

## GMRC Analyzer & Reliability Workshop

July 27-29, 2011      Presenter: Mark Lueger



Turbocharger Management  
System for Informed Decisions



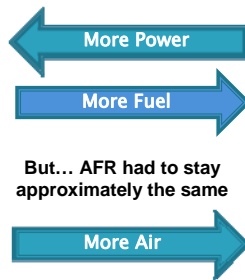
### **TURBO SHIELD** Will Save You \$\$

- Determine and quantify turbocharger degradation rate
- Better plan outages and overhauls
- Forecast engine parameters that impact emissions



## Why Turbocharge an Engine?

In the early days...

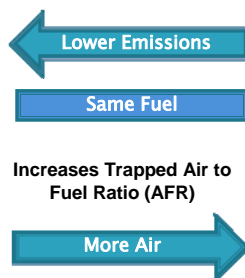


TURBO SHIELD

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## Why Turbocharge an Engine?

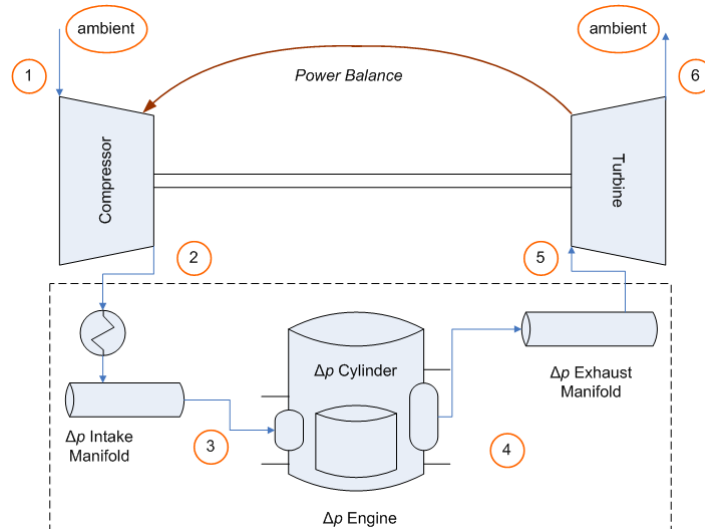
Today...



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## How the Turbo Fits in the System



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## Got Turbo Issues?

- Poor Performance?
- Unplanned Outages?
- High Emissions?
- Catastrophic Failures?



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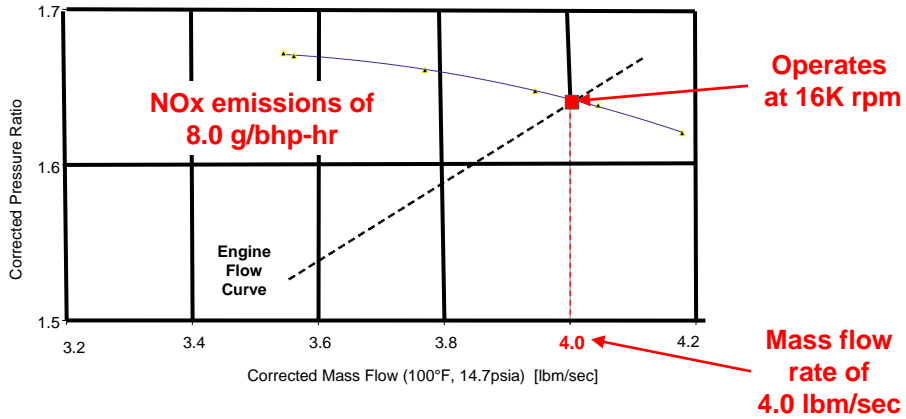
**Not sure if an operating  
problem  
is turbo  
related?**



**Let's Take a Look at the Impact of  
Turbo Degradation Over Time**



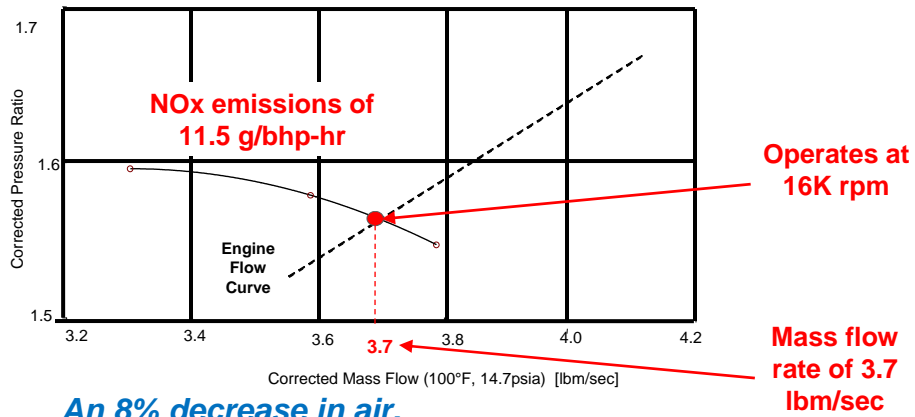
## Turbo After Overhaul



Courtesy of :  
National Gas Machinery Laboratory, Kansas State University  
and Advanced Engine Technologies Corporation



## Turbo After 17,000 Hours



**An 8% decrease in air,  
increased NOx more  
than 40%!**

Courtesy of :  
National Gas Machinery Laboratory, Kansas State University  
and Advanced Engine Technologies Corporation



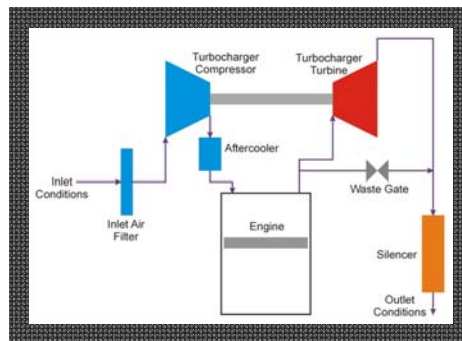
## Degradation Bottom Line

A small decrease in air flow...

... can greatly  
increase NOx  
emissions



But you can't  
improve  
operation if you  
don't measure  
or monitor  
turbocharger  
performance



## The Solution...

# TURBO SHIELD™

Turbocharger Management System



Take a New Road to Informed Decisions



## Turbo Shield™ Diagnostic Advantages

- Monitor real time operating parameters
  - Pressures
  - Temperatures
  - Air flow
- Verify operation along engine flow line
- Identify operating issues
  - Air flow restrictions
  - Turbocharger degradation
- Analyze turbo vibrations
- Maintain targeted TER based on actual air flow (optional)





### 1. Hardware



### 2. Electronics

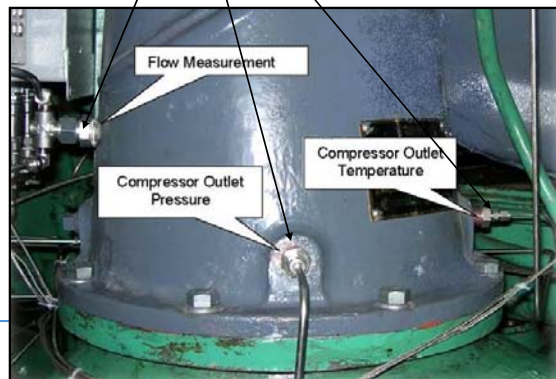


### 3. Software



## TURBO SHIELD On-Board Sensors

- Mag pickup for turbo speed
- Thermocouples for inlet/outlet temperatures
- Pressure tubing for inlet/outlet pressures
- Pitot tube for air flow





## ELECTRONICS

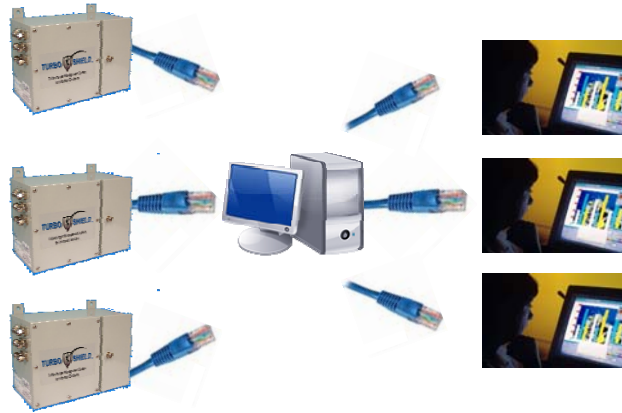
Receive and process operating signals via an electronic board located within a Class 1 Div 2 (or Div 1) enclosure.



## SOFTWARE

Send signals via the Ethernet to a central computer containing the **Management Software** that normalizes, trends, and stores all operating data.





## MULTIPLE USERS

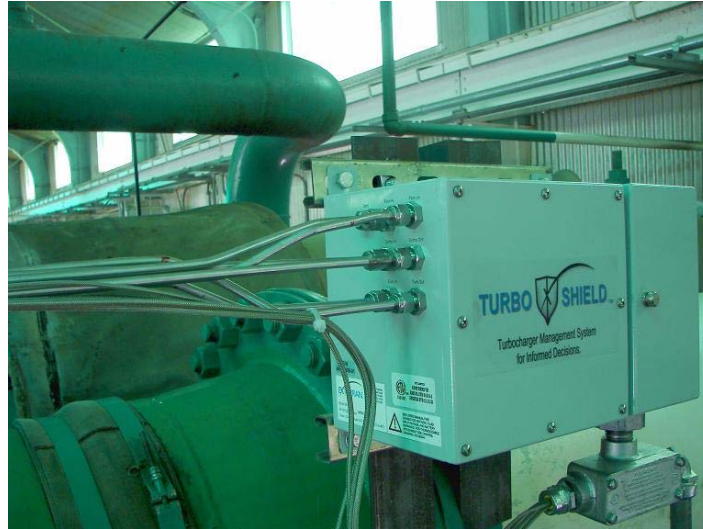
Multiple company engineers & technicians may access turbo performance information across your entire turbo fleet on your pipeline.



## Installation Picture



## Install Close Up



## Version 2.0 Model & Option List

Model	Application	Pressures, Temperatures, & Airflow	Speed & Vibration	Real Time Monitoring	Trending & Forecasting	Communication with Control Panel PLC	Trapped Equivalence Ratio (TER)
SS-RT	Single Turbo Single Scroll	Standard	Standard	Standard	N/A	Standard	Optional
SD-RT	Single Turbo Dual Scroll	Standard	Standard	Standard	N/A	Standard	Optional
DS-RT	Dual Turbo Single Scroll	Standard	Standard	Standard	N/A	Standard	Optional
SS-TF	Single Turbo Single Scroll	Standard	Standard	Standard	Standard	Standard	Optional
SD-TF	Single Turbo Dual Scroll	Standard	Standard	Standard	Standard	Standard	Optional
DS-TF	Dual Turbo Single Scroll	Standard	Standard	Standard	Standard	Standard	Optional



## On-Screen Data

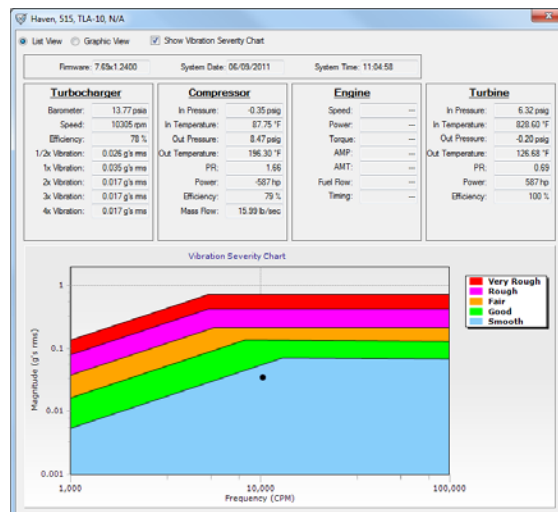
- Air flow
- Turbo speed
- Turbo vibration
- Turbine
  - Inlet temperature & pressure
  - Outlet temperature & pressure
- Compressor
  - Inlet temperature & pressure
  - Outlet temperature & pressure



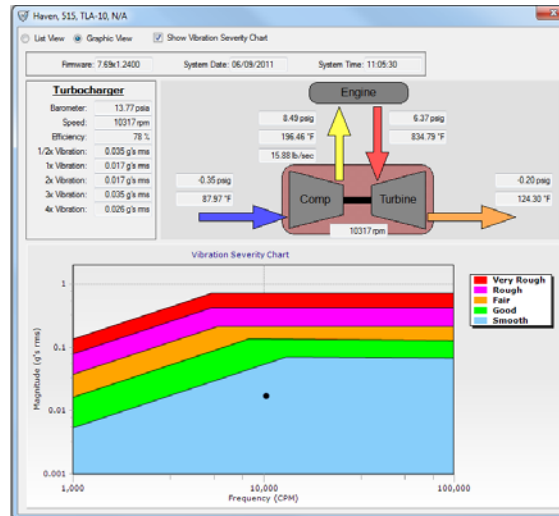
Will help you assess  
the health of your turbos



## Real Time Data: List View



## Real Time Data: Graphic View

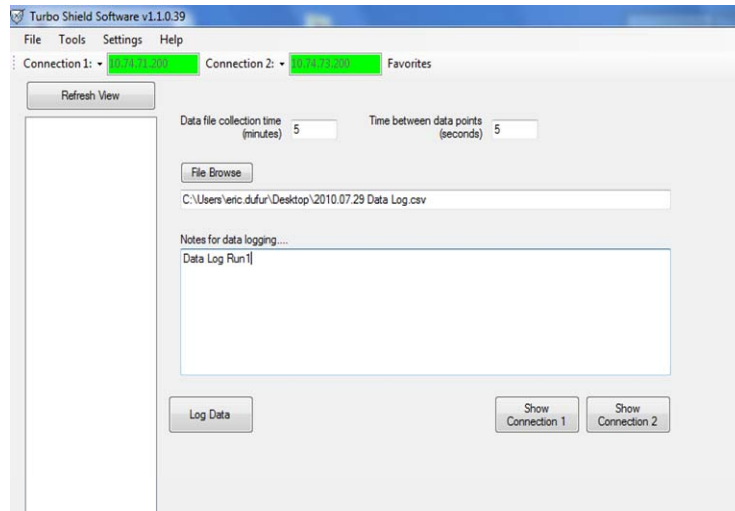


## Can I Capture Real Time Data?

- Utilizing the Data Logging feature, any real time data captured by the Turbo Shield™ can be stored in a .csv file
- Operators can log data at anytime while connected to the Turbo Shield™
  - Specify duration and time between points
- User notes can also be captured
- Excellent performance mapping or troubleshooting tool



## Data Logging

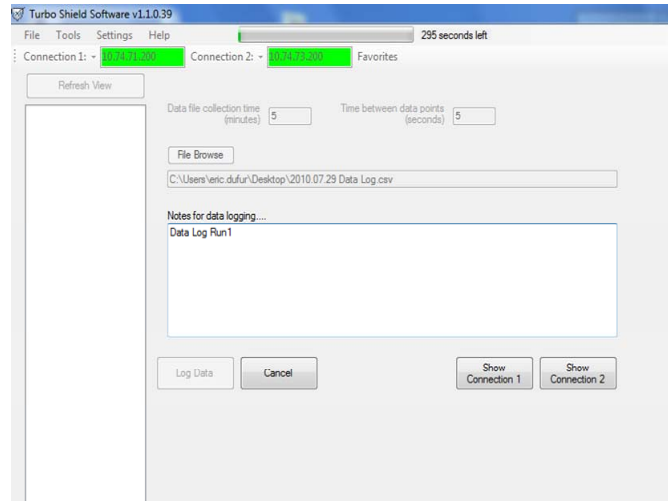


## Once Data Logging Starts...

- A progress bar shows time remaining until complete
- User notes can still be entered anytime
- Real Time Data screens can be viewed while data is being captured



## Data Logging: Capturing Data



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## Historical Reports

- All historical data captured by Turbo Shield™ is available to operators
- Captured historical data can be used to create trends and determine degradation
- Allows operators to determine when an issue may have occurred

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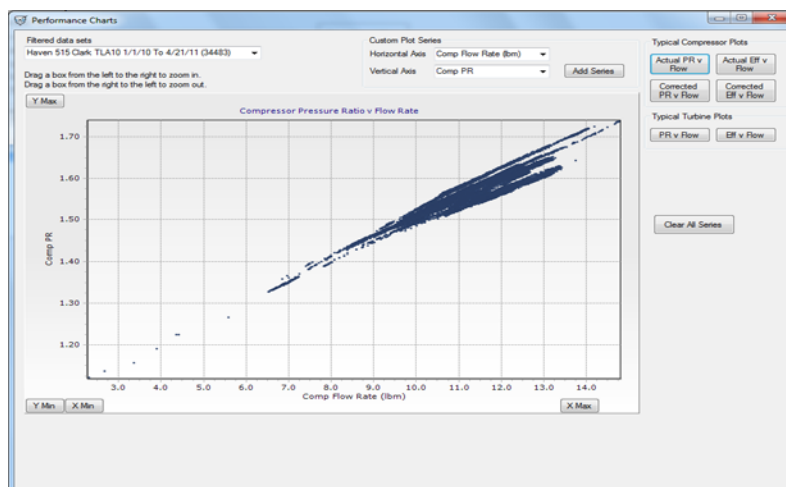
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## Pressure Ratio vs. Flow

- The Turbo Shield™ can be utilized to show restrictions in airflow by using the PR vs. Flow Reports.
- The report generated for an Exterran customer is included on the next slide.



## Actual PR vs. Flow: Visual



## Actual PR vs. Flow: Use

- The previous graph shows an overall view of the current flow characteristics of the turbocharger.
- The nicely grouped data points along the engine airflow line indicate that the turbo is operating appropriately; however, for a more accurate and reliable view of the data, users should use the Corrected Flow Curve.

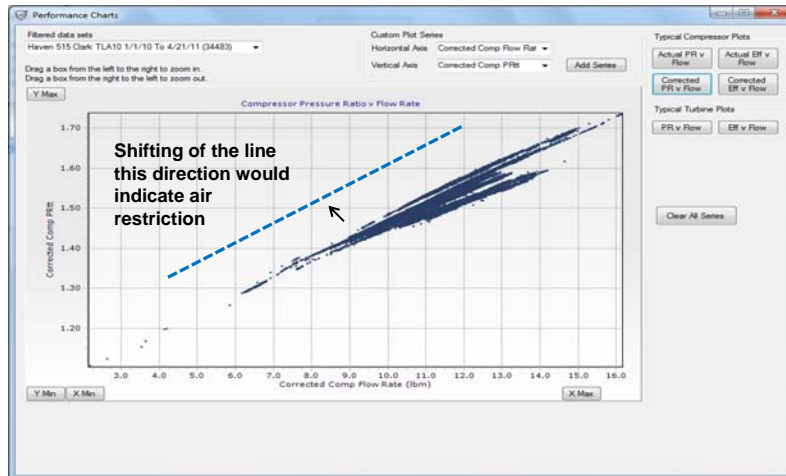


## Corrected PR vs. Flow

- This diagram can be used to indicate any restrictions in airflow over time.
- No significant shifts have been identified under this data set, but over the life of this turbo any shifting of this line up and to the left would indicate an airflow restriction (see following graph).
- Such a restriction could include clogged ports, clogged filters, or issues with the aftercooler.
- If a restriction is identified the system can then be used to drill down to the actual issue.



## Corrected PR vs. Flow



## Turbine PR vs. Flow

- Another valuable analysis that can be performed with the Turbo Shield™ is the Turbine Pressure Ratio vs. Flow Analysis.

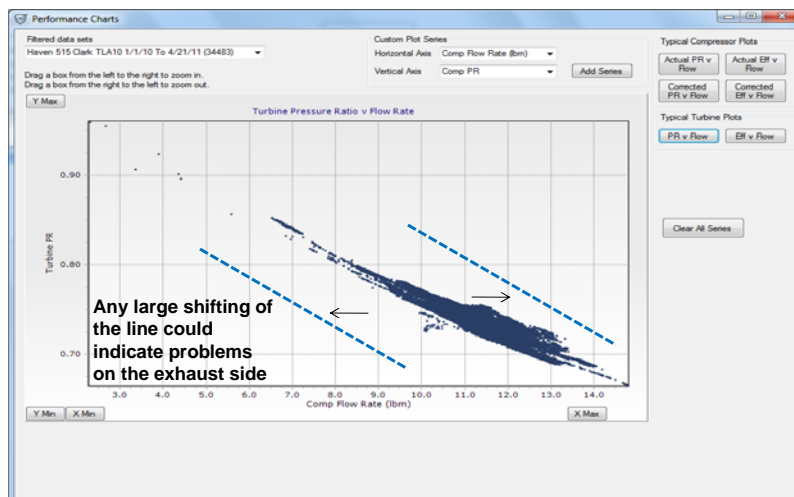


## Turbine PR vs. Flow

- The Turbine PR vs. Flow diagram can be used to indicate any additional restrictions in airflow on the exhaust side over time.
- No significant shifts have been identified under this data set, but over the life of this turbo any shifting of this line would indicate that there may be problems with the silencer, muffler, or other equipment on the exhaust side.
- If a restriction is identified the system can then be used to drill down to the actual issue.



## Turbine PR vs. Flow



## Turbocharger Degradation

- A turbo's operation will degrade over time
- Mainly caused by:
  - Compressor wheel becoming fouled by dirt
  - Exhaust gas products coating turbine components
    - Ash or carbon build up on turbine wheel or nozzle ring
- As components become dirtier they become less efficient

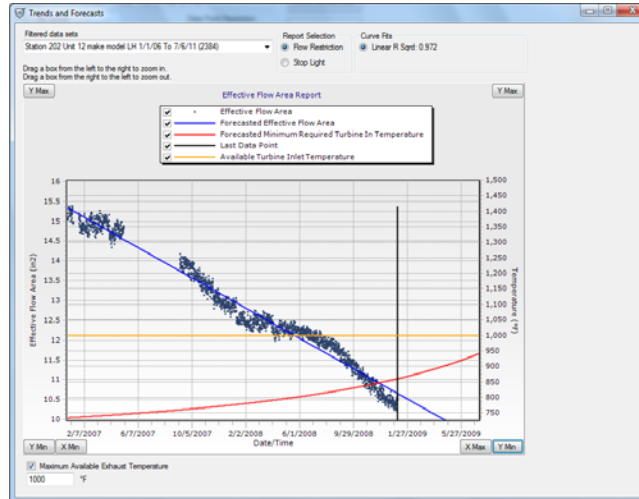


## Turbocharger Degradation

- As components become less efficient, it takes more horsepower to overcome the loss in efficiency and maintain operation
- To meet the horsepower demands, the required minimum turbine inlet temperature has to increase
- Maximum turbine inlet temperature is limited; mainly by the physical characteristics of the engine and turbocharger



## Trending and Forecasting



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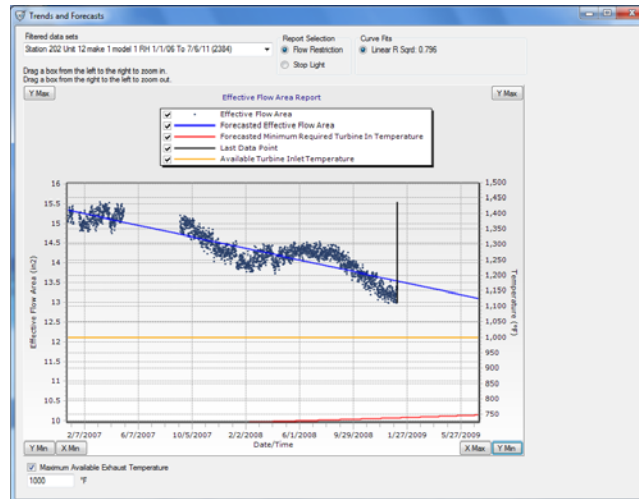
## Trending and Forecasting

- The previous graph shows as the turbocharger degrades, the required minimum turbine inlet temperature increases
- Trending the turbo degradation and minimum turbine inlet temperature allows operators to forecast when their turbo will no longer provide sufficient air for proper operation
  - Allows for scheduling of overhauls
- The slower the degradation rate the longer the time between overhauls

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## Trending and Forecasting



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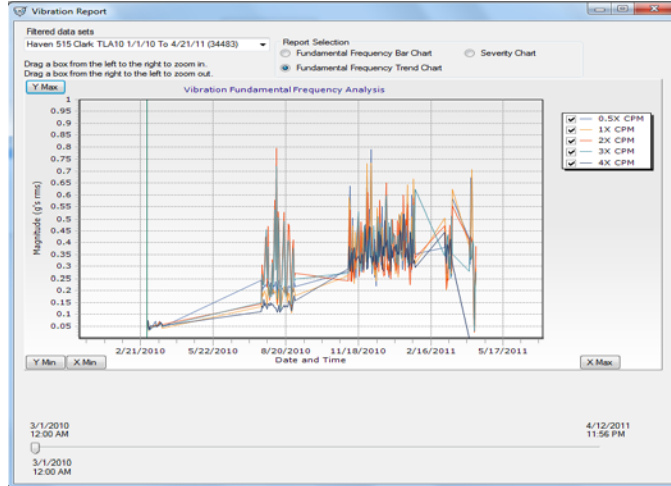
## Vibration Reports

- Vibration Analysis can be presented as a Fundamental Frequency Trend, Bar, or Severity Chart. These can be used in conjunction with each other to identify any vibration problems.
- Utilization of both the Line, Bar, and Severity Chart are included in the following slides.

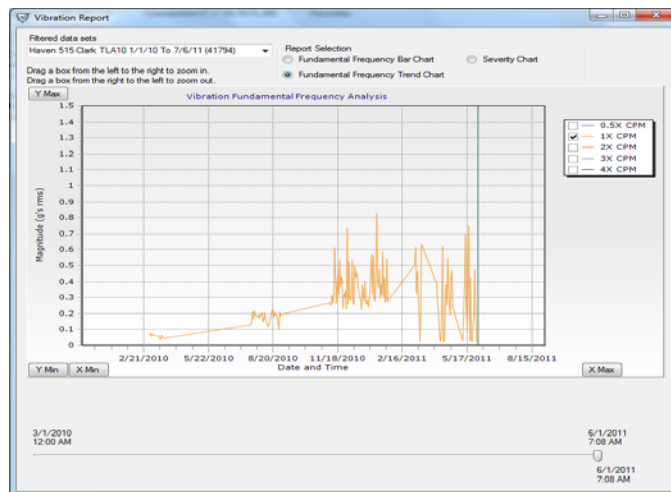
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# Vibration Trend Chart



# Vibration Trend Chart

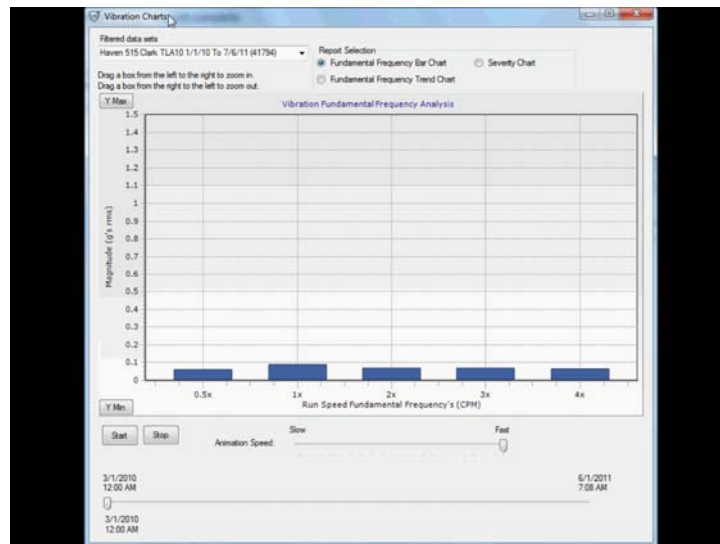


## Another View: Vibration Bar Chart

- The Fundamental Frequency Bar Chart provides an alternative graphical format for viewing the vibration data
- An animation of this function is provided in the following slide



## Vibration Bar Chart Animation

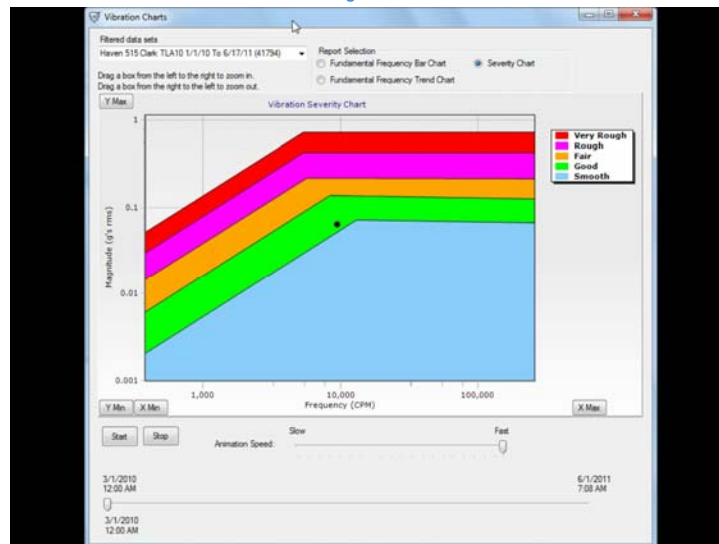


## Vibration Trend & Bar Charts

- The Fundamental Frequency Trend and Bar Charts for the customer's turbo indicates that there is a shift in amplitude around the beginning of November 2010.
- Noting this shift, the station operator should then determine the severity of the amplitude change and the potential hazard to their equipment by running the Vibration Severity Report; which can show both the historical and real time severity of the vibration during operation.
- An animation of this function is provided in the following slide.



## Vibration Severity Chart Animation



## Vibration Severity Chart Results

- The Vibration Severity Chart indicates that the turbo is running in the Good to Fair range until November 5<sup>th</sup>, at which time it moves into the Rough to Severe Range for the remainder of the data set.
- Further analysis of the Turbo Shield™ data shows that this shift in vibration occurred as the turbocharger RPM's were reduced.
- Operators may want to consider the increased stress on the rotating components caused by running at lower RPM.



## Trapped Equivalence Ratio aka: TER

It's not magic...



## Technically Speaking

$$TER(\phi) = \frac{AFR_{stoich}}{AFR_{trapped}}$$

$$AFR_{trapped} = \frac{\dot{m}_{air, trapped}}{\dot{m}_{fuel}}$$

$$AFR_{stoich} \approx 17.24 \text{ lb air/lb fuel}$$

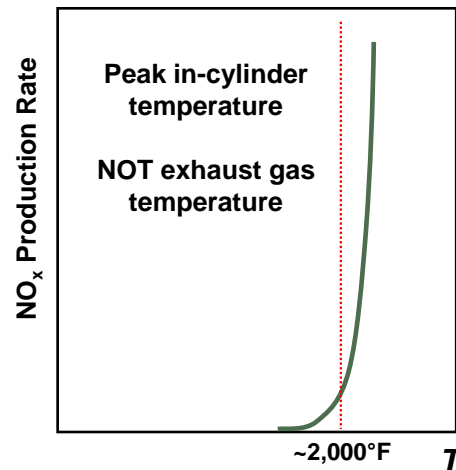


## Trapped Equivalence Ratio (TER)

- Most important engine parameter governing pollutant formation
  
- As the mixture becomes leaner
  - (Lower trapped equivalence ratio)
  - Reduces peak combustion temperature
  - Reduces NO<sub>x</sub> formation
  - If you go too far, CO can increase



## NO<sub>x</sub> Variation with Temperature



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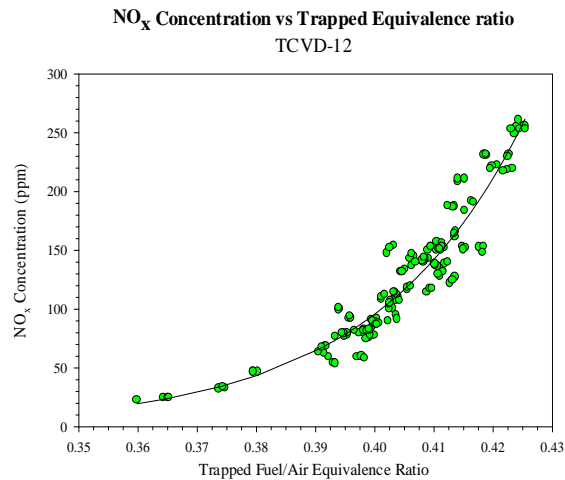
## NO<sub>x</sub> Reduction

- NO<sub>x</sub> formation is
  - Unrelated to the fuel itself
  - Due solely to the high temperatures associated with combustion
- NO<sub>x</sub> formation is reduced by minimizing
  - Peak combustion temperature
  - Time at that temperature (i.e. combustion duration)
- This can, however, have detrimental effects!

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## Trends of NO<sub>x</sub> vs. Equivalence Ratio



## How Does This Relate to Turbos?

- Turbocharging
  - Increases in-cylinder air mass
  - Decreases TER
- Increased in-cylinder air mass → Lower in-cylinder peak temperature
- Lower in-cylinder peak temperature → Lower NO<sub>x</sub> emissions
- CO emissions
  - Increased air lower CO, but only to a point
  - CO formation is complicated
  - Can increase CO if too lean!



## TER Control

- Advanced engine air/fuel ratio control method
  - Utilized to keep engines at acceptable emissions targets
  - With increasing emissions regulations, **precise** air/fuel ratio control is becoming more important.
- Turbo Shield™ uses real time airflow as opposed to a surrogate such as air manifold pressure
  - Any changes in airflow can be compensated for via real time adjustment of wastegate and ignition timing



## TURBO SHIELD Other Features

- Modbus TCP communication:
  - Allows Turbo Shield™ data to be displayed on engine control panel
  - Engine data can be captured by Turbo Shield™ software
- Export historical data to .csv file
  - Can be opened in Excel
  - Custom analysis can be performed on any captured data



## Managing Turbo Performance Makes Financial Sense

- Operations
  - Optimally timed overhauls → **Delayed overhauls = more fuel & risk of failure**
  - Avoid catastrophic failures → **One failure can cost tens of thousands of dollars**
  - Improved fuel efficiency → **Estimated at 3-6% for large engines**
- Emissions
  - Helps maintain compliance → **Tens of thousands of dollars per day**
  - Avoid over-sized turbos → **Tens of thousands of dollars per turbo**



MAKE INFORMED DECISIONS...

...AND TAKE THE GUESS-WORK OUT OF AIR FLOW THROUGH YOUR TURBOCHARGED ENGINE FLEET

