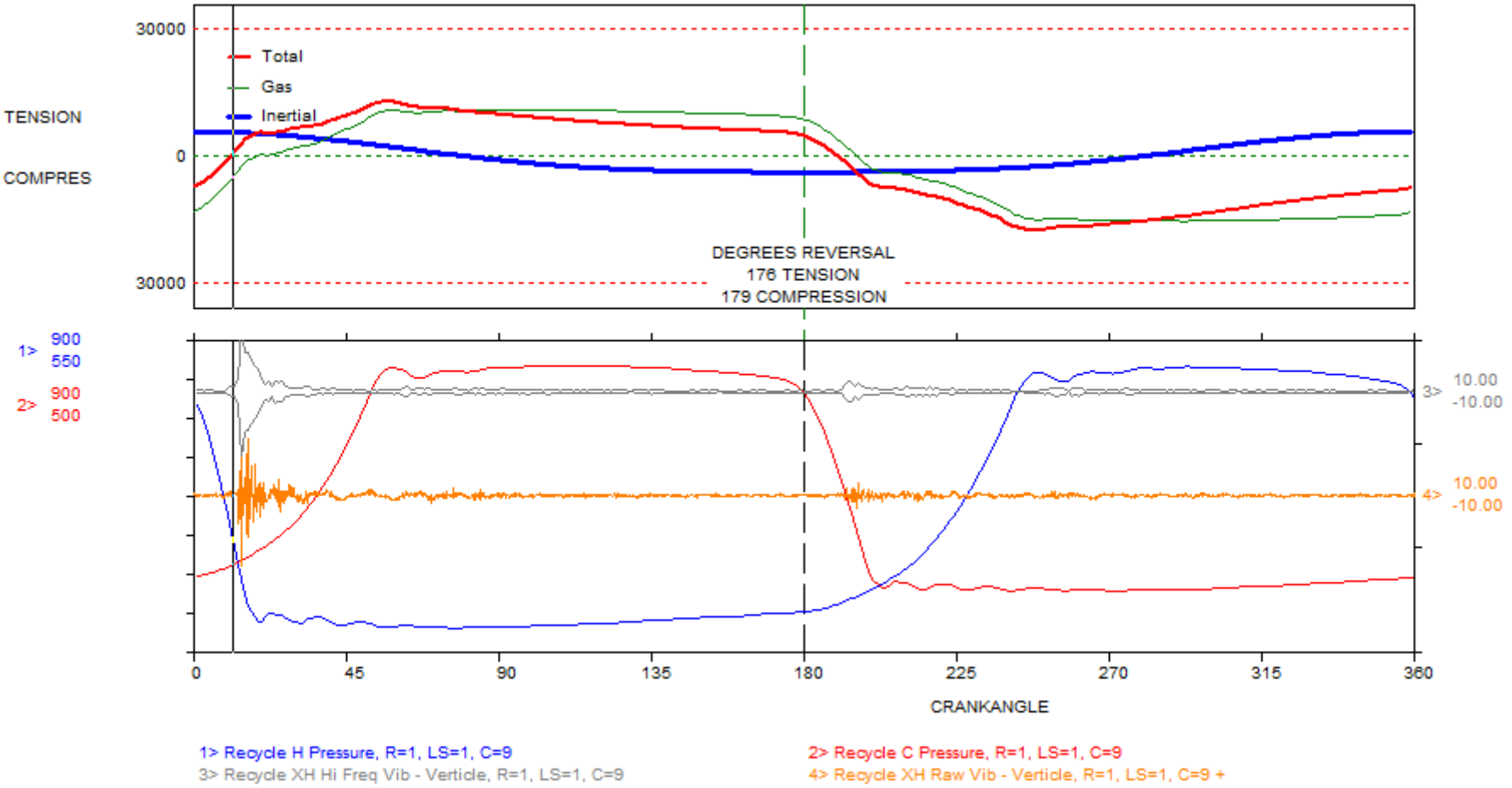




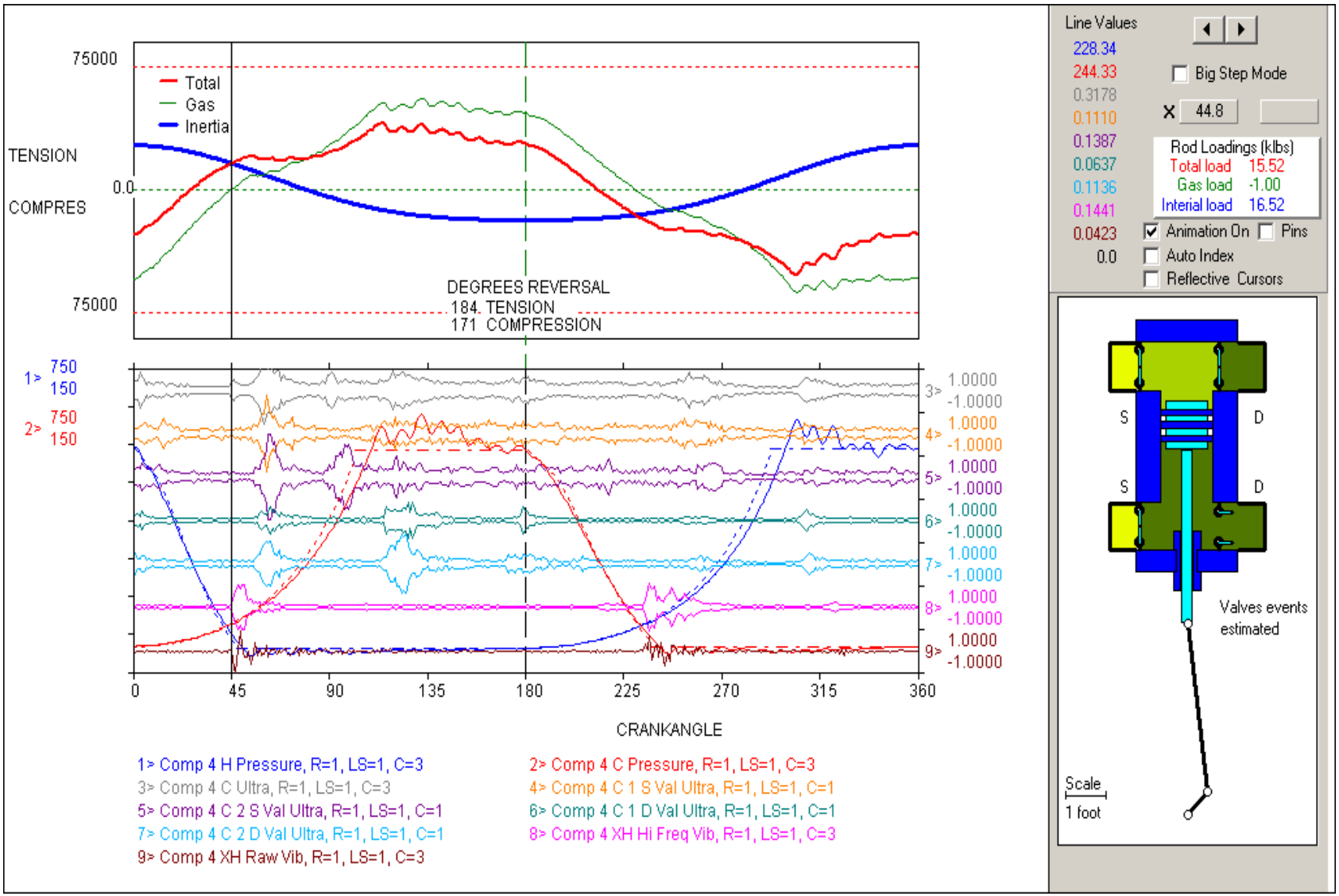
Crankangle Degree

Crosshead Knock

- **Vibrations are easily traced to cause. Below a crosshead knock occurs at force reversal.**

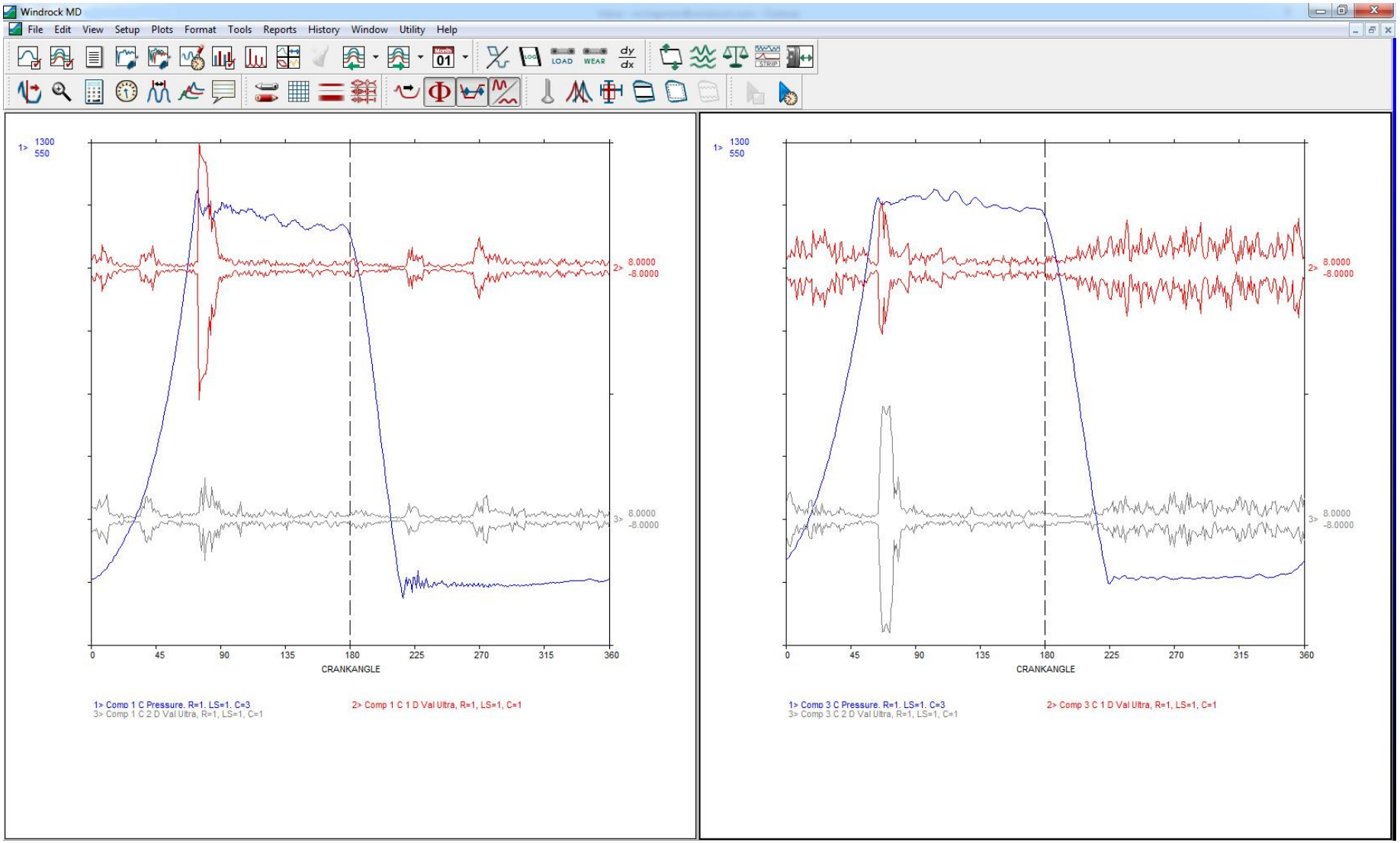


Worn Out Rider Rings

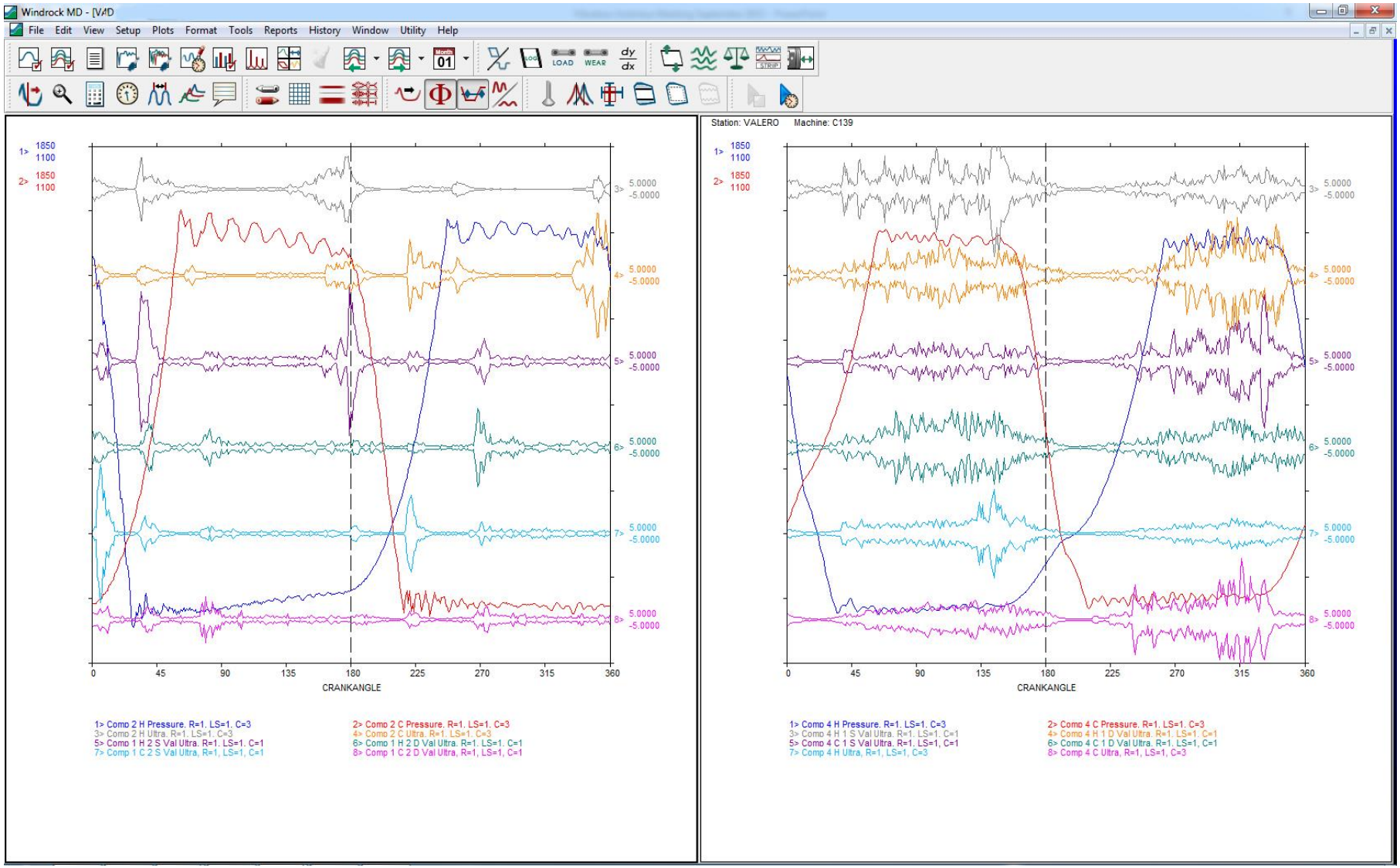


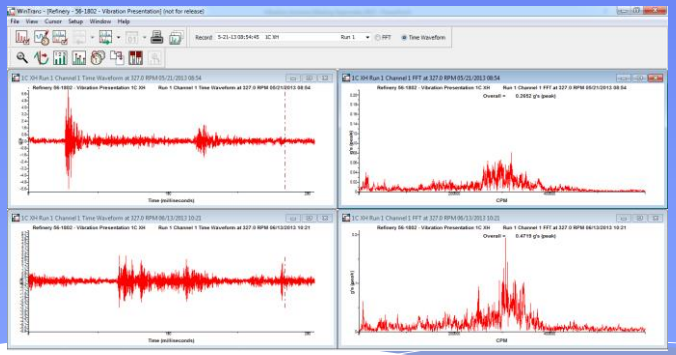
UltraSonics to Identify Mechanical Defects

Discharge Leak – shown in Ultrasonic data



Ring Leak – shown in Ultrasonic data

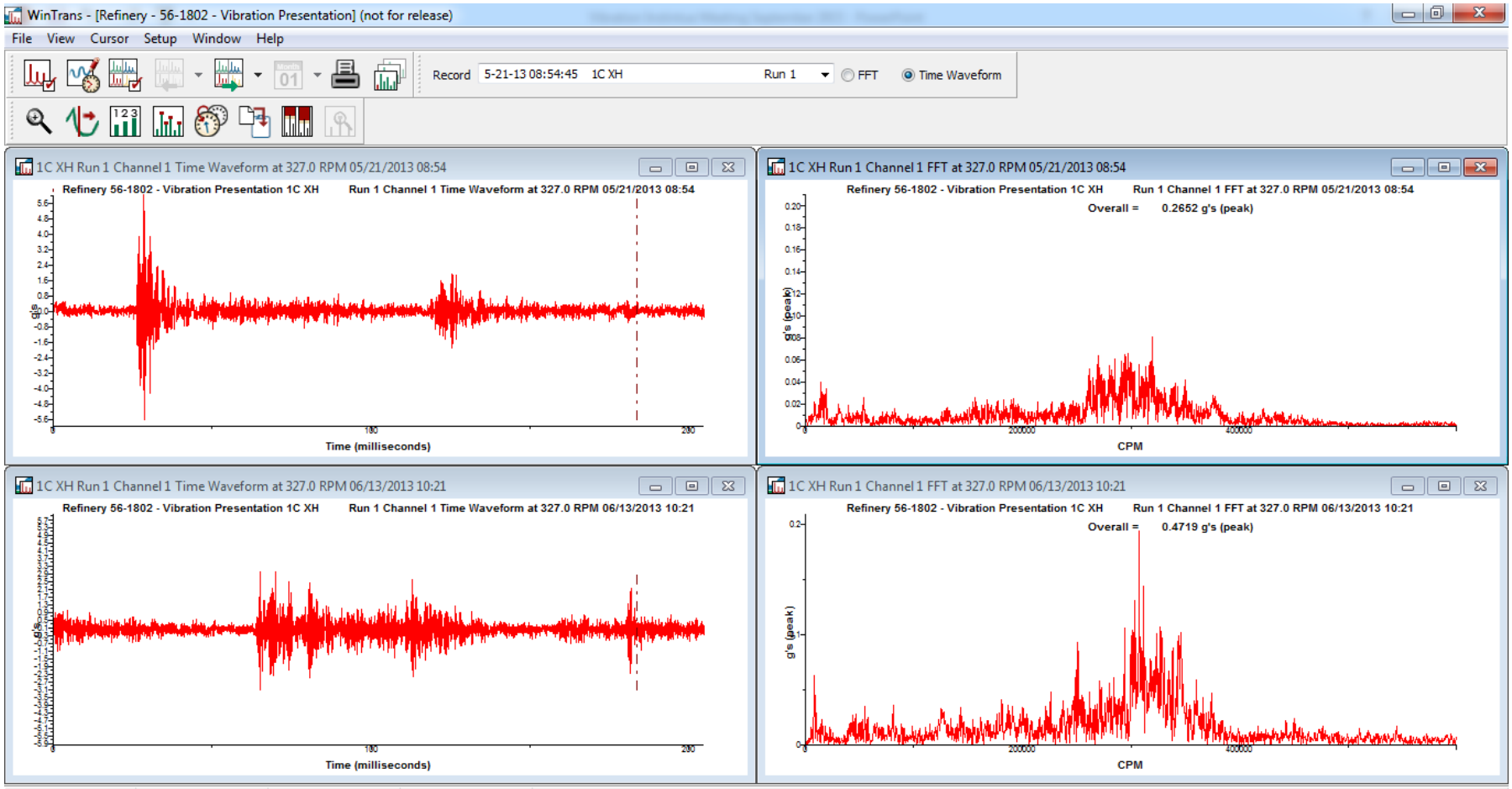




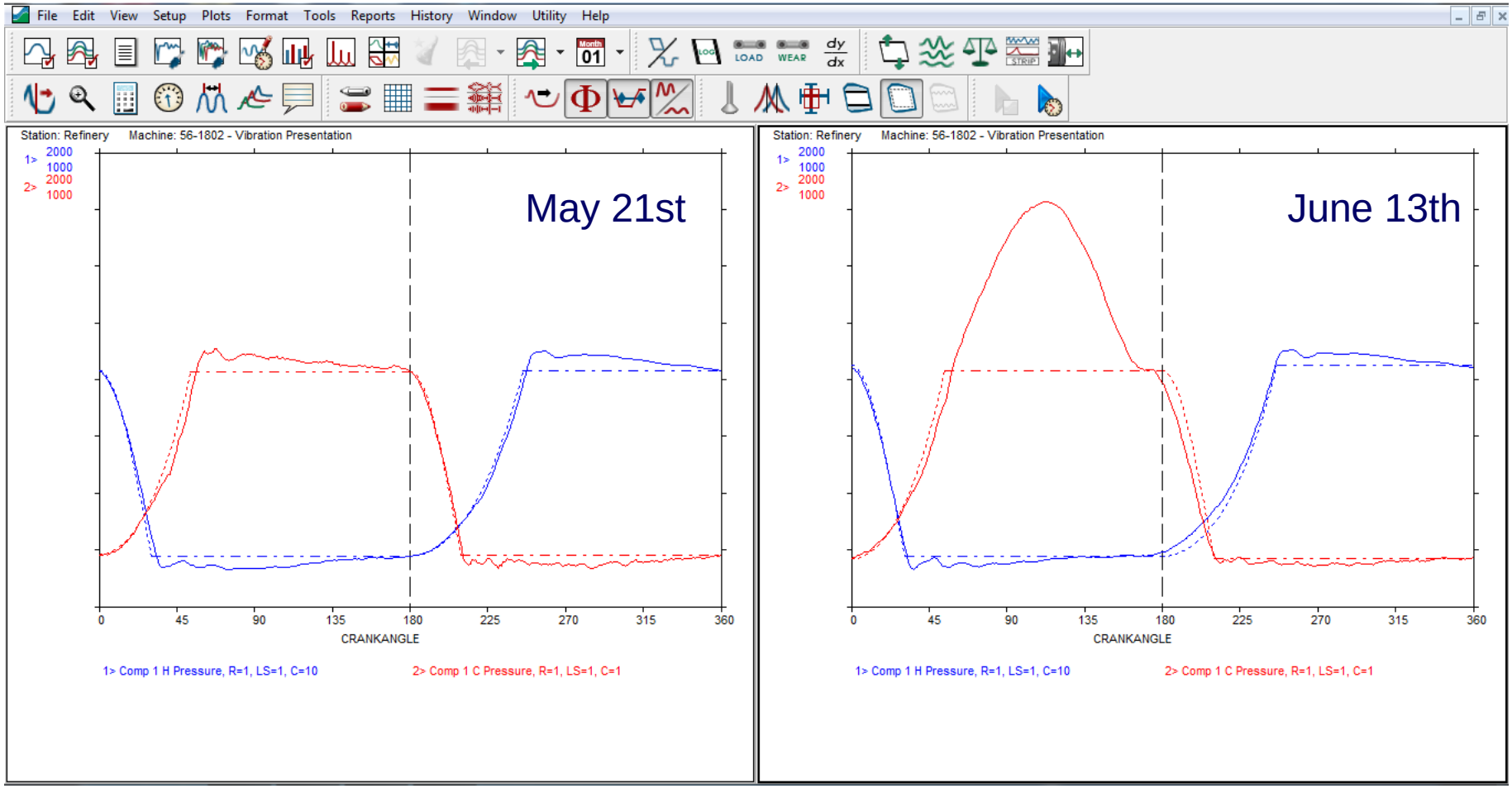
Remember the Spectrum and Waveform data from the beginning of the presentation?

Back to our example from the beginning

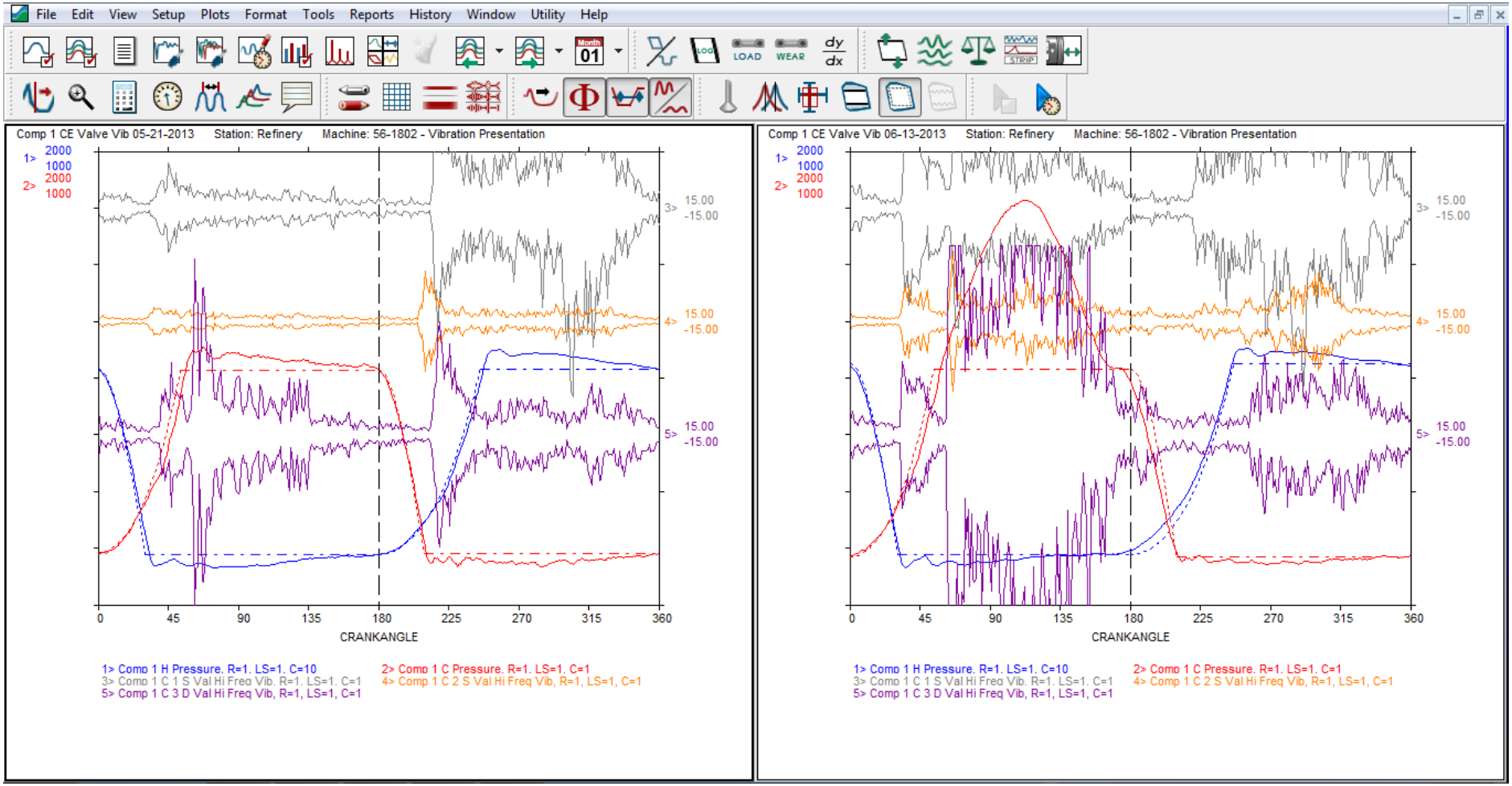
- **Since we know something is different, but can not determine what it is with FFT – lets look at the crank angle data.**



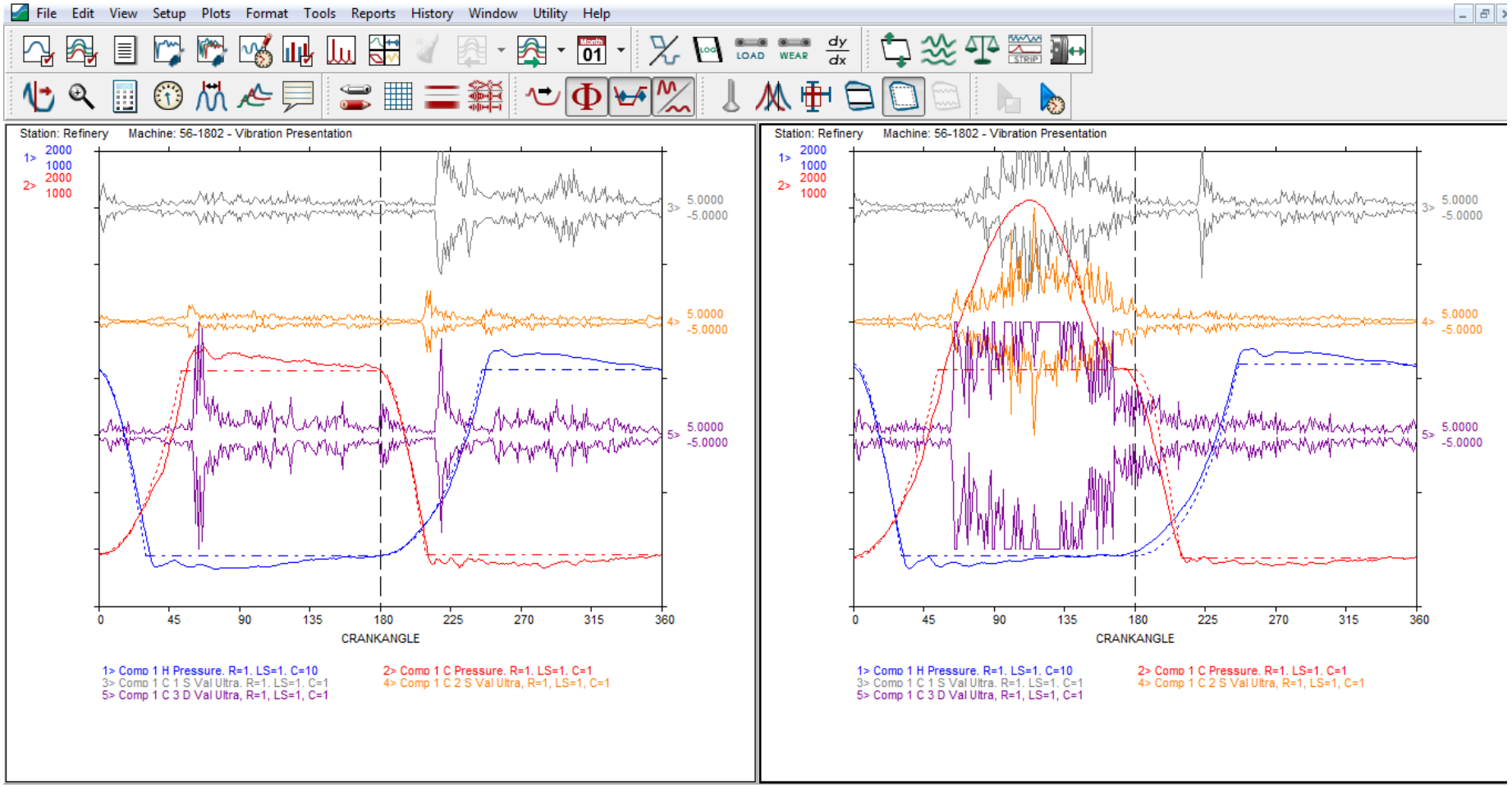
Pressure Trace



Pressure Traces with Vibration

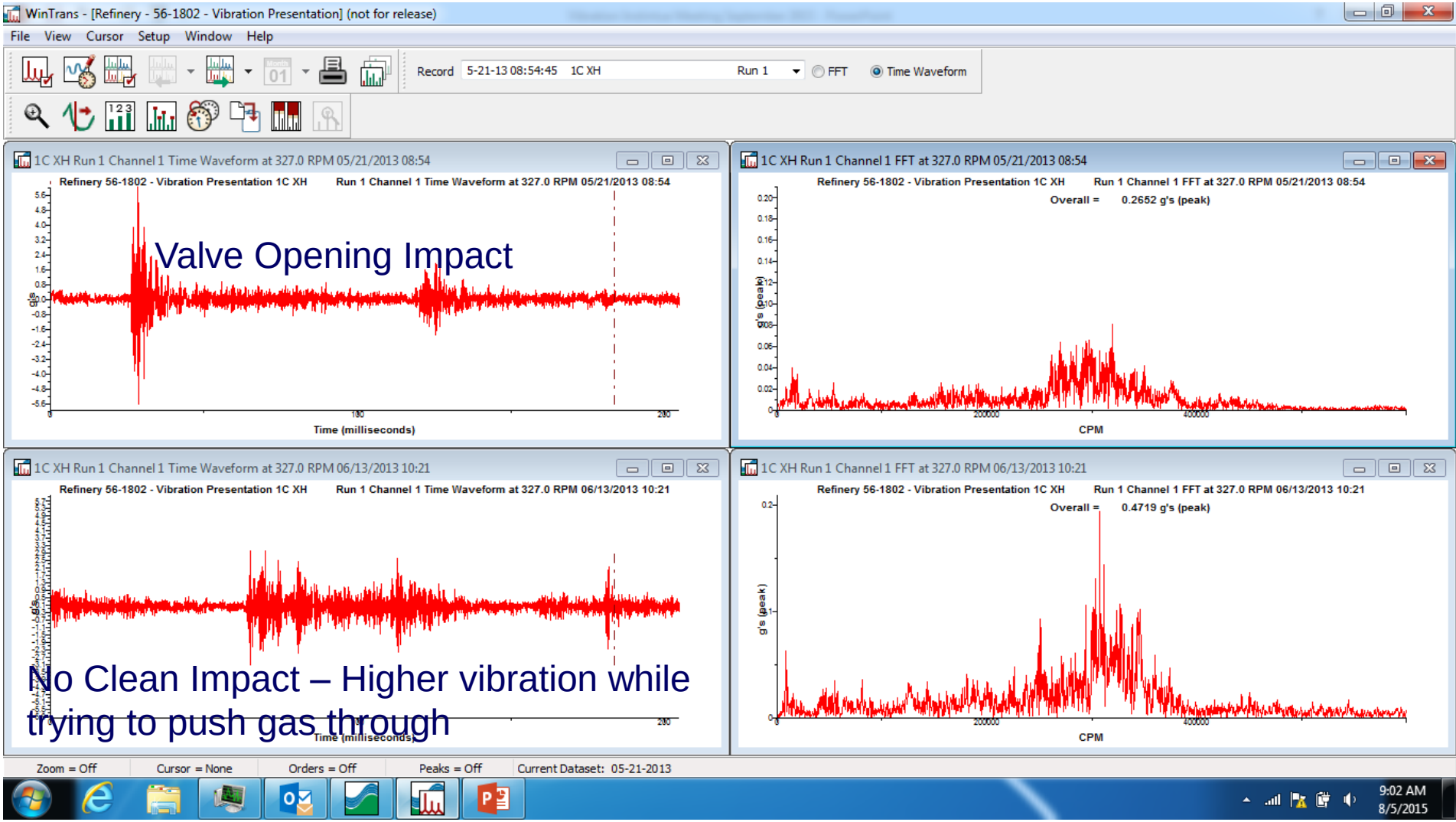


Ultra Sonics Traces with Vibration



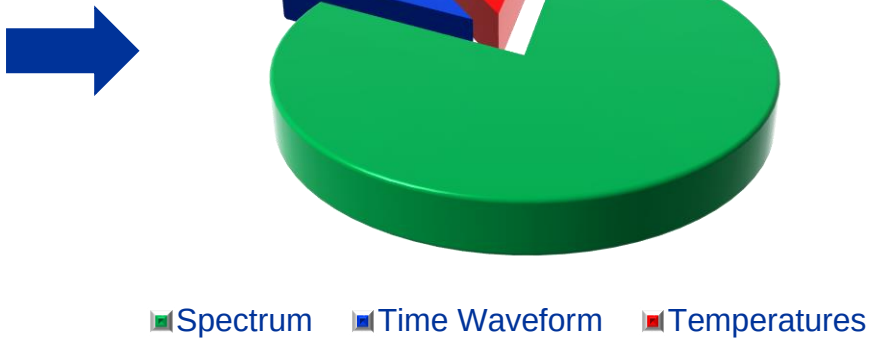
Plugged Valves Due to Worn Riders

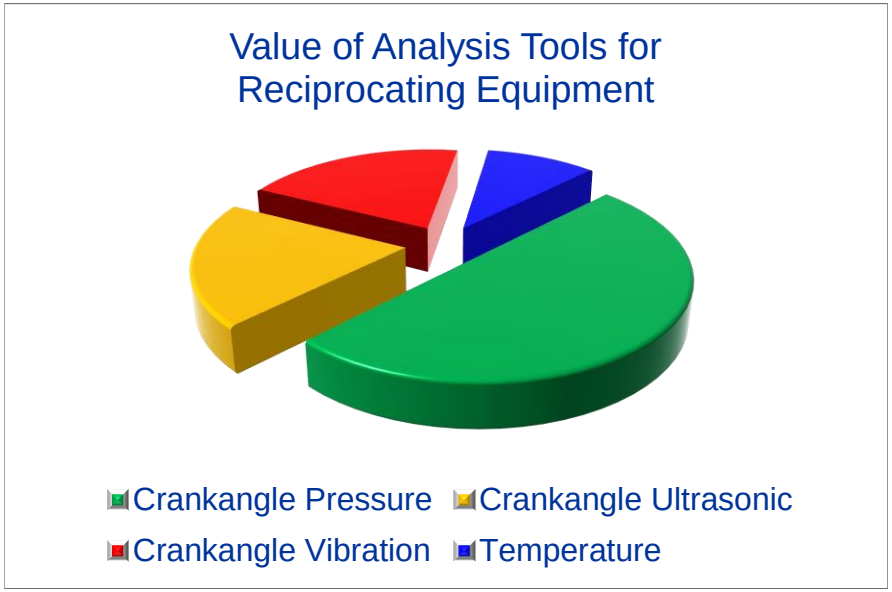
Vibration on the head end of a compressor Throw



Conclusion

- **Where Spectrum vibration data is the most valuable on rotating equipment**





- **Crank angle data is most valuable on reciprocating equipment**

Question?

- **Slicing up the PIE for Analysis Tools**

  - Spectrum Data for Rotating Equipment
  - Crank-angle Data for Reciprocating Equipment