MACHINERY
MONITORING
SYSTEMS, LLC

MMS Product Overview

KINDER MORGAN

K-M Tech Roundtable Meeting
East Bernard, TX
5/17/2023

Kent Petersen – Product Manager
Bryan Stewart – VP Sales and Operations
Steve Follmar – CEO

Agenda

MACHINERY MONITORING SYSTEMS, LLC

- MMS Management Introduction
- Alliance Partners
- Technology Partners
- Current Product Portfolio Overview
  - Snapshot Engine Balancer
  - MachineryRx Web Application
  - ProBalance and ProBalance Plus
  - Sentinel Compressor Monitoring
  - What's Next

MMS Management

MACHINERY MONITORING SYSTEMS, LLC

Steve Follmar, CEO, President
- Windrock (Co-Founder)
- Cook Compression
- Beta Monitors
- Bentley Nevada

Bryan Stewart, CFO, VP Operations
- Hoerbiger
- Digicon
- KCI (Exterran)
- Ingersoll-Rand

Glenn Mincher, VP Engineering
- Windrock (Co-Founder)
- CSI (Emerson)
- Bentley Nevada

John Biondolillo, CTO, VP Business Development
- Linde (Praxair)
- JM Canty Process Technology

Kent Petersen, VP, Product Management
- Windrock
- MAARS
- Nuclear Power Industry

Warren Laible, Subject Matter Expert
- Windrock
- Weatherford Global Compression
- Ro-Cip

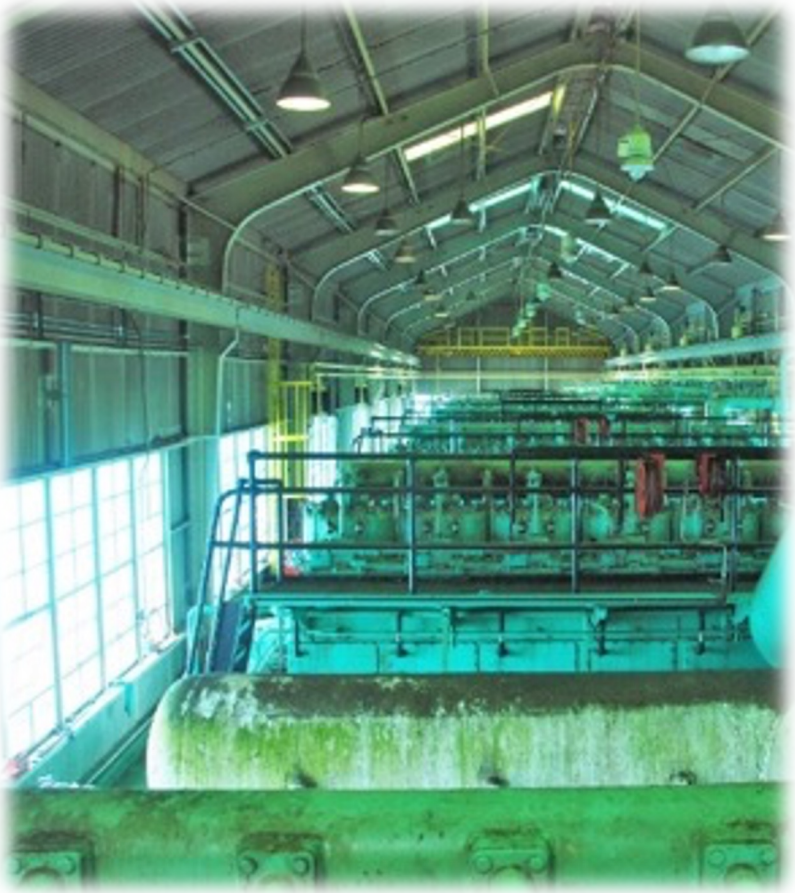
Donna Stewart, VP Marketing & Training
- Healthcare Administration & Education

Rachel Clark, Director of Manufacturing
- Windrock
- Siemens

MACHINERY
MONITORING
SYSTEMS, LLC

MMS Background

- Founded 2018
- Innovative machinery monitoring products & services
- Industrial reciprocating and rotating machinery
- Gas transmission, midstream, processing & petrochemical industries

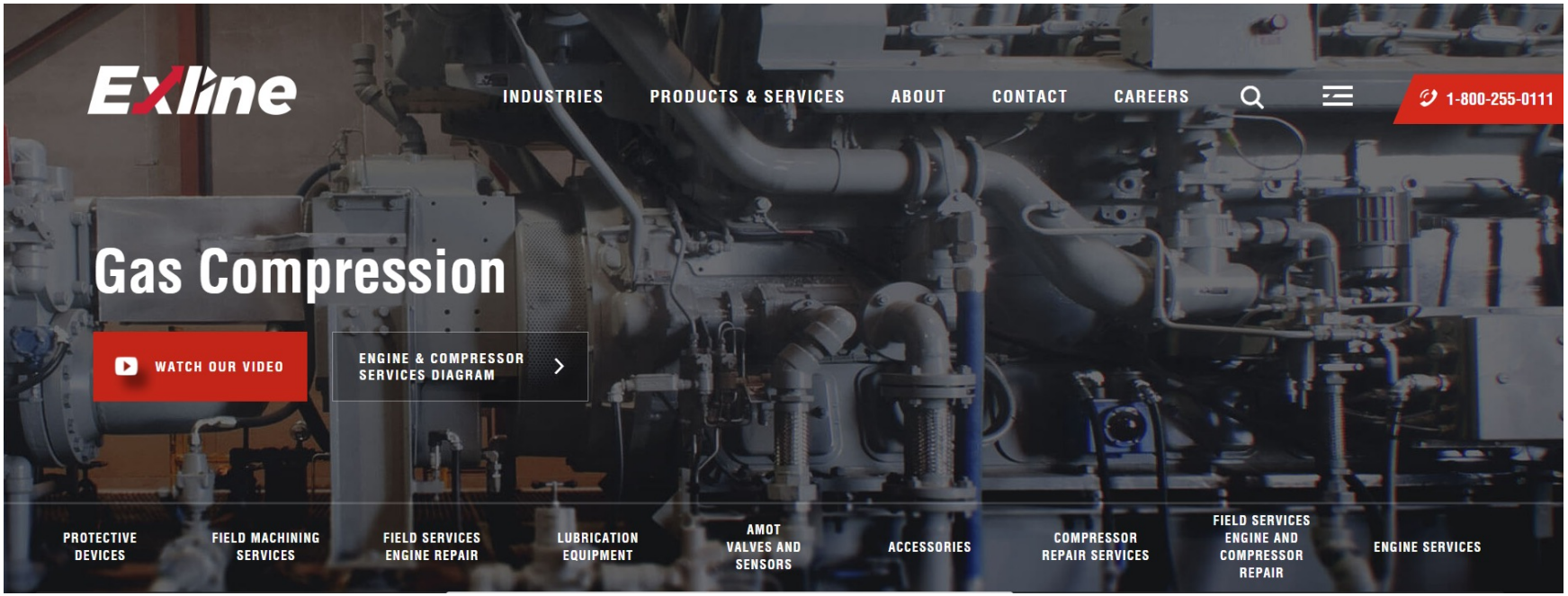


Channel Partner

MACHINERY MONITORING SYSTEMS, LLC

Exline

- Exclusive MMS Distributor
- Installation Services
- Technical Services
- Field Support



Technology Partners

MACHINERY MONITORING SYSTEMS, LLC

IMES

- Pressure Sensors
- Engine Monitoring

CTC

- Proximity Products
- Vibration Monitoring

Kistler

- Engine Pressure Sensors

ACI Services

- Software
- Compressor Models

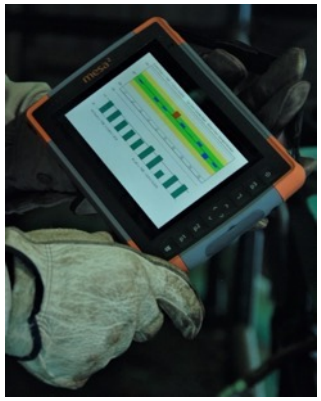
Radical Combustion Technologies

- Clean Energy Solutions
- Advanced Engine Controls

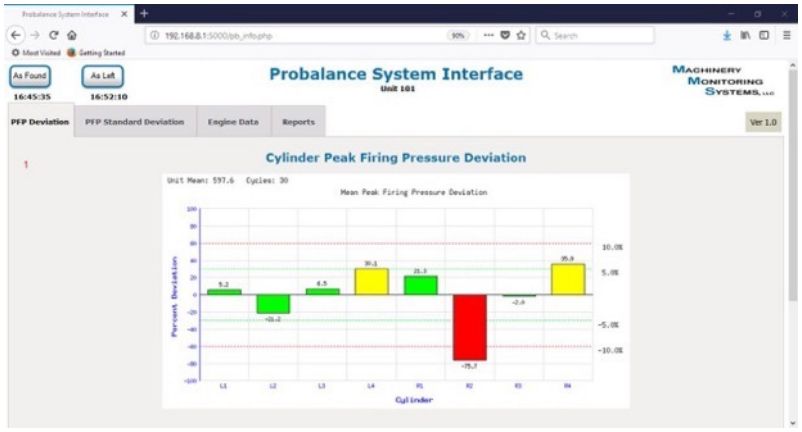
Current Product Portfolio

MACHINERY MONITORING SYSTEMS, LLC

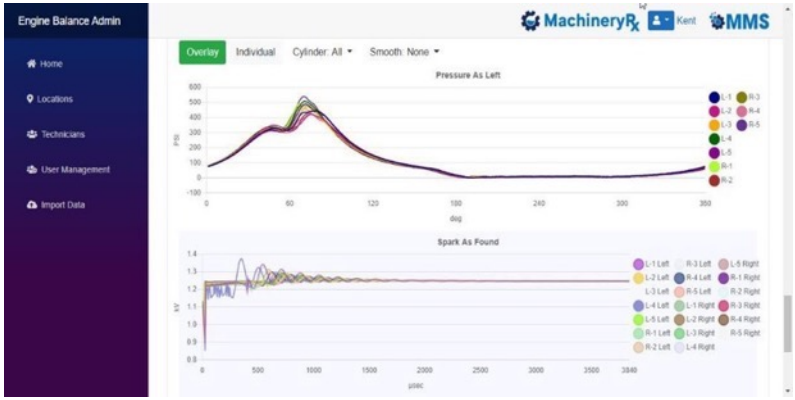
Snapshot® - Portable Engine Balancer
Pressure and Ignition Analyzer



ProBalance® - 24/7 Monitoring
or
ProBalance® Plus – 24/7 Balancing



MachineryRX® Web Application



Sentinel® Compressor Monitoring
Embedded ACI eRCM Model

Kinder Morgan Installations

MACHINERY MONITORING SYSTEMS, LLC

Snapshot Portable Engine Balancers

Date	Location	
7/3/2019	Stations 96 & 871 Campbellsville, KY	
12/10/2019	Franklinton, LA	
11/13/2020	Station 32, Jasper, TX	
4/6/2021	Station 5000 (Shady Side) Centerville, LA	
4/6/2021	Station 5110 (Toca) St. Bernard, LA	
11/18/2021	Station 823 Kinder, LA	Repeat Order
1/18/2023	Station 538 Heidelberg, MS	Repeat Order

Snapshot®
Portable Engine Balancer

MACHINERY MONITORING SYSTEMS, LLC

Snapshot® - Balancer Key Features:

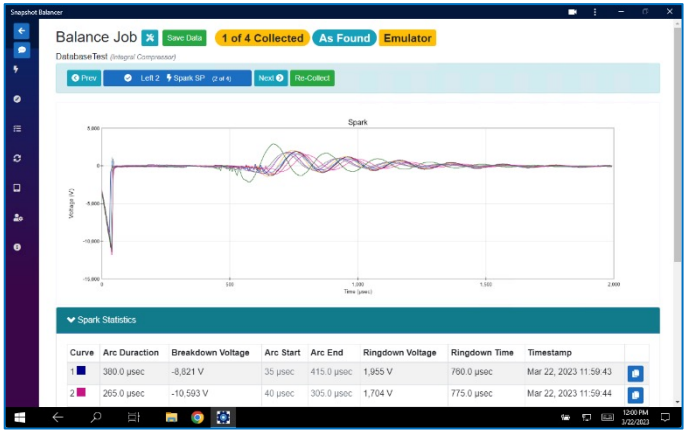
- Portable balancer for engines
- Two channel unit, Ruggedized-EMI Resistant
- Engine cylinder pressure
- Spike Removal/Smoothing
- 2-Stroke/4-Stroke
- Secondary Ignition
- Wireless communication from data module to tablet
- 8-hour battery life
- Class I, Division 2 rating pending

Snapshot®
Portable Engine Balancer

MACHINERY MONITORING SYSTEMS, LLC

Dynamic Engine Pressure

Ignition



MachineryRx®

MACHINERY MONITORING SYSTEMS, LLC

MachineryRx®

MACHINERY MONITORING SYSTEMS, LLC

A new way to track Machinery Health across the company

- Accessed with Browser
- Can be run in the Cloud or on a User's Network
- Type of Machine, OEM, Vintage or Sensor suite does not matter
- Data is encrypted
- SQL database is setup by Company, Division, Area, Station and Machine
- Adding, deleting and setting Users access\capabilities is done by Sys Admin
- Static, dynamic and calculated data can be collected, arranged and displayed as Management Reports, Dashboards or Trend graphs
- Technical Staff with proper credentials can drill down to individual sensor waveforms in a wide variety of typical formats

MachineryRx®

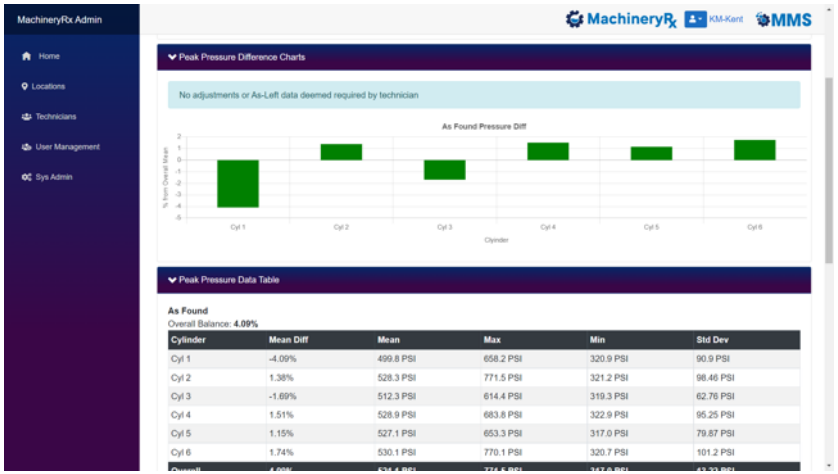
Typical Display – Reports and Plots

MACHINERY MONITORING SYSTEMS, LLC

Pressure and Ignition waveforms

Vibration waveform and FFT

Engine Balance Plot



Panel Points

Panel Points

Name	As-Found	As-Left
Torque Load	99.3%	---
Engine Speed	300.0 RPM	---
Compressor Brake Power	1,530 hp	---
Ignition Timing	11 °ATDC	---
Air Manifold Pressure	7.14 PSI	---
Fuel Flow	12.6 ft³/hr	---
Fuel Pressure	46.2 PSI	---
Lower Heating Value	7,576 BTU/ft³	---
Exhaust Temp	Cyl 1 750.0 F Cyl 2 749.0 F Cyl 3 839.0 F Cyl 4 817.0 F Cyl 5 782.0 F Cyl 6 919.0 F	Cyl 1 --- Cyl 2 --- Cyl 3 --- Cyl 4 --- Cyl 5 --- Cyl 6 ---
Brake Specific Fuel Consumption	62.39059BTU/HP-hr	

Kinder Morgan Installations

ProBalance / ProBalance Plus

MACHINERY MONITORING SYSTEMS, LLC

Date	Location	Equipment	
8/29/2018	Station 860 Centerville, TN	TLA-8	1st Demo System
6/17/2019	Station 9 Victoria, TX	GMW-8	
12/2/19	Station 860 Centerville, TN	TLA-8	Upgrade to Plus
1/28/2020	Station 823 Kinder, LA	TCV-16	ProBalance Plus
11/2/2020	Station 823 Kinder, LA	2x - TCV-16s	Repeat Order
6/10/2021	Station 5222 Enterprise, MS	GMVH-12	
11/18/2021	Station 823 Kinder, LA	HBA-10	ProBalance Plus, Repeat Order
9/26/2022	Station 1775 Topock, AZ	8-W330	
12/17/2022	Station 542 DeKalb, MS	TCV-16	
12/18/2022	Station 546 Columbus, MS	12-Z330	

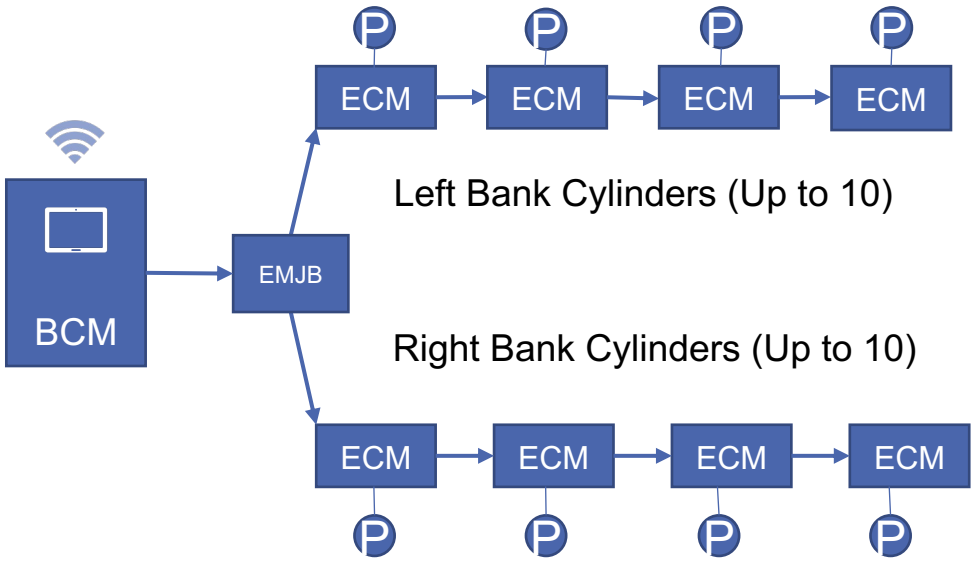
ProBalance / ProBalance Plus

MACHINERY MONITORING SYSTEMS, LLC

- Continuous balance monitoring
- Significant reduction in time required for manual balancing
- Continuous automatic balancing (Plus version)
- Quick, easy installation

ProBalance / ProBalance Plus

MACHINERY MONITORING SYSTEMS, LLC



- BCM (Balance Control Module) mounted to UCP (Magnet or Bolted)
- Customer provided conduit BCM – EMJB (Engine Mounted Junction Box) for power & communication
- MMS-supplied cables EMJB – ECMs (Engine Cylinder Module)
  - Armored
  - 6-Pin Amphenol Connectors
- MMS-supplied cables ECM-ECM
- Dual Port Kiene valves on each cylinder
- IMES or Kistler pressure sensors on each cylinder

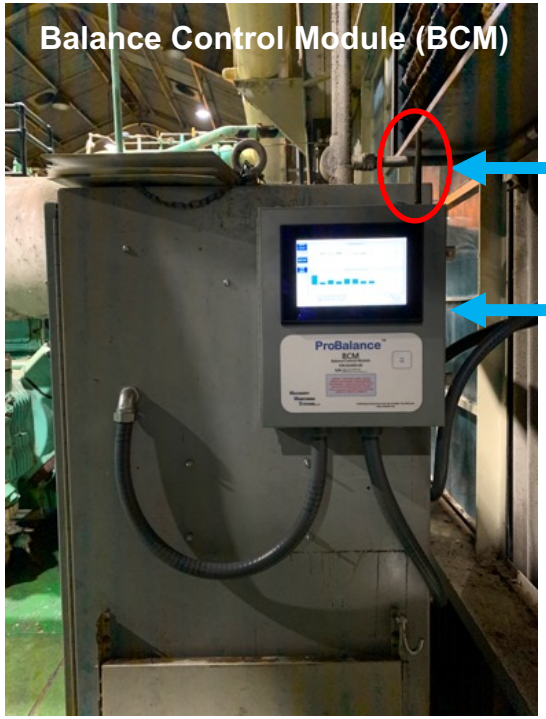
ProBalance Components

MACHINERY MONITORING SYSTEMS, LLC

BCM mounted to UCP

ProBalance Components

MACHINERY MONITORING SYSTEMS, LLC



Wireless antenna

BCM mounted to UCP

ProBalance Components

MACHINERY MONITORING SYSTEMS, LLC

Wireless antenna

BCM mounted to UCP

Conduit to EMJB

ProBalance Components

MACHINERY MONITORING SYSTEMS, LLC

Wireless antenna

BCM mounted to UCP

Conduit to EMJB

Power (24VDC) & communications
(MODBUS IP or RS-485)

ProBalance Components

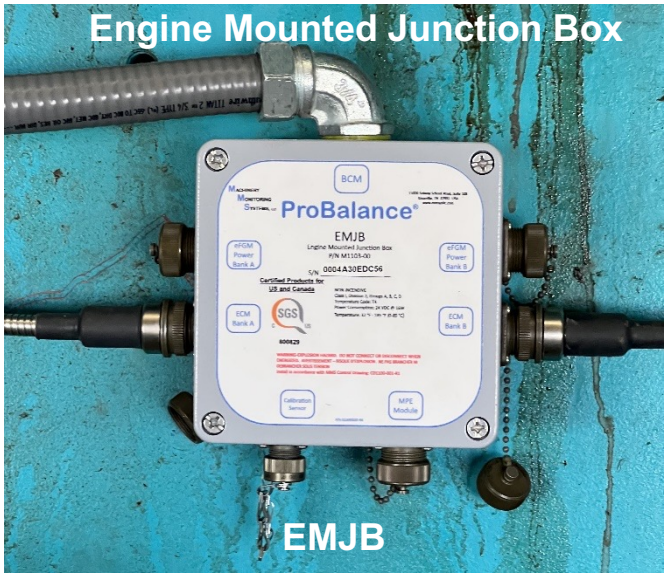
MACHINERY MONITORING SYSTEMS, LLC

Wireless antenna

BCM mounted to UCP

Conduit to EMJB

Power (24VDC) & communications
(MODBUS IP or RS-485)



ProBalance Components

MACHINERY MONITORING SYSTEMS, LLC

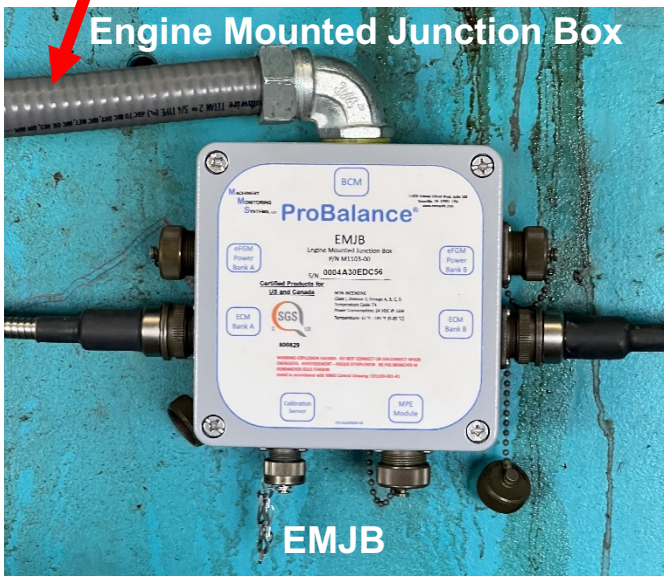
Wireless antenna

BCM mounted to UCP

Conduit to EMJB

Power (24VDC) & communications
(MODBUS IP or RS-485)

Conduit from BCM



ProBalance Components

MACHINERY MONITORING SYSTEMS, LLC

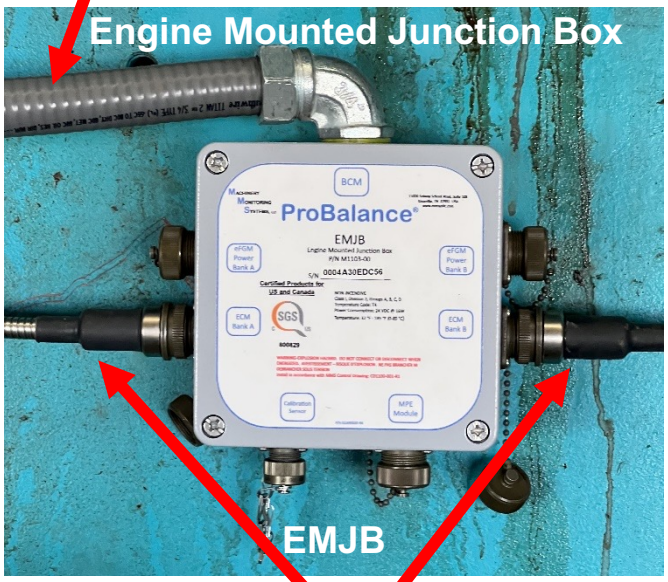
Wireless antenna

BCM mounted to UCP

Conduit to EMJB

Power (24VDC) & communications
(MODBUS IP or RS-485)

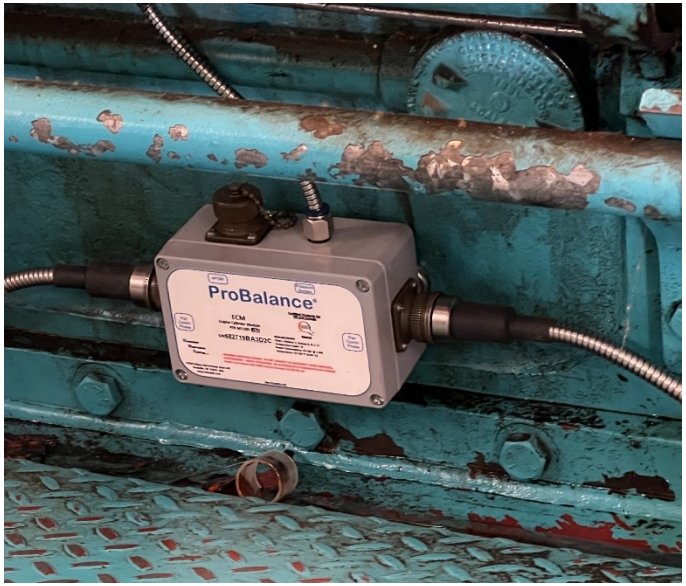
Conduit from BCM



Armored Cables to
ECMs

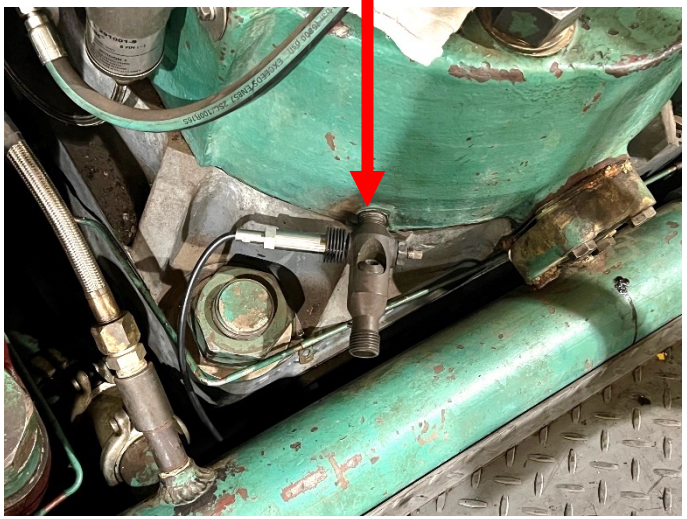
ProBalance Components

MACHINERY MONITORING SYSTEMS, LLC



ECM, One per cylinder, magnet-mount daisy-chained communications & power, connection to pressure sensor

Dual-port Kiene valve w/ pressure sensor



ProBalance Use

MACHINERY MONITORING SYSTEMS, LLC

- Live, continuous PFP data wirelessly to tablet
- Adjust balancing valve on cylinder
- See effect on balance for all cylinders immediately
- Operator verifies balance anytime on the BCM (at UCP)

ProBalance Use

MACHINERY MONITORING SYSTEMS, LLC

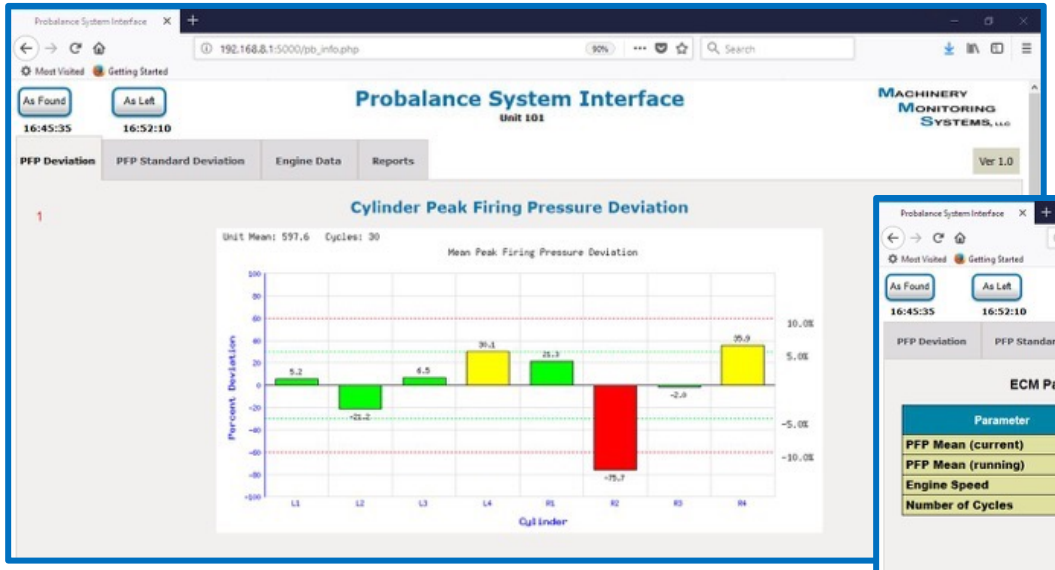
- Live, continuous PFP data wirelessly to tablet
- Adjust balancing valve on cylinder
- See effect on balance for all cylinders immediately
- Operator verifies balance anytime on the BCM (at UCP)

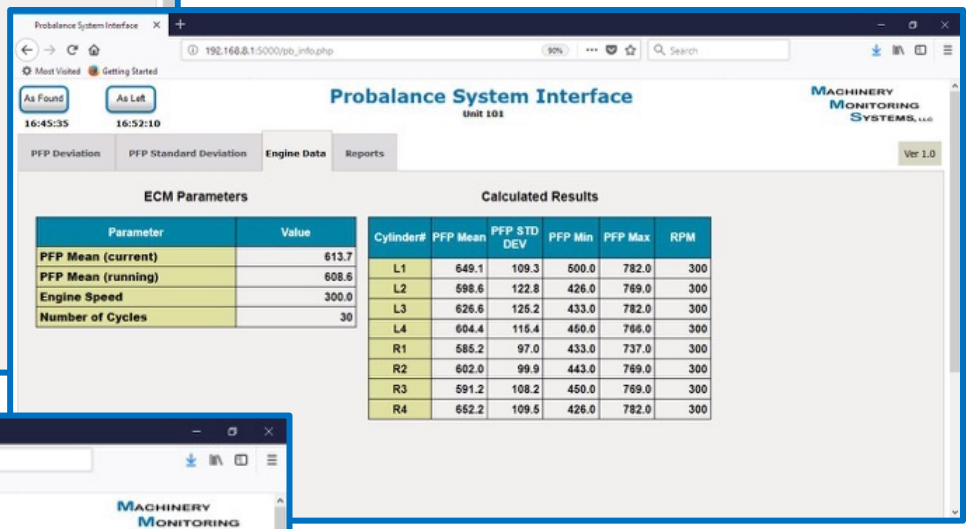
10

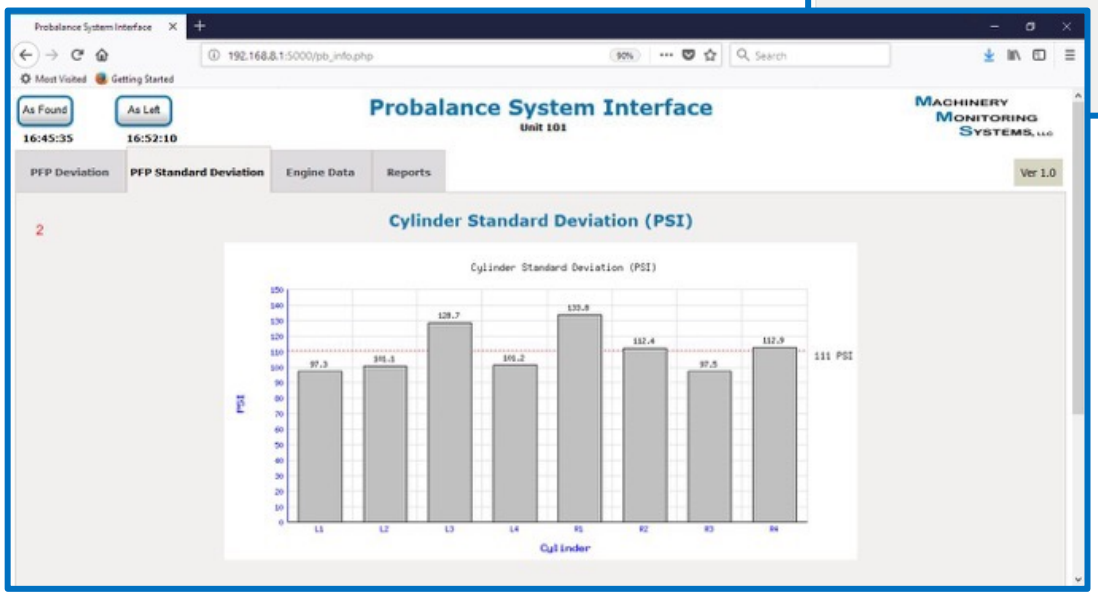
~~45-90~~ *Minutes for an 8-cylinder engine*

ProBalance Tablet Screens

MACHINERY MONITORING SYSTEMS, LLC

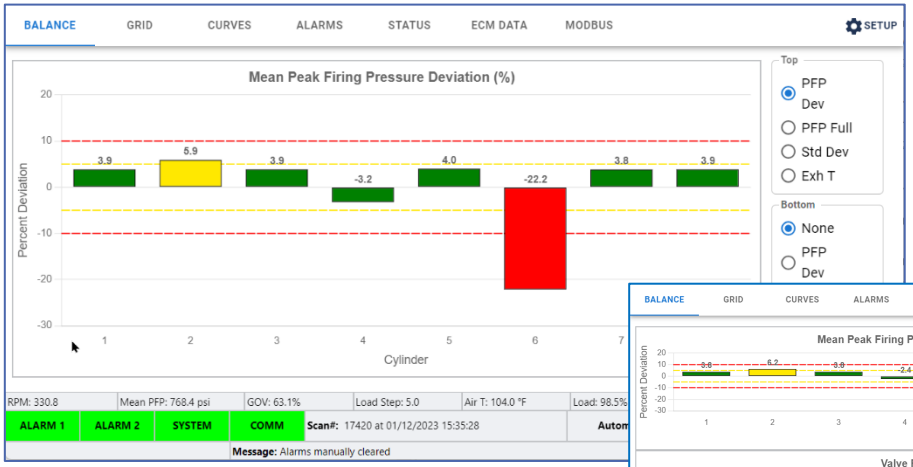


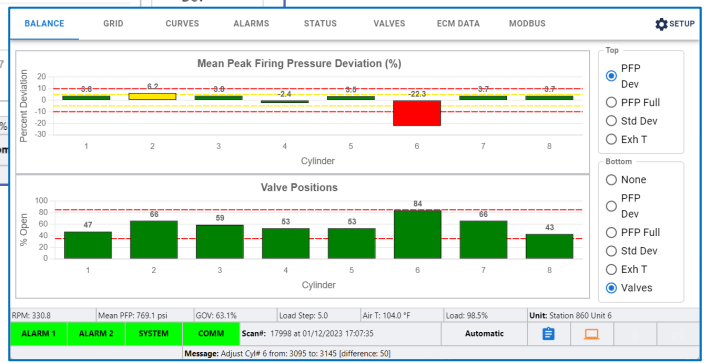


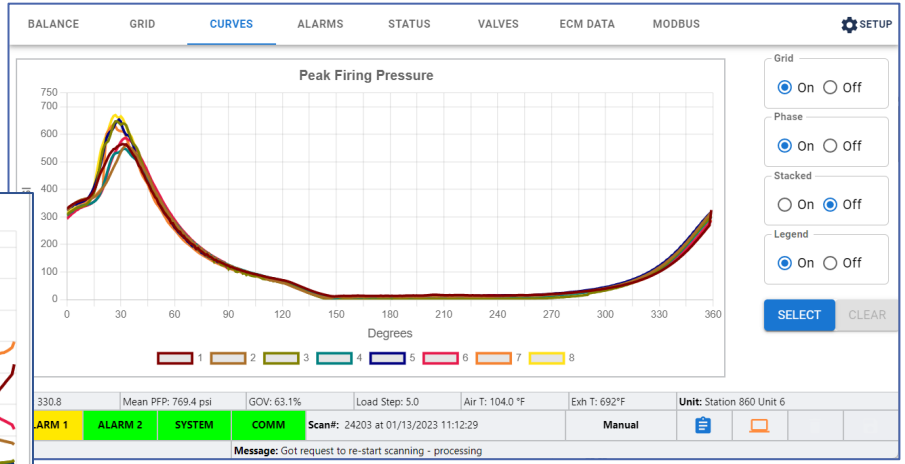


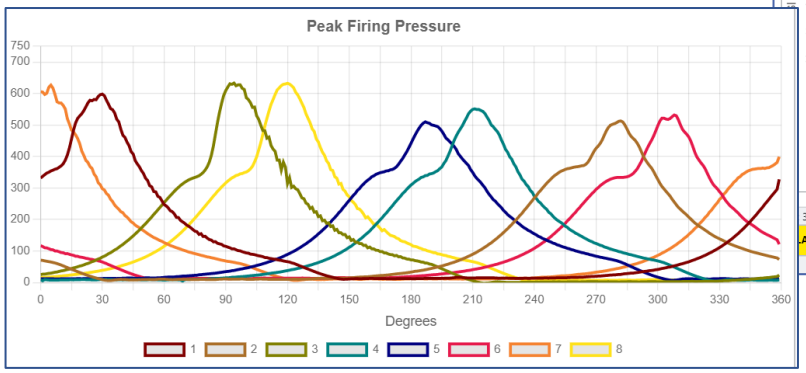
ProBalance BCM Screens

MACHINERY MONITORING SYSTEMS, LLC







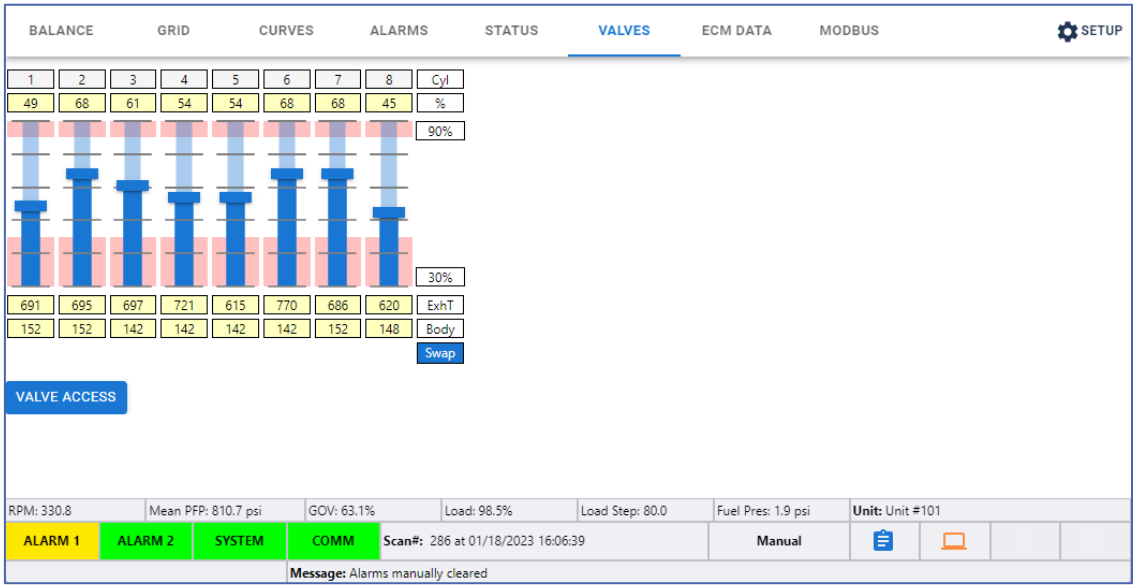


ProBalance Plus Upgrade

MACHINERY MONITORING SYSTEMS, LLC

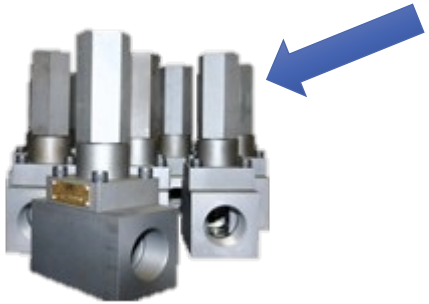
Automatic Balancing w/ ProBalance Plus

- Add electronically controlled fuel balancing valves
- Comm cable from each ECM
- Daisy-chained power from EMJB



Electronic Balancing Valve Features

MACHINERY MONITORING SYSTEMS, LLC



Comparison of MMS ProBalance Plus Balancing Valve to Others		
MMS/CECO eFGM	**Others**	**Comments**
Position feedback	None	No calibration of valves necessary
Stepper motor directly coupled to valve	Rubber belt	Reliability
Temperature sensor in valve	None	Identifies hi temp valve body Common valve failure is from a failure of the cam operated fuel valve
Retrofittable to existing manual CECO FGMs	No	Years of operating experience with CECO balancing valves
EMI & Vibration ruggedized	No	Reliability
Simplified wiring (Power – 24VDC & Serial Pair)	6 conductor cable from UCP to each valve	Reliability, ease of installation & cost
Manual override adjustability	No	Stem on top of stepper motor
High torque stepper motor	No	Supports manifold pressures up to 125 PSI

MMS's Electronic Balancing Valve Features

MACHINERY MONITORING SYSTEMS, LLC

Comparison of MMS ProBalance Plus Balancing Valve to Others		
MMS eFGM	**Others**	**Comments**
Electronic and visual position feedback – 360°	None	No calibration of valves necessary
Stepper motor directly coupled to valve	Rubber belt	Reliability
Temperature sensor in valve	None	Identifies hi temp valve body Common valve failure is from a failure of the cam operated fuel valve
Reduced height / moment arm	None	
EMI & Vibration ruggedized	No	Reliability
Simplified wiring (Power – 24VDC & Serial Pair)	6 conductor cable from UCP to each valve	Reliability, ease of installation & cost
Manual override adjustability	No	Stem on top of stepper motor
High torque stepper motor	No	Supports manifold pressures up to 125 PSI

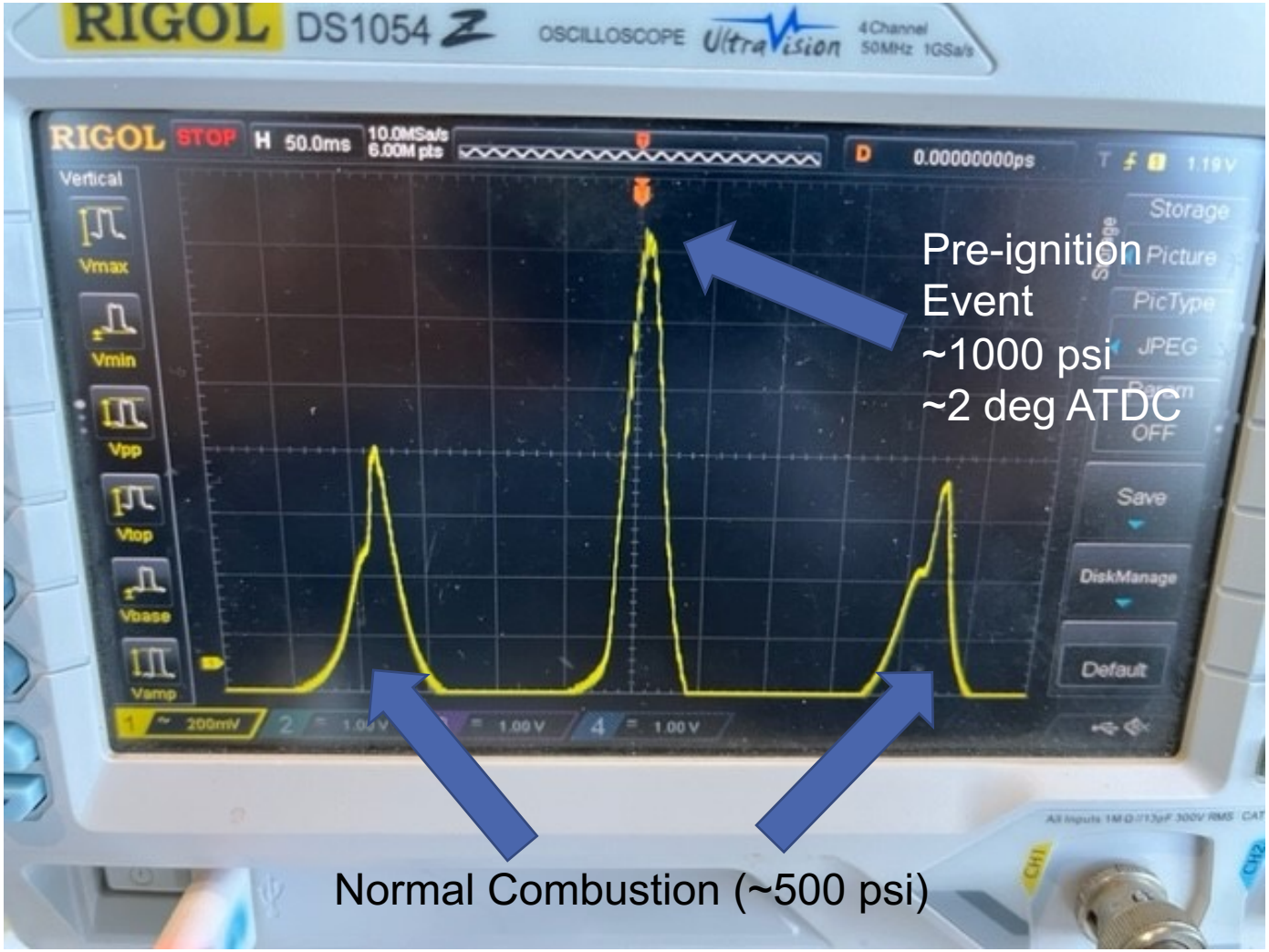
ProBalance / Probalance Plus Experience

MACHINERY MONITORING SYSTEMS, LLC

- TLA-8
- TLAD-5
- GMW-8
- GMVH-12
- HBA-6
- HBA-10
- TCV-16
- W-330
- Z-330
- KVR-8 (PO Pending) – will be 1st 4 stroke engine
- Cooper Quad

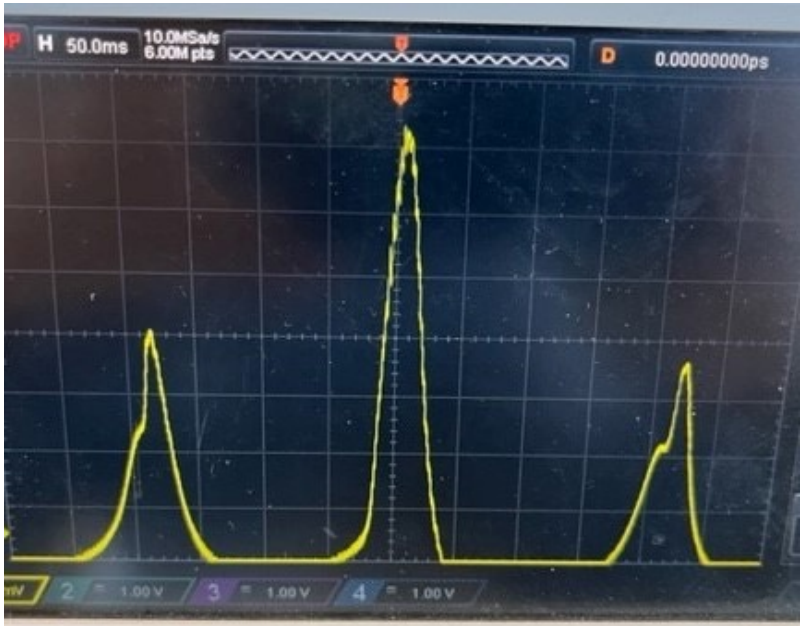
Discussion Item (TLA-8)

MACHINERY MONITORING SYSTEMS, LLC



Discussion Item (TLA-8)

MACHINERY MONITORING SYSTEMS, LLC



- Can identify pre-ignition events during scan
- Calculate % of identified curves in scan (e.g., 30 – 100 averages)
- User settable threshold (e.g., 10%)
- Alarm if threshold exceeded?

Discussion Item
Optional Balancing Methods

MACHINERY MONITORING SYSTEMS, LLC

- **Peak Firing Pressure (PFP)** is the most common balancing method – probably due to the history of balancing – it was easy to measure.
- It is accomplished by measuring the firing pressures of all the cylinders, calculating the mean of those pressures, and adjusting the firing pressures as close to that mean pressure as possible.

OR

Peak Pressure Ratio (PPR) is a method suggested in EPPL / SWRI / DOE study in 2008. In this method, the PFP and the unfired Compression Pressure (Cp) of each cylinder is measured.

The compression pressure is an indication of how much air is trapped in the cylinder. Since we cannot change that, by inputting the proper amount of fuel into each cylinder, we can control the equivalence ratio, which profoundly influences the combustion process.

Discussion Item
Peak Pressure Ratio Balancing

MACHINERY MONITORING SYSTEMS, LLC

- The PFP is divided by the Cp establishing the PPR.

$$PPR = PFP \div Cp$$

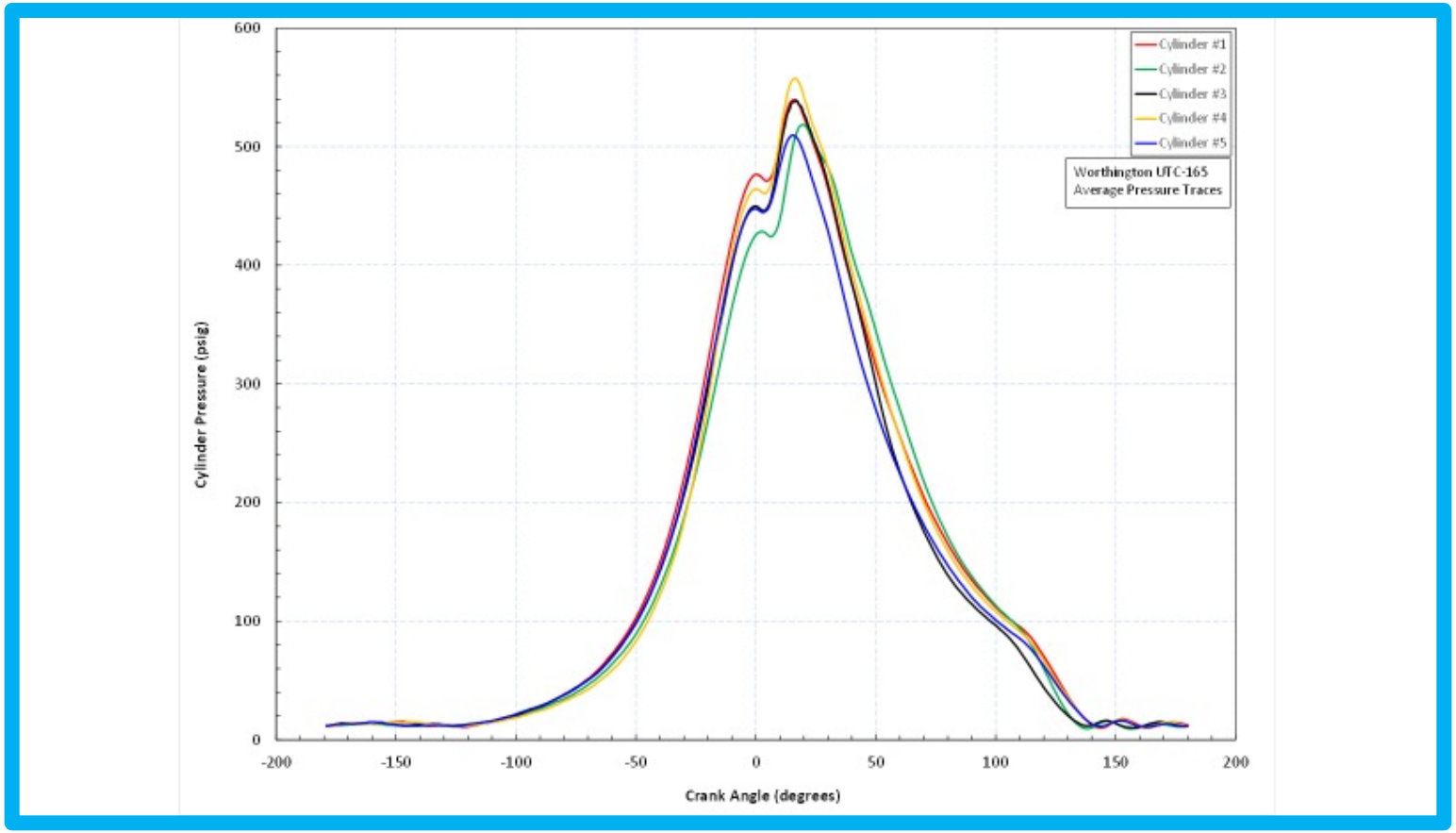
- Multiplying the Average PPR by the individual cylinder Cp's generates the target PFP for that cylinder.

- Research has proven that utilization of the PPR method reduces NOx, COV's and associated crankshaft stresses induced by rapid variations in angular velocities imparted by unbalance and misfires*.

*FINAL REPORT
SwRI® Project No. 18.06223
DOE Award No. DE-FC26-02NT41646

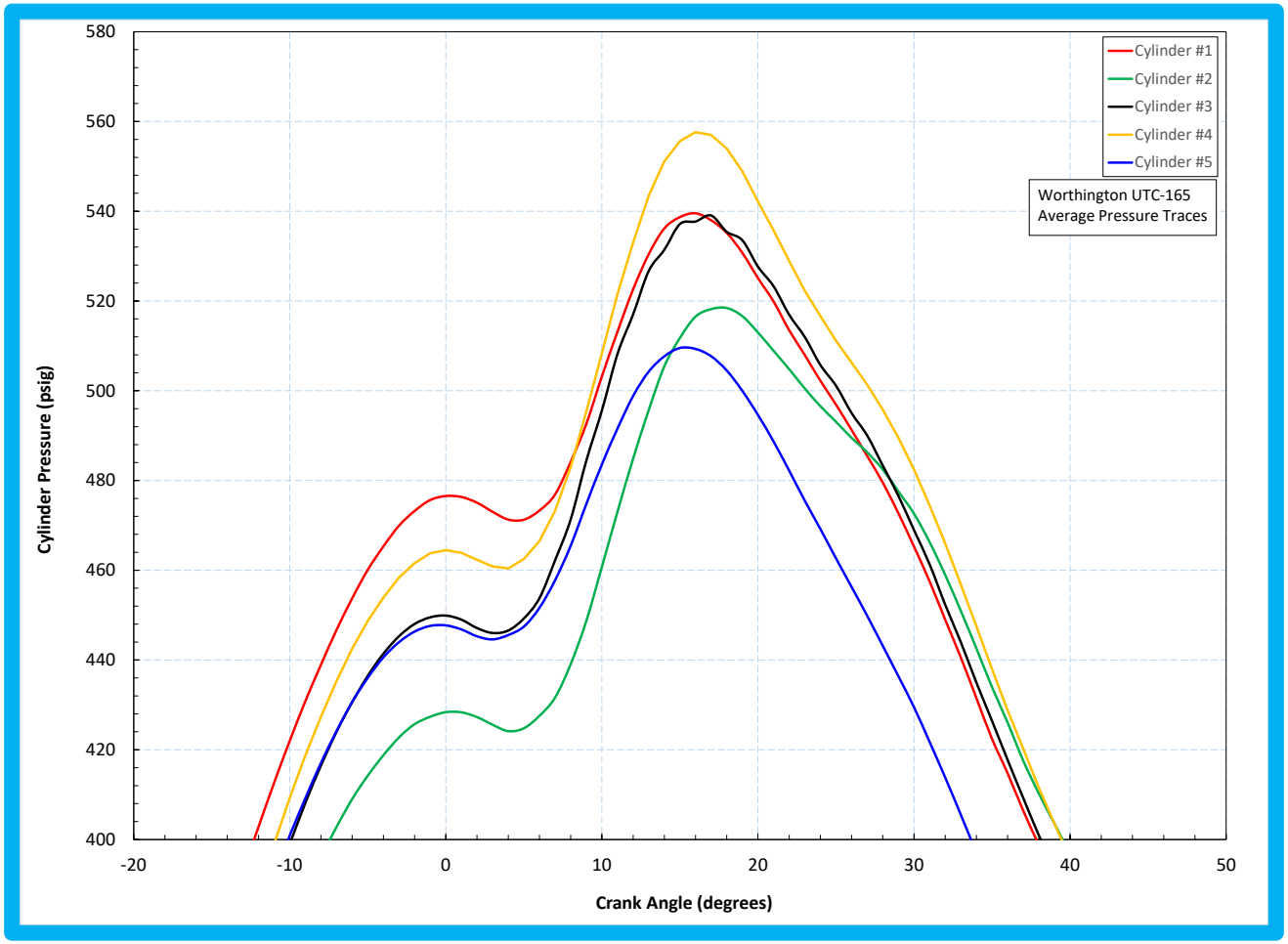
Cylinder Pressure v Crank Angle
0 to 600 psi Scale

MACHINERY MONITORING SYSTEMS, LLC



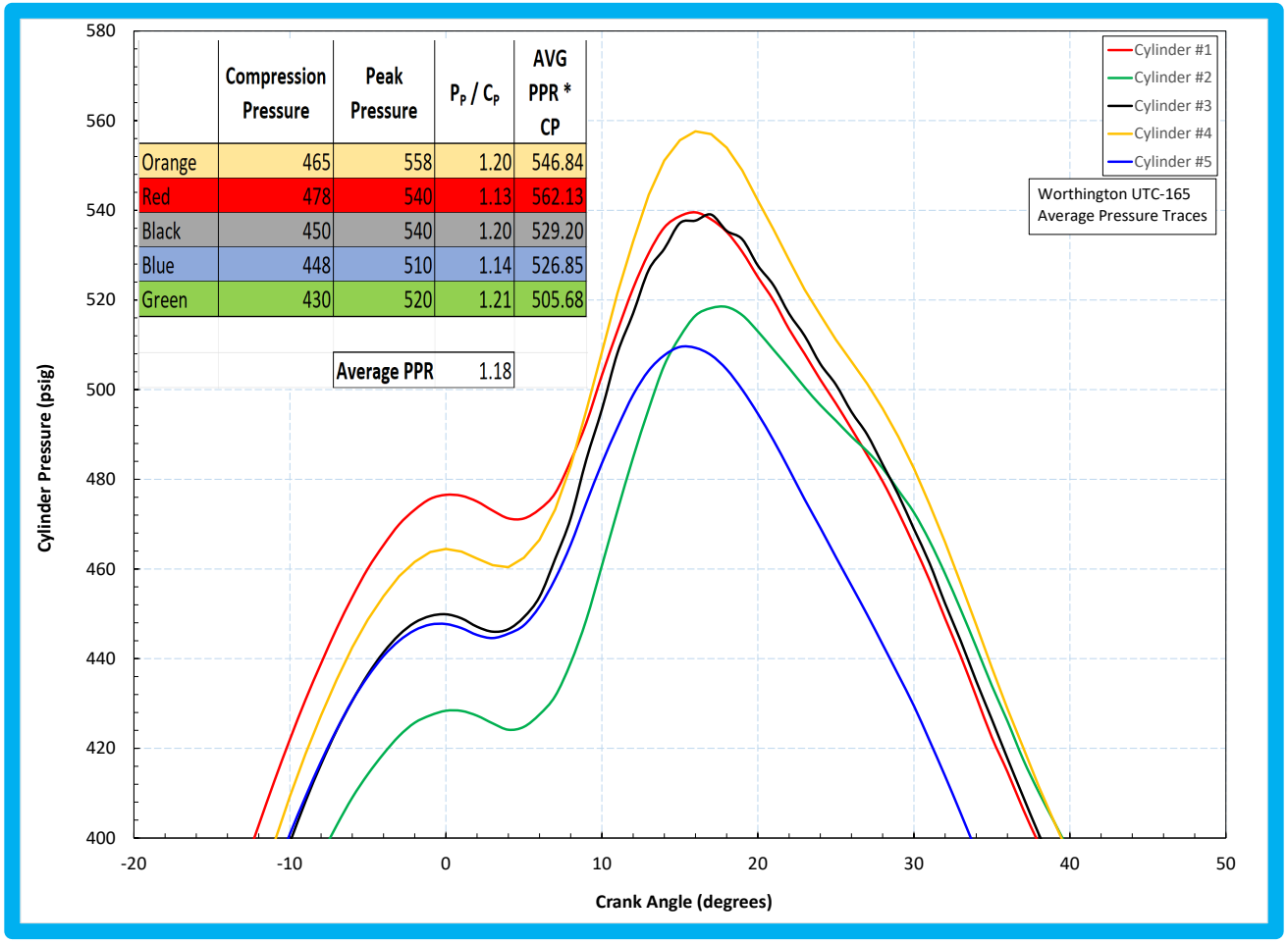
Cylinder Pressure v Crank Angle
400 to 580 psi Scale

MACHINERY MONITORING SYSTEMS, LLC



PFP vs PPR

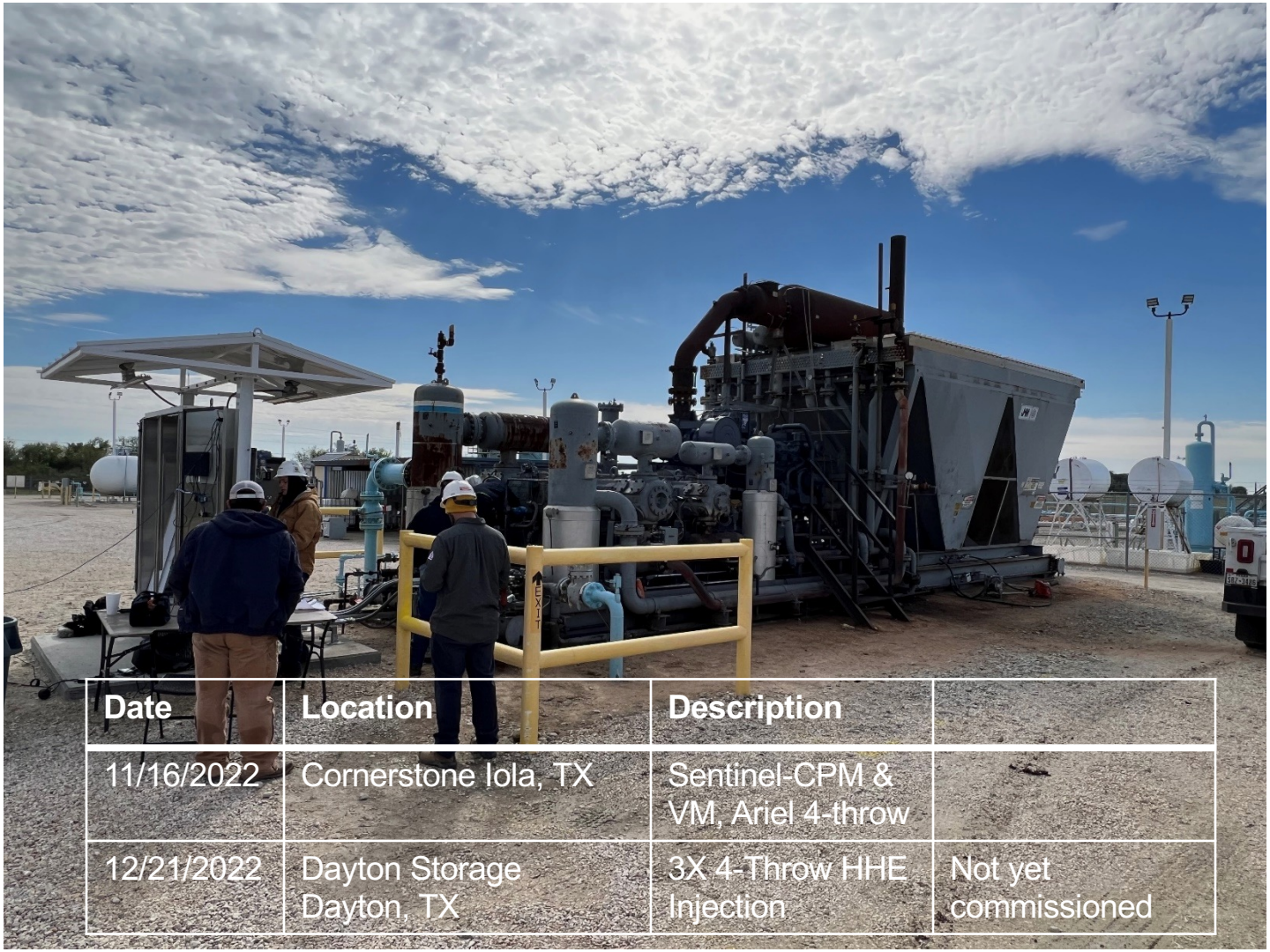
MACHINERY MONITORING SYSTEMS, LLC



Kinder Morgan Installations

MACHINERY MONITORING SYSTEMS, LLC

Sentinel-CPM / VM Compressor Performance



Date	Location	Description	
11/16/2022	Cornerstone Iola, TX	Sentinel-CPM & VM, Ariel 4-throw	
12/21/2022	Dayton Storage Dayton, TX	3X 4-Throw HHE Injection	Not yet commissioned

Sentinel® - Compressor Monitoring

MACHINERY MONITORING SYSTEMS, LLC

- Designed for high-speed data collection
  - Used for Safety alarming – startup issues, rod Loading, Vibration etc.
  - Real time IHP for control application
- 3 Versions available
  - CPM – compressor dynamic pressures
  - VM – Vibration and Flow sensors
  - EPM – Engine dynamic pressures
- Wide range of sensors for most applications
  - Voltage and current pressure sensors
  - Packing vent flow sensors
  - Rod Drop sensors
  - Vibration sensors
    - Accelerometers
    - Velometers
    - Proximity
    - Impact Sensors

Sentinel®-CPM
Compressor Performance Monitor

MACHINERY MONITORING SYSTEMS, LLC

- 12 Input channels plus 2 phase trigger inputs.
  Cylinder PVs & PTs

- Utilizes an ACI eRCM Kernel to calculate horsepower and additional performance parameters for each compressor cylinder.

- Results of the performance calculations & diagnostics are communicated to the customer PLC via TCP MODBUS or Serial RS485.

Embedded MMS version - ACI eRCM Kernel

MACHINERY MONITORING SYSTEMS, LLC

- ACI eRCM Kernel with MMS enhanced performance calcs using *real time dynamic waveforms* (PVs & PTs).
- Compares theoretical calculated values from the eRCM Model with *actual measured* values in real time. Notable differences can help identify problems before they become failures.
- Real time measurements and alarming of rod loads, degrees of reversal, IHP and flow.

Additional Diagnostics

MACHINERY MONITORING SYSTEMS, LLC

The CPM automated diagnostic program alerts on all of the most common compressor faults

- Suction and Discharge valve leakage
- Piston ring leakage
- Packing leakage
- Unloader\Load step issues

The alert levels can be tuned for specific applications along with a User's tolerance for the amount of leakage that is acceptable

Sentinel-CPM Sensor Suite

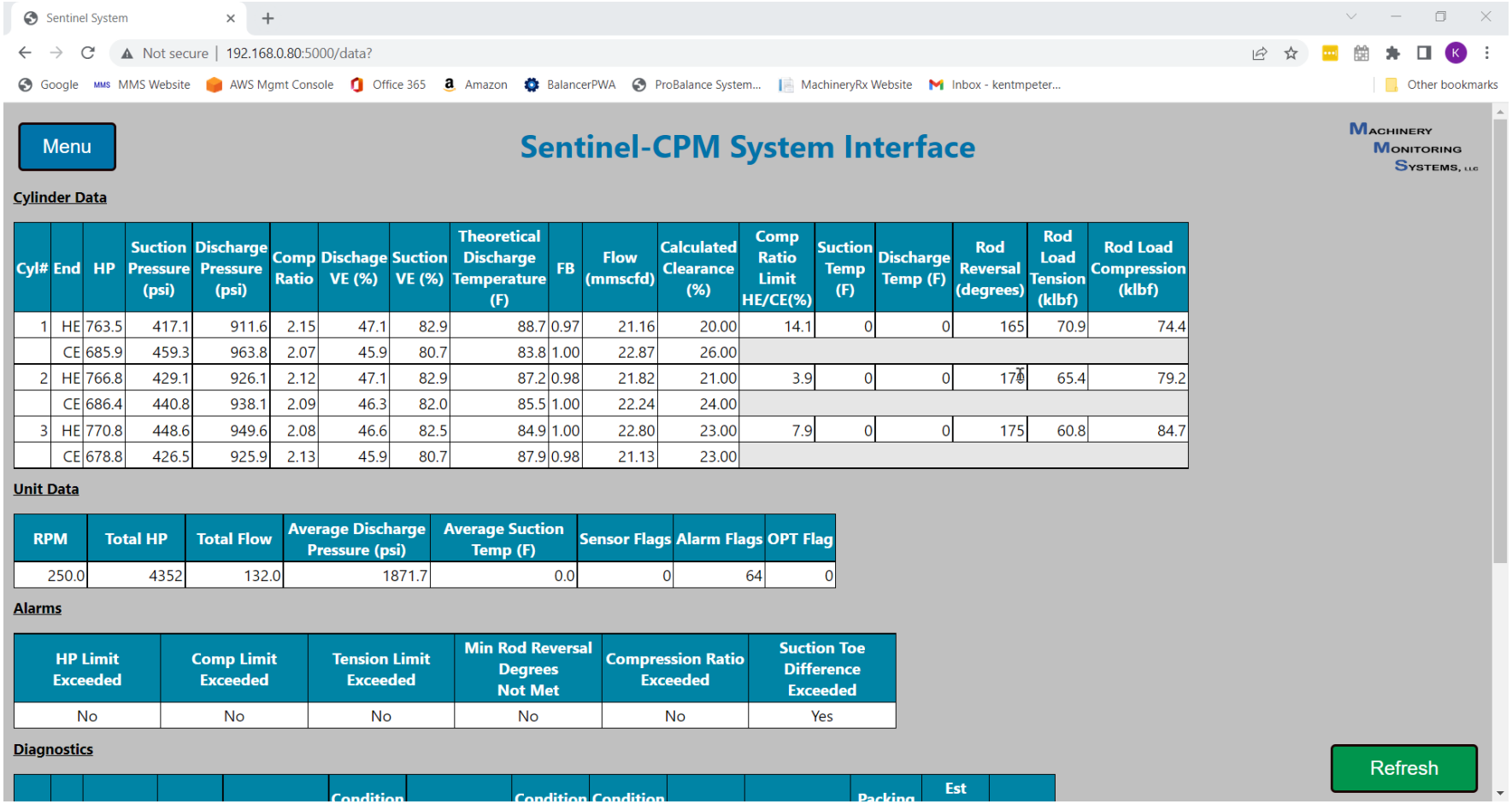
MACHINERY MONITORING SYSTEMS, LLC

- DC pressure sensors
  - IMES DC pressure sensors
- Magnetic Pickups
  - Altronic Magnetic pickups
- Packing Vent Flow Sensor
  - Used to enhance the embedded diagnostic program to differentiate between suction valve and packing leakage

Detail Cylinder Data

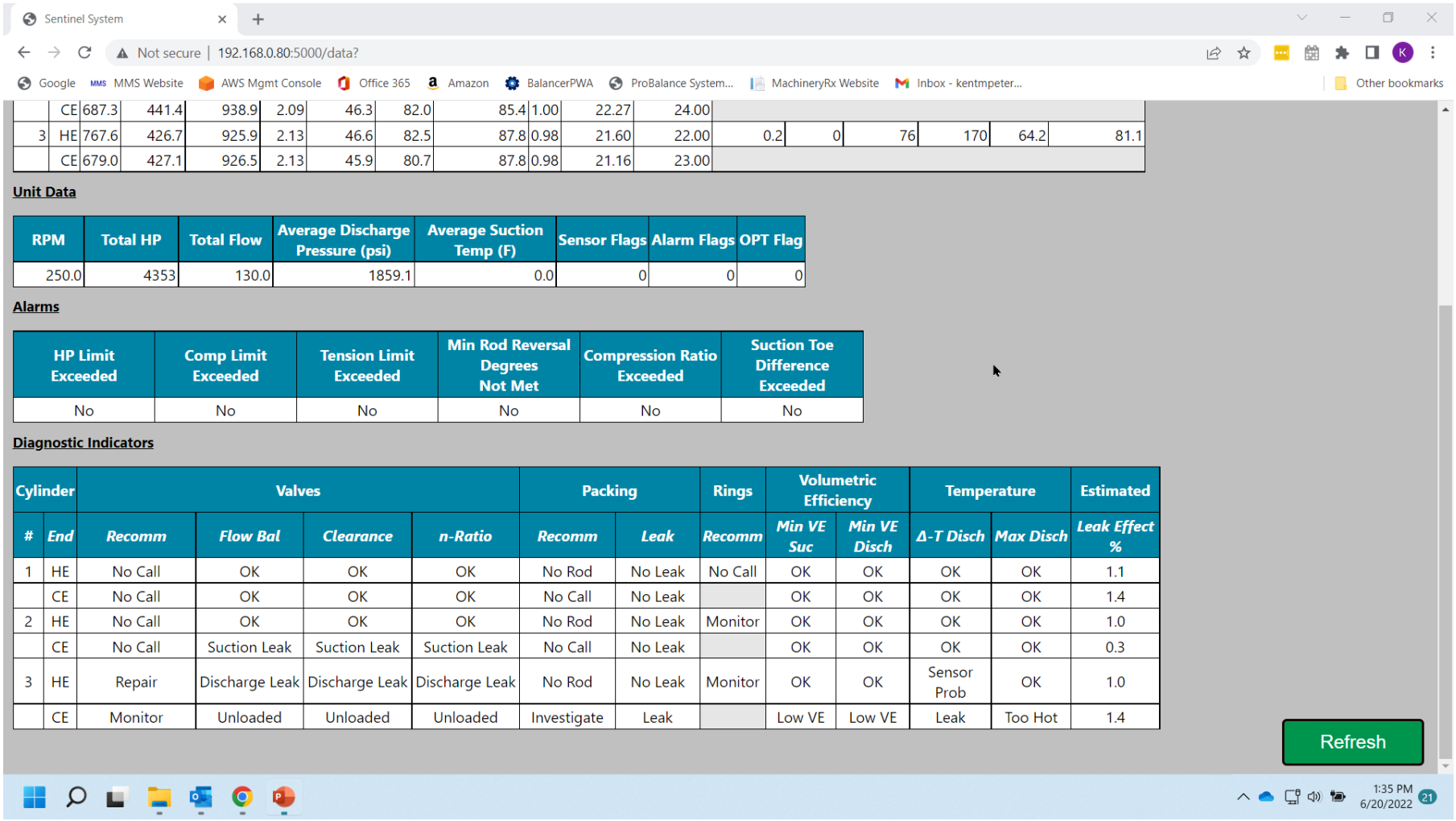
MACHINERY MONITORING SYSTEMS, LLC

Data available via Modbus and Web Browser



Sample Diagnostic Data

MACHINERY MONITORING SYSTEMS, LLC



	CE	687.3	441.4	938.9	2.09	46.3	82.0	85.4	1.00	22.27	24.00						
3	HE	767.6	426.7	925.9	2.13	46.6	82.5	87.8	0.98	21.60	22.00	0.2	0	76	170	64.2	81.1
	CE	679.0	427.1	926.5	2.13	45.9	80.7	87.8	0.98	21.16	23.00						

Unit Data

RPM	Total HP	Total Flow	Average Discharge Pressure (psi)	Average Suction Temp (F)	Sensor Flags	Alarm Flags	OPT Flag
250.0	4353	130.0	1859.1	0.0	0	0	0

Alarms

HP Limit Exceeded	Comp Limit Exceeded	Tension Limit Exceeded	Min Rod Reversal Degrees Not Met	Compression Ratio Exceeded	Suction Toe Difference Exceeded
No	No	No	No	No	No

Diagnostic Indicators

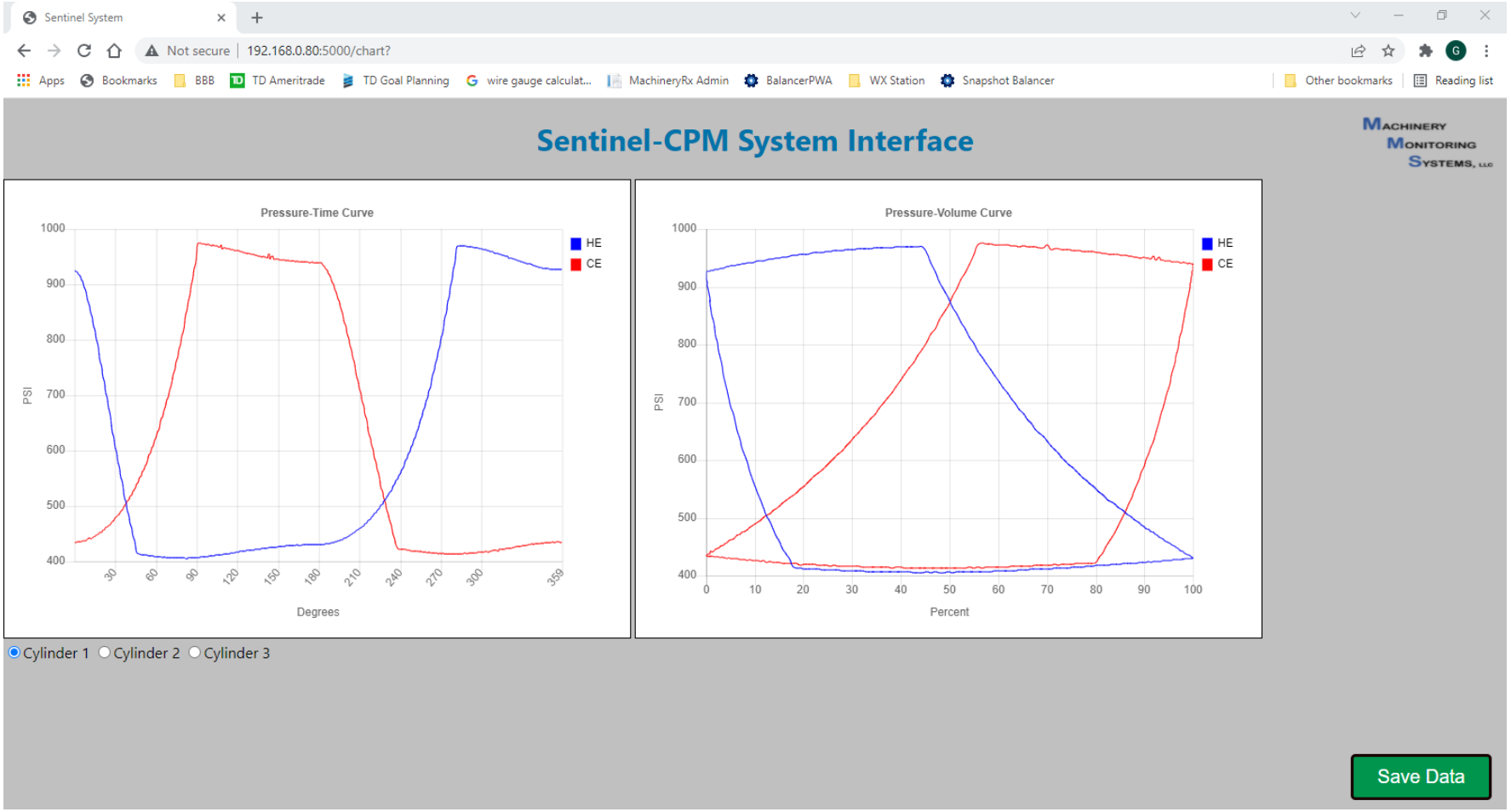
Cylinder		Valves				Packing		Rings	Volumetric Efficiency		Temperature		Estimated
#	End	Recomm	Flow Bal	Clearance	n-Ratio	Recomm	Leak	Recomm	Min VE Suc	Min VE Disch	Δ-T Disch	Max Disch	Leak Effect %
1	HE	No Call	OK	OK	OK	No Rod	No Leak	No Call	OK	OK	OK	OK	1.1
	CE	No Call	OK	OK	OK	No Call	No Leak		OK	OK	OK	OK	1.4
2	HE	No Call	OK	OK	OK	No Rod	No Leak	Monitor	OK	OK	OK	OK	1.0
	CE	No Call	Suction Leak	Suction Leak	Suction Leak	No Call	No Leak		OK	OK	OK	OK	0.3
3	HE	Repair	Discharge Leak	Discharge Leak	Discharge Leak	No Rod	No Leak	Monitor	OK	OK	Sensor Prob	OK	1.0
	CE	Monitor	Unloaded	Unloaded	Unloaded	Investigate	Leak		Low VE	Low VE	Leak	Too Hot	1.4

Refresh

Phased P-T & P-V Curves

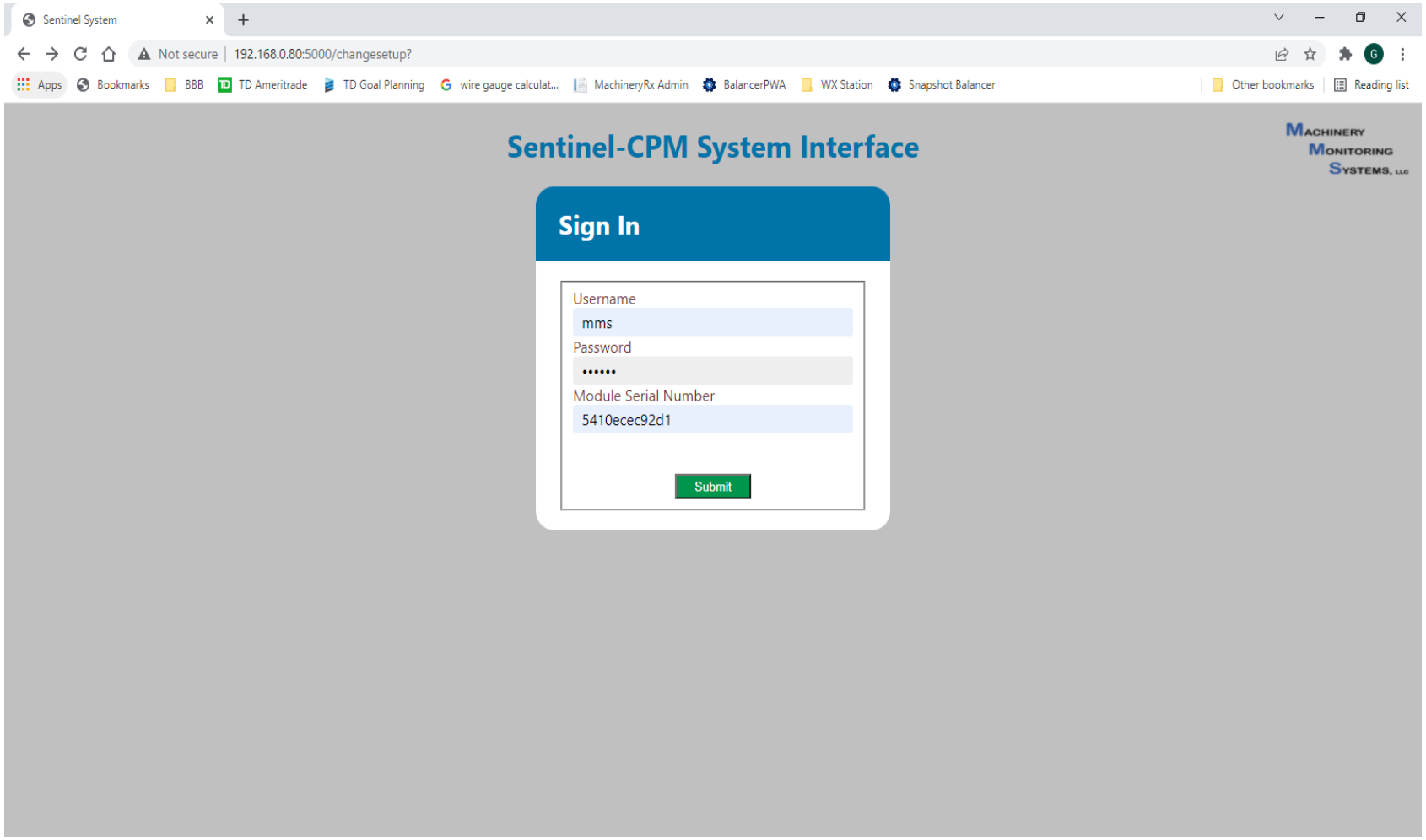
MACHINERY MONITORING SYSTEMS, LLC

Dynamic waveforms available via Network connection



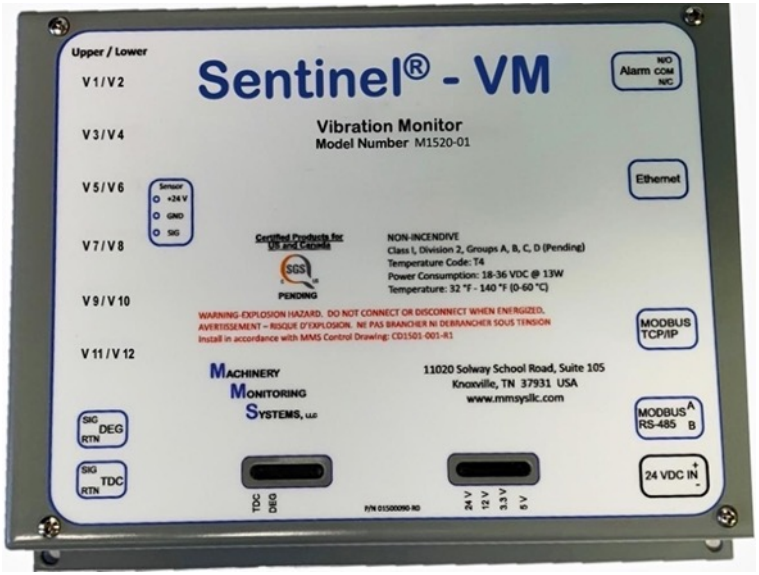
TSA Compliant Log-In

MACHINERY MONITORING SYSTEMS, LLC



Sentinel®-VM
Vibration Monitor

MACHINERY MONITORING SYSTEMS, LLC

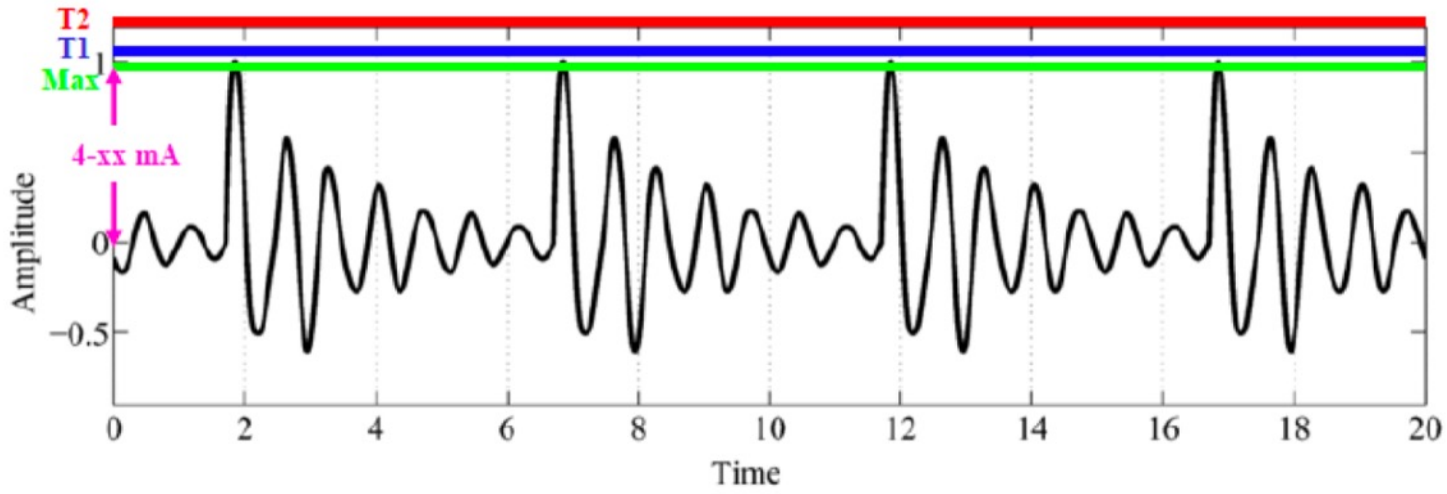


- 12 Vibration sensor inputs
  - Accelerometers
  - Velocity pickups
  - Proximity probes
- Crosshead vibration/impacts
- Frame/Bearing vibration
- Cylinder/Frame Movement
- Rod Drop/Rod Runout
- Communicate to Unit PLC
  - Modbus TCP
  - Modbus RS-485
- Web interface

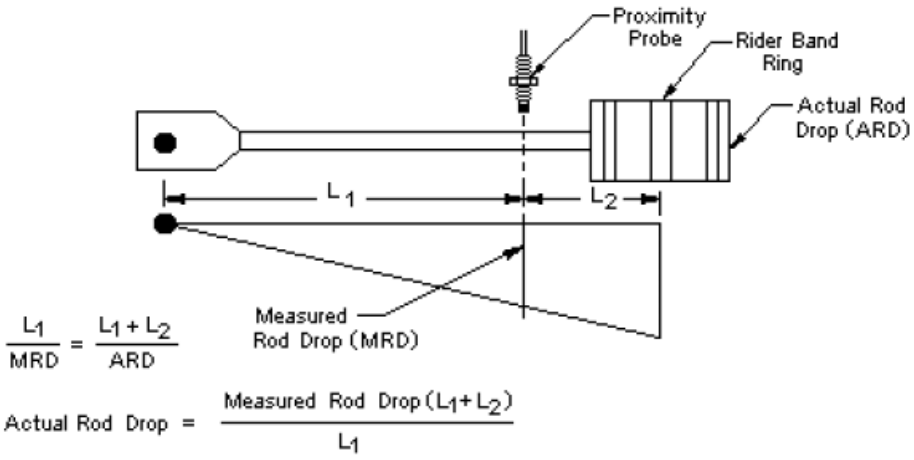
Sentinel®-VM input devices - Samples

MACHINERY MONITORING SYSTEMS, LLC

New method to detect Xhead mechanical impacts

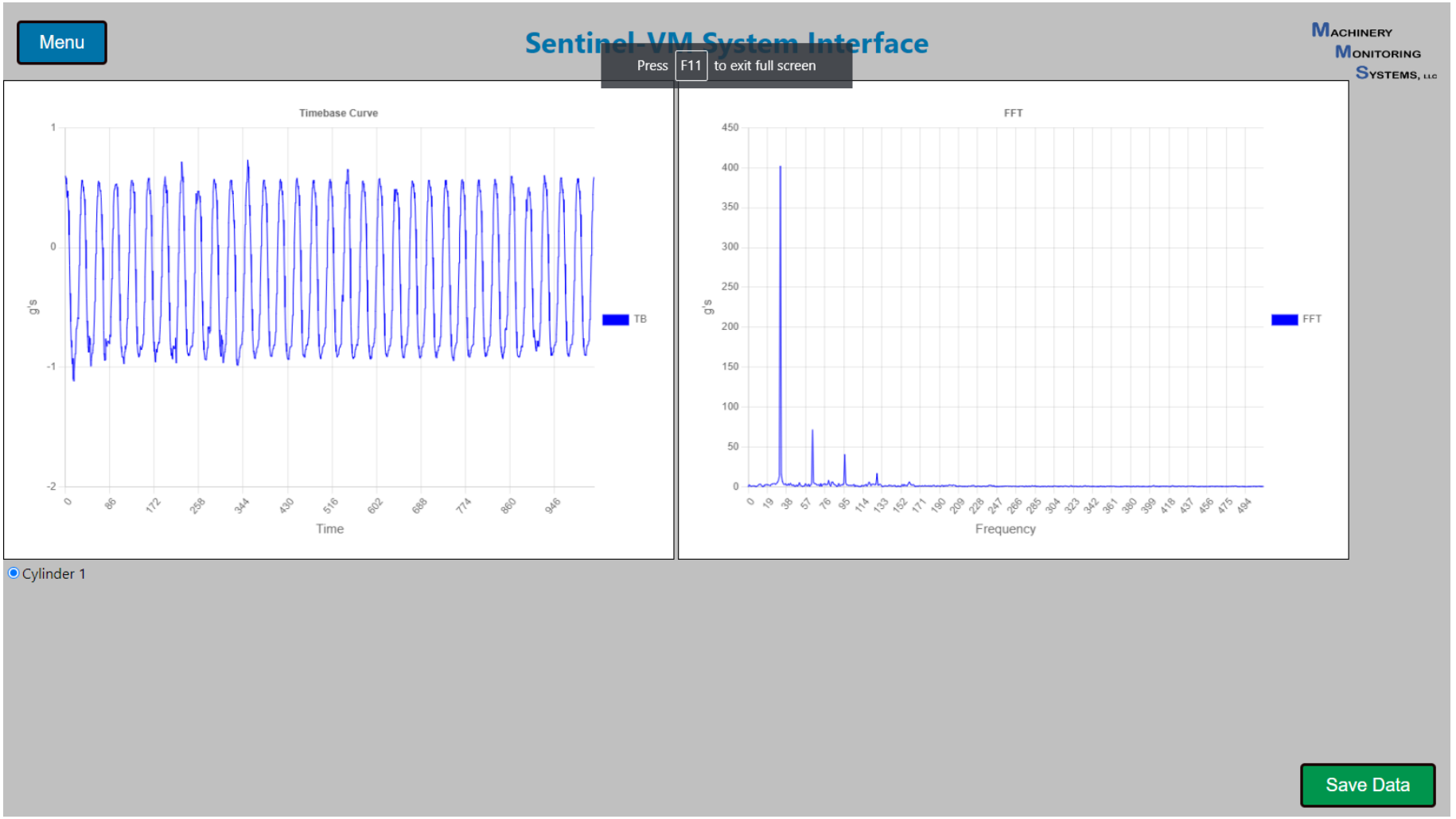


- Rod Drop = Rider Band Wear
- Rod Runout = Mechanical looseness



Time Based Curve and FFT

Machinery Monitoring Systems, LLC



MMS Next Generation Compressor Monitoring

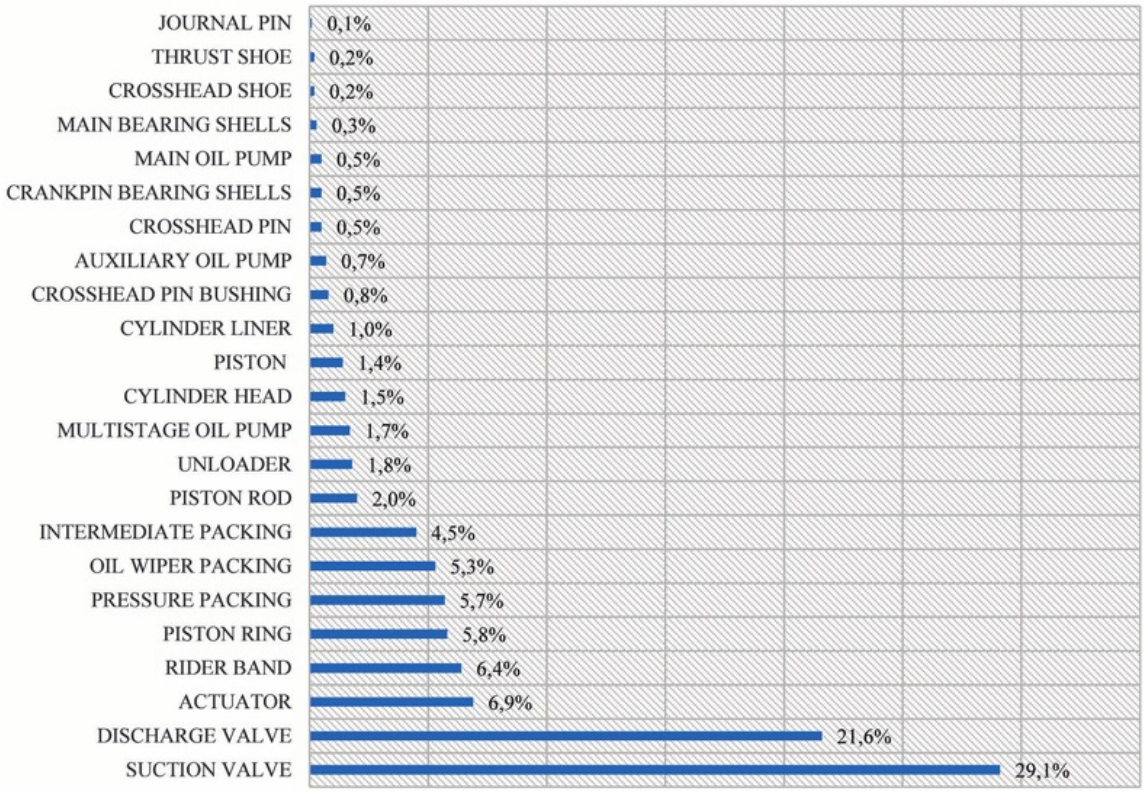
MACHINERY MONITORING SYSTEMS, LLC

Failure Mode \ Detection	Press. / Vol. & Temp. Model	Impacting / Crosshead Vibration	Frame / Bearing Vibration	Cylinder Head Vibration	Rod Position
Valve Leakage	✓				
Packing Leak	✓				
Piston Ring Leak	✓				
Non-Reversal	✓				
Rod-Load	✓				✓
Unloader	✓	✓			
Overloading	✓	✓			
Crosshead Guide Shoe & Shims		✓			✓
Piston Rod Looseness		✓	✓		✓
Piston Nut Looseness		✓	✓		✓
Foundation			✓	✓	
Main Bearing			✓		
Liquid Slug	✓	✓	✓		✓
Piston Rider Band Wear					✓
Cylinder Alignment				✓	✓

MMS Next Generation Compressor Monitoring

MACHINERY MONITORING SYSTEMS, LLC

Failure Percentage Share For Reciprocating Compressors



Maintenance Costs in Terms of Components

Component	Percentage
Valves	50
Packing	20
Piston Rings	20
Rider Bands	7
Piston Rods	2
Cylinder Liners	0.5
Bearings	0.5

Focused on Diagnostics

What's Next

MACHINERY MONITORING SYSTEMS, LLC

- New ProBalance 2.0 Software Released
- Add PPR as an optional balancing method
- 1st & 2nd derivatives for added combustion diagnostics
- Integration of ProBalance into the MachineryRx app
- New Automatic Balancing Valve
- New Balance of Plant System

Questions?

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Thank You!