Revolution in Fluid Film Bearing Monitoring

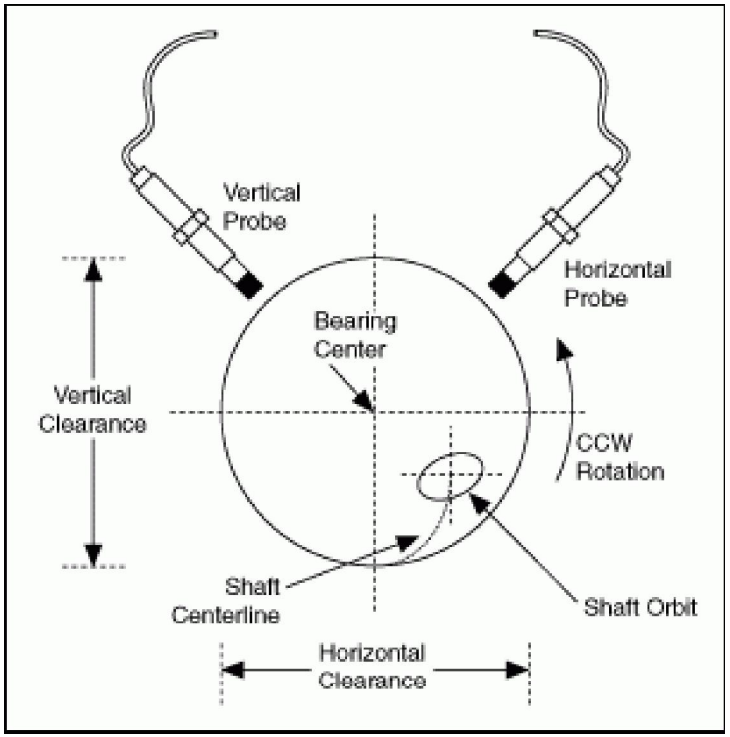
Insight Force Detection Sensor

Voyager INSTRUMENTS
Providing Dynamic Measurement Solutions

PRÜFTECHNIK

Monitoring Techniques

Proximity Probes



Pros

- Actual shaft position in housing (DC/gap)
- Dynamic shaft movement (AC/orbit)
- Easy to evaluate vs bearing clearance
- Diagnostic possible

Cons

- Slow roll compensation
- Cost (hardware >2k$)
- Retrofit installation, drill-tap ($ >>> Hardware)

Monitoring Techniques

- **Temperature**
  - Bearing housing or Babbitt temperature
  - Lubricant temperature
- Pros
  - Easy to install
  - Better than no indication
- Cons
  - No diagnostic
  - Thermal Lag
  - Alarm too late (temperature after damage)

Monitoring Techniques

Case Mounted Vibration

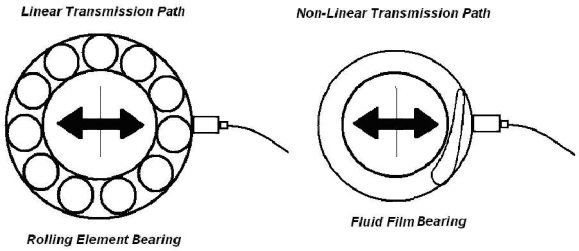
- Accelerometer or Velometer on casing housing
- Casing vibration combined with relative shaft vibration (full picture)

Pros

- Easy to install or collect with route data collection
- Trending and some diagnostics
- Together with prox. probe get full picture
- Better than nothing

Cons

- Transmission path not linear
- Force from shaft to measurement location
- Many harmonics hard to make diagnostic conclusions



Monitoring Techniques

- **Not at all??**
- Pros
  - Cheap
- Cons
  - Very Expensive

Monitoring Techniques

Conclusion

- Proper configured X-Y proximity probes currently **best**
  - Expensive for retrofit installation (Hardware + Installation + Shutdown)

- Other monitoring techniques not sufficient individually

Need for innovation

- Low (retrofit) installation cost
- Trending (protection) and diagnostic of fluid film bearings
- New technology

Insight Force Detection Sensor

Insight FDS
Force Detection Sensor

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Principle

Use dynamic strain sensor on the housing of a fluid film bearing, installed in the load zone of the bearing (pressure wedge), to measuring indirectly the bearing forces and monitor the condition of the machine. (US Patent nr. US9841329B2)

https://patents.google.com/patent/US9841329B2/en

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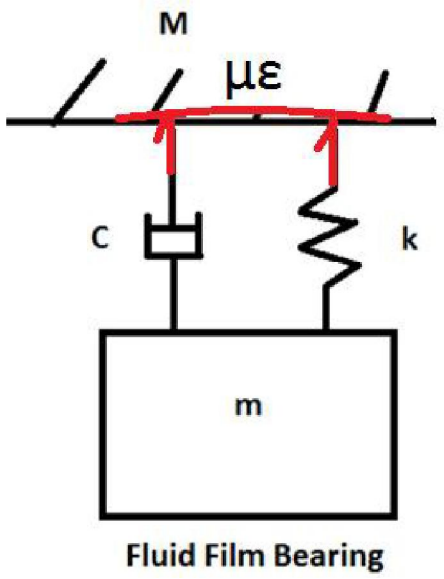
Kinematics

- Even though bearing acceleration is low, large forces are still transmitted resulting in significant strain (με)
- Trends and alarms are direct measures of potential damage



Results in microstrain (ΔL/L)

Insight FDS

Technology

- Piezoelectric sensing element
- Titanium bottom plate (engineered thickness)
- IEPE power (same as ICP sensor)
- Unidirectional

Technical Specs (PTA-FDS102-VOY)

- Dimensions: .425” x .6” x .180”
- Sensitivity: 50 mV/με (± 20%)
- Measurement Range: +-100 με
- Frequency Range: 0.5Hz-10kHz
- Temperature Range: -22°F to 250°F
- Integral cable with 10-32 UNF Connector
- Sensor and cable submersible (oil)
- Class 1 Div. 2

Insight FDS

Technology

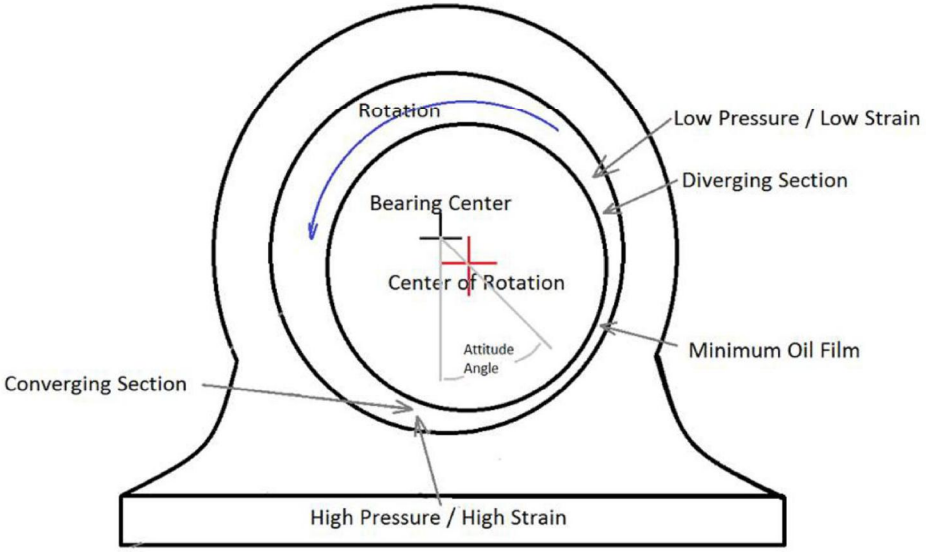
- Piezoelectric sensing element
- Titanium bottom plate (engineered thickness)
- IEPE power (same as ICP sensor)
- Unidirectional

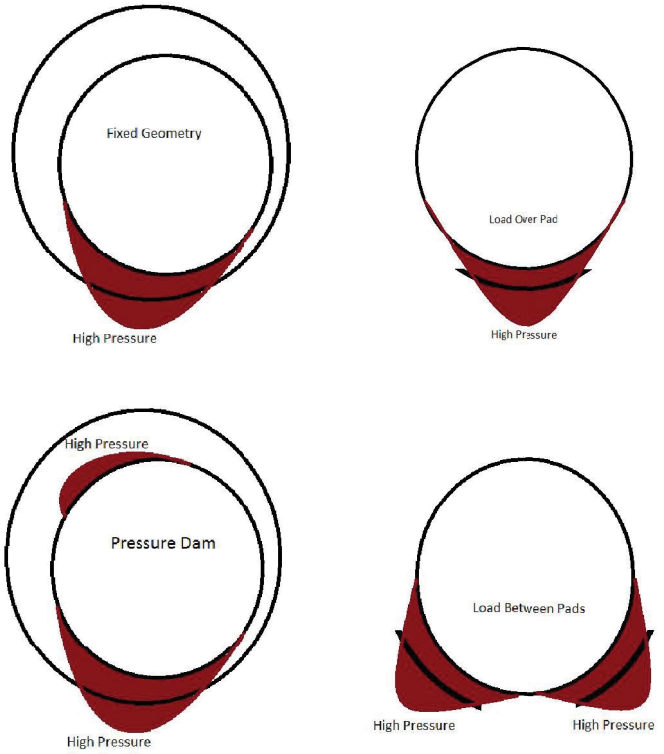
Technical Specs (PTA-FDS101-VOY)

- Dimensions: 1.57” x .67” x .58”
- Sensitivity: 40 mV/με (± 20%)
- Measurement Range: +-100 με
- Frequency Range: 0.01Hz-10kHz
- Temperature Range: -22°F to 250°F
- 10-32 UNF Connector

Pressure Wedge

- Predictable for all bearing types
- Ideal location for FDS sensor install (BDC or 430 & 730)

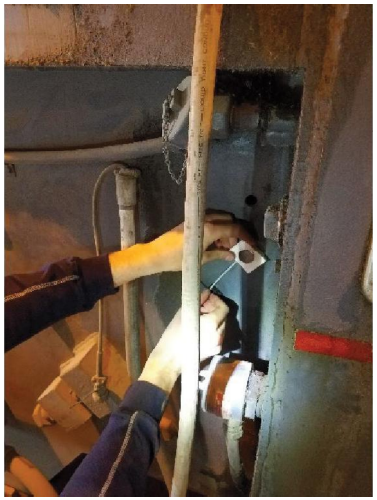




Insight FDS

- **Install (<1h)**
  - Define pressure wedge location (Load?)
  - Remove loose paint, oil and solvents
  - ± Flat surface (not interested in static strain)
  - Glue sensor to bearing housing
  - Magnetic installation tool

→ ***Measure***



Insight FDS

- **Measure (as ICP sensor)**
  - Setup sensor (50 mV/με)
  - Trend overall strain for alarming
  - Spectra and Time Waveform for detailed analysis
- **Trending in DCS**

Insight FDS

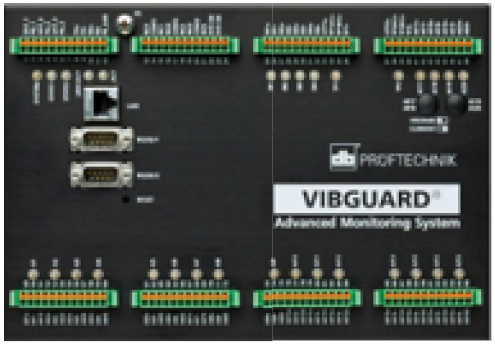
- **Measure (as ICP sensor)**
  - Setup sensor (50 mV/µε)
  - Trend overall strain for alarming
  - Spectra and Time Waveform for detailed analysis

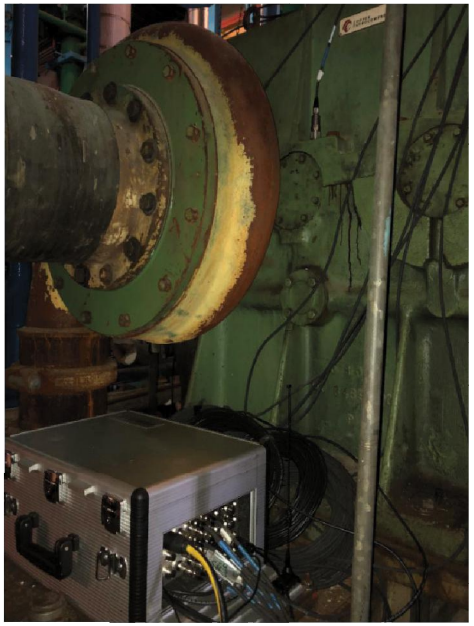
- **Handheld data collector** (does not have to be Pruftechnik device)

Insight FDS

- **Measure (as ICP sensor)**
  - Setup sensor (50 mV/με)
  - Trend overall strain for alarming
  - Spectra and Time Waveform for detailed analysis

- **Continuous Monitoring** (does not have to be Pruftechnik device)

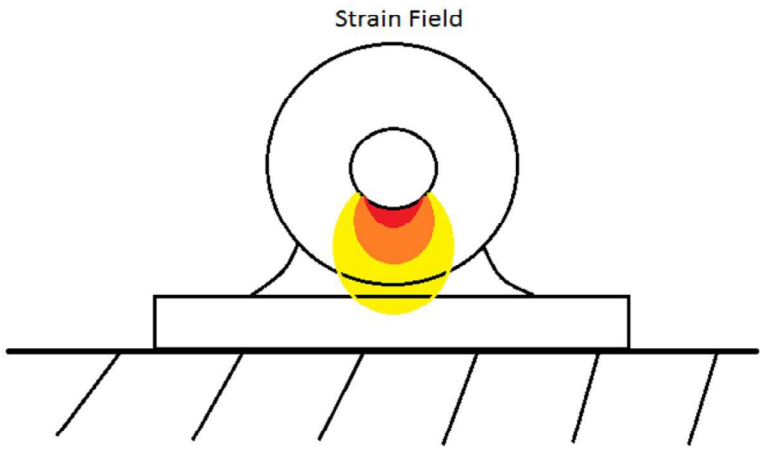




Insight FDS

Alarming

- Evolving process (just like vibration)
- Trending and statistical alarms (just like vibration)
- Critical alarm level can be calculated (application specific)
  - Load and Speed
  - Babbitt material properties (elastic limits)
  - Young's Modulus
  - Alarm percentages (15-25%) of calculated max due to mounting location



Insight FDS

PRÜFTECHNIK

- **Pricing**
  - PTA-FDS102-VOY
  - PTA-FDS101-VOY

CONTACT US FOR PRICING
920.730.0615 or
http://ctrline.net/request-information.html

- PTA-MT-MK04-VOY - Installation Kit (for FDS102)
- PTA-MT-MK03-VOY - Installation Kit (for FDS101)

- PTA.SCA-1032F-BNCM.VO - Adapter (10-32F to BNCM, 3ft)

- Installation cost <<< compared to retrofit prox. Probes (shutdown time)
- Monitoring cost
  - Overall mA to DCS
  - Route data collection
  - Continuous online monitoring

Example Data

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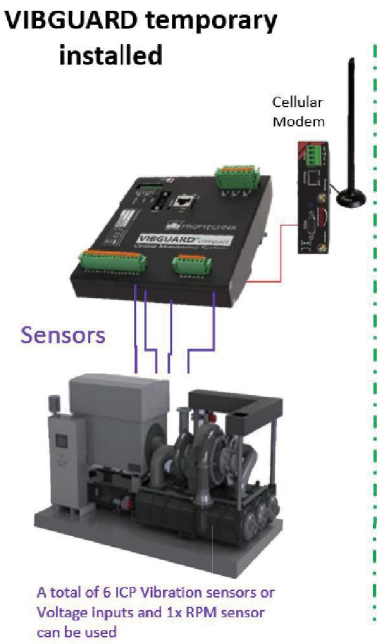
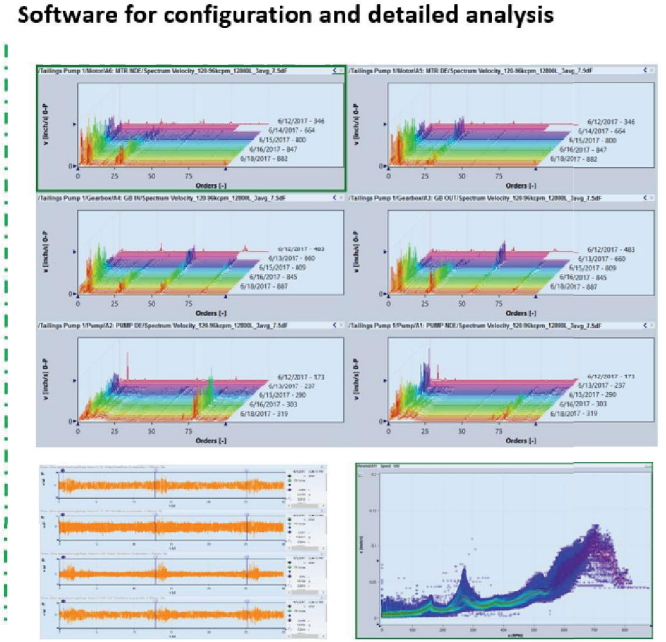
Data VIBGUARD

Comparing data

- High Speed compressor
- Prox., Accel., FDS
- VIBGUARD portable (Cloud Connectivity)
- OMNITREND Center Cloud Server
- Online View (Live data and condition visualization)





Data VIBGUARD

- Overall Pk-Pk

SPEED

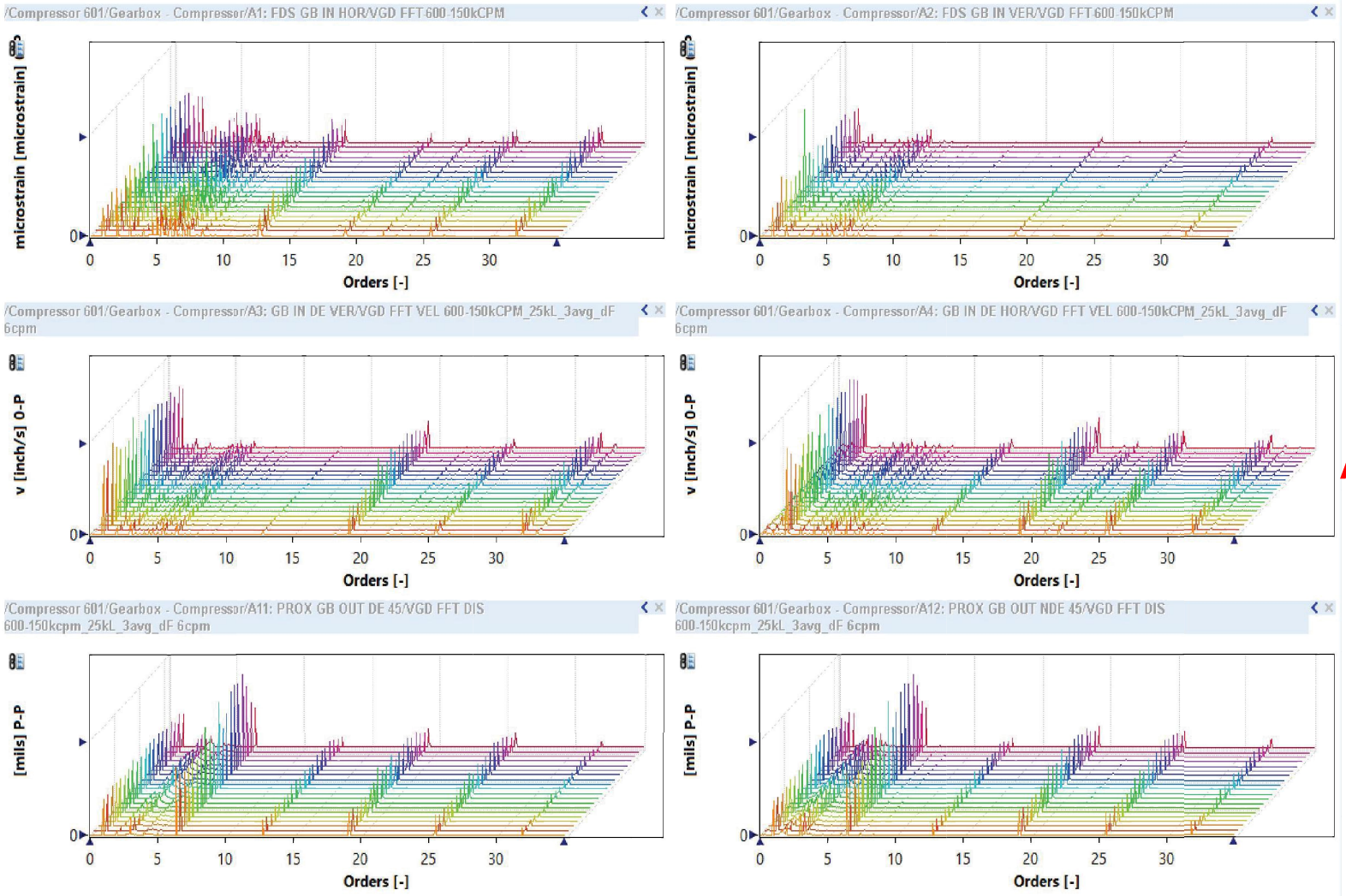
FDS

ACCEL

PROX

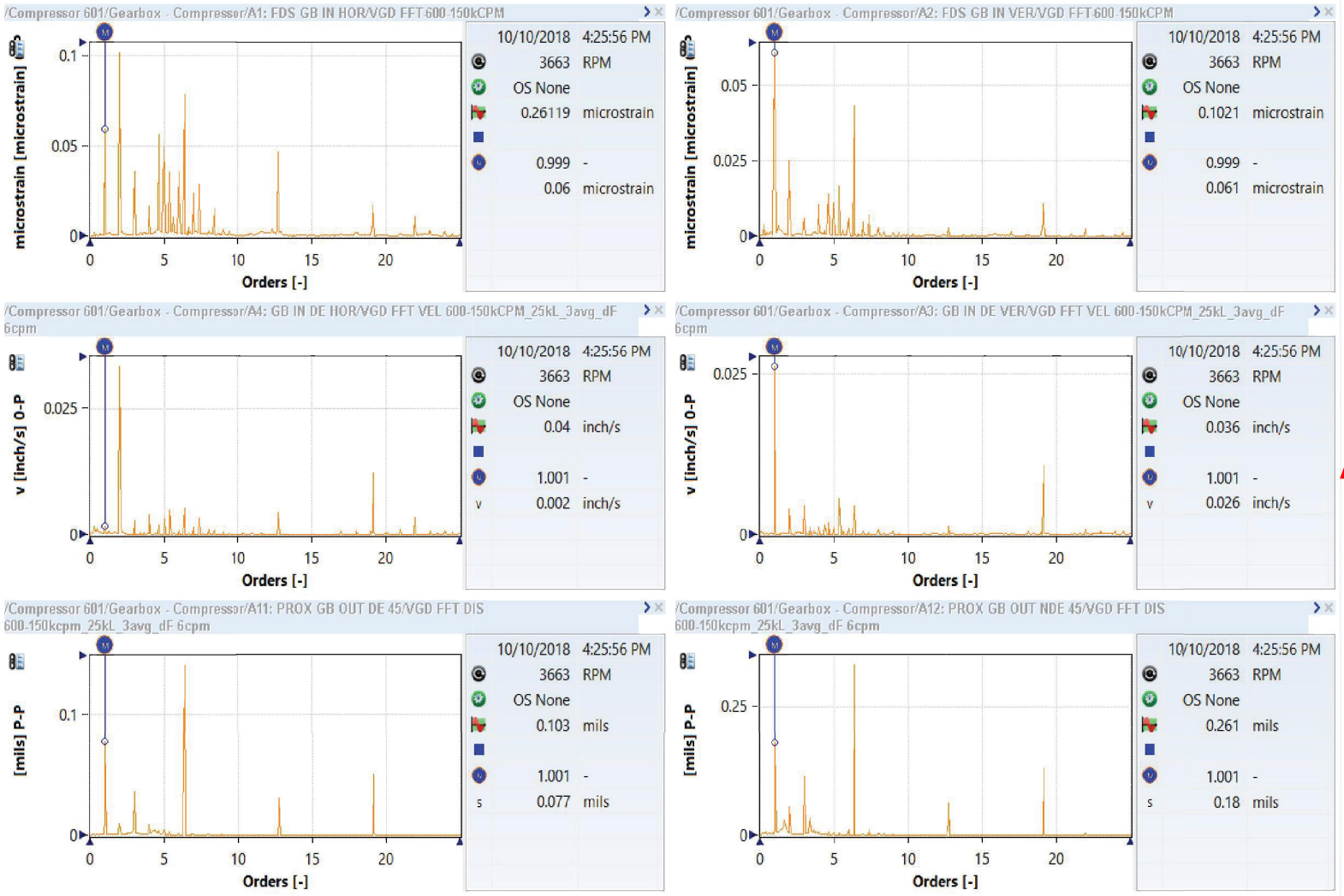
Data VIBGUARD

- Spectra



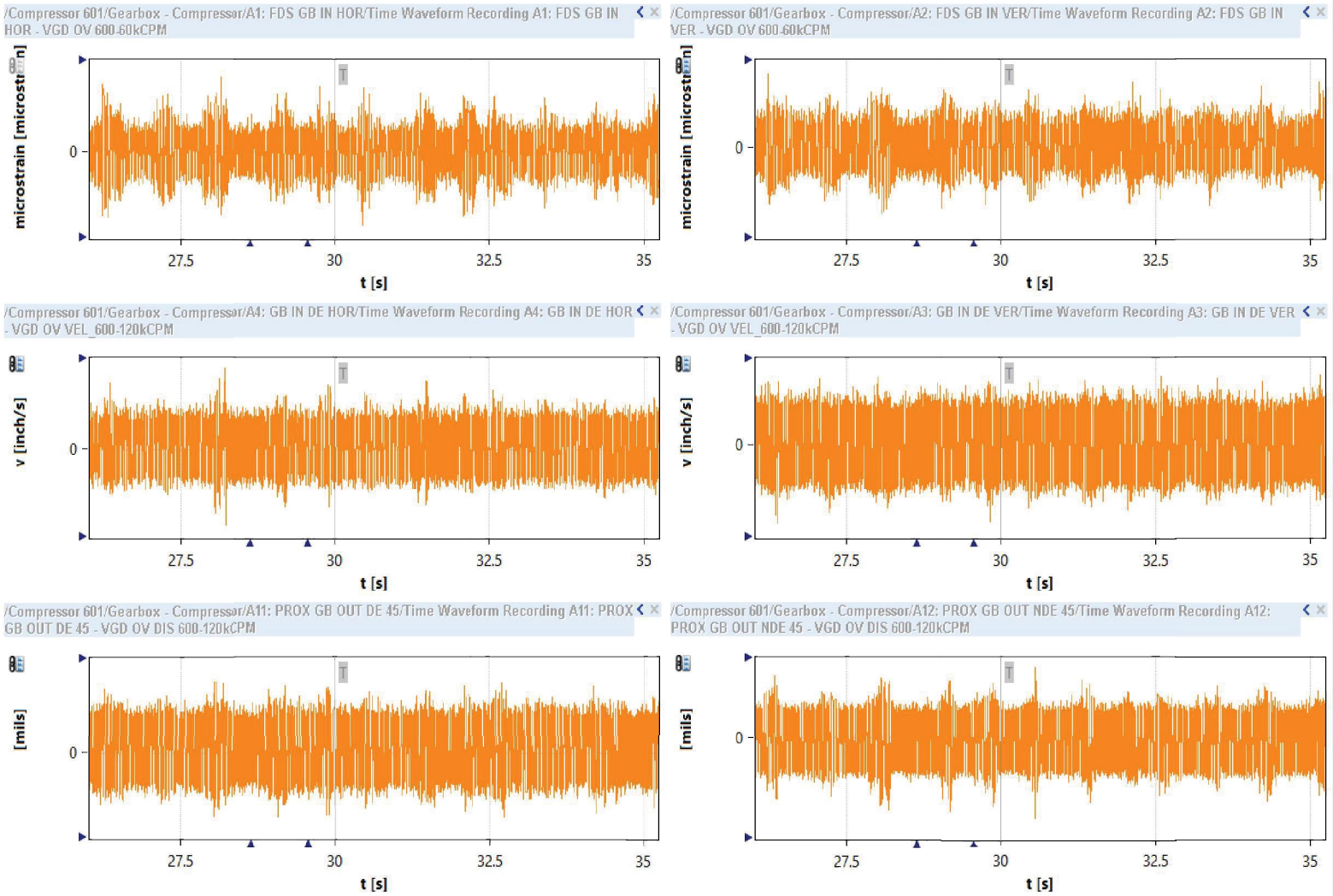
Data VIBGUARD

- Spectra - detail



Data VIBGUARD

- Timewave form - detail

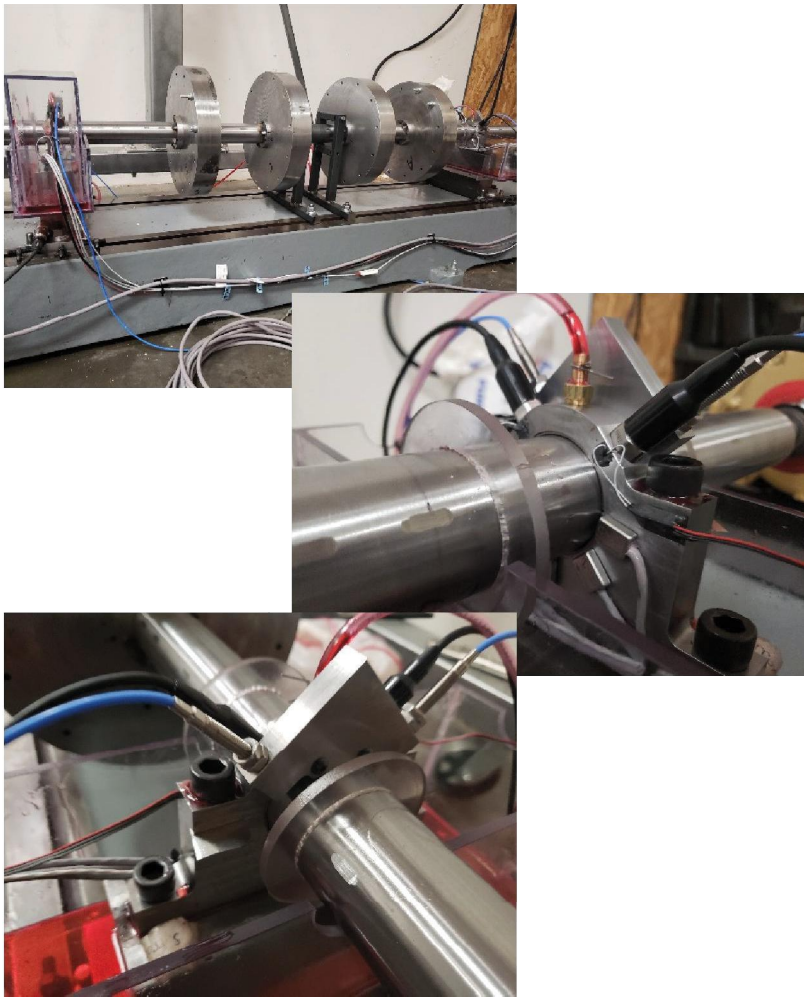


Lab Data

Lab Rotor Setup

- 100 psi bearing pressure
- 0 – 1800 RPM
- Critical Speed at 1320 RPM
- Internally designed hydrodynamic bearings
- Thick Film Lubrication at 115 RPM
- ISO VG 35 Equivalent Oil
- IB Bearing 0.00275” Clearance
- OB Bearing 0.004” Clearance
- 2”Diameter Shaft, L/D = 0.375
- Thick Babbitt 0.0625”

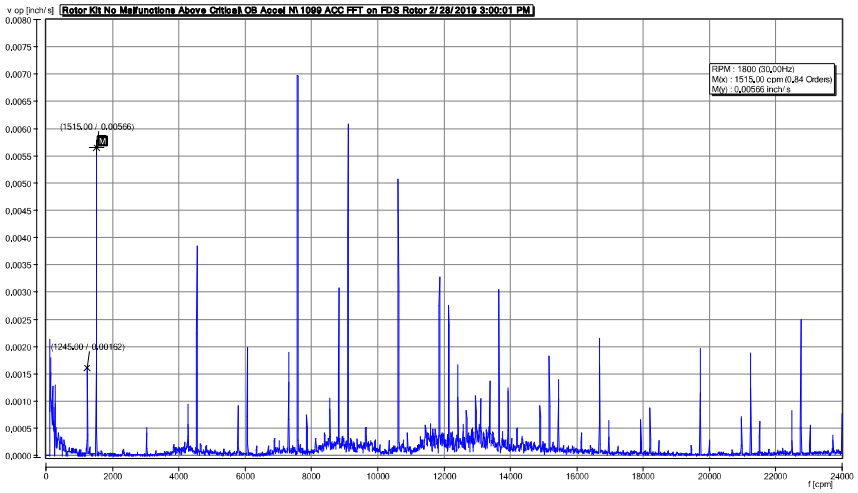
- Sensors:
  - Insight FDS
  - Proximity Probes
  - RTD’s



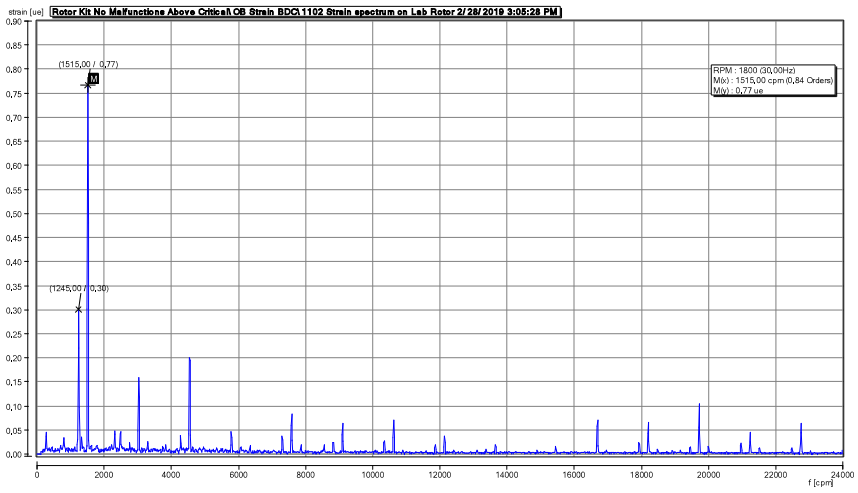
Lab Data

Amplitude/pattern comparison

- Velocity



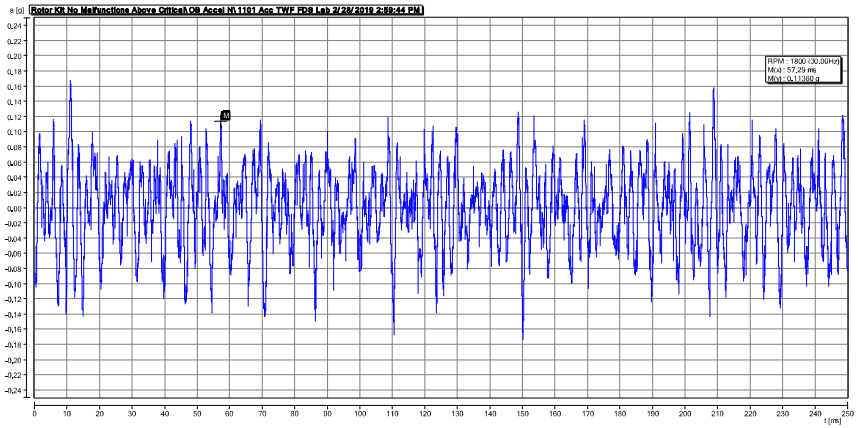
- Dynamic Strain



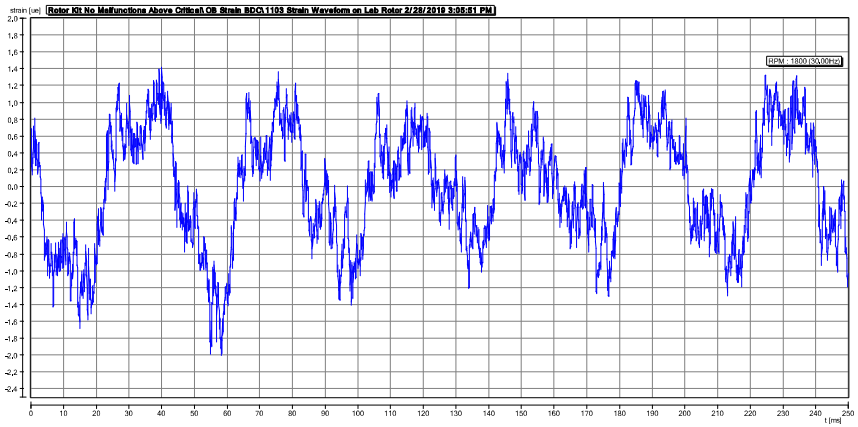
Lab Data

Amplitude/pattern comparison

- Acceleration



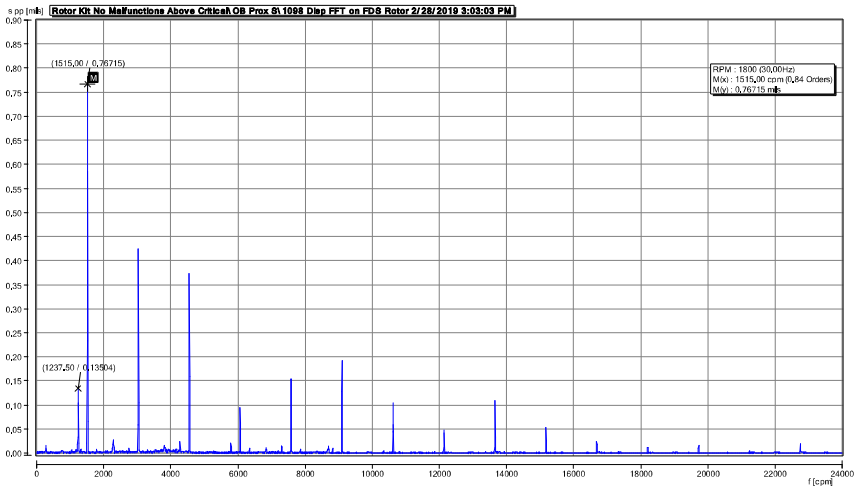
- Dynamic Strain



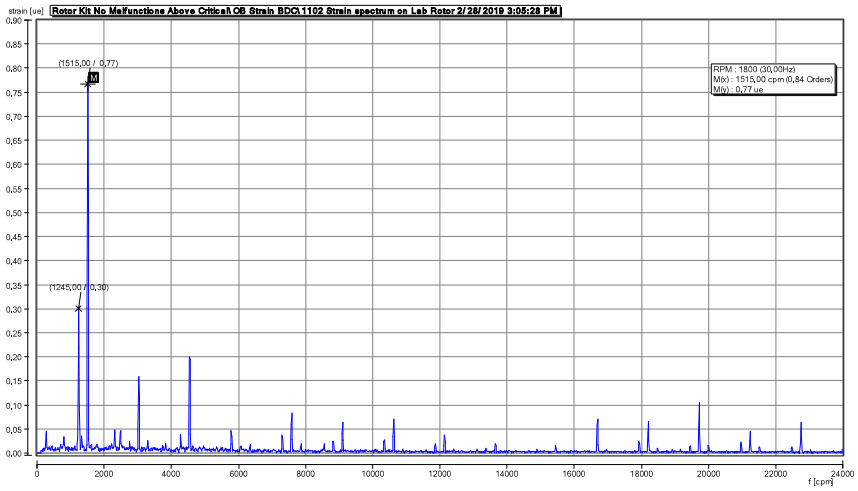
Lab Data

Amplitude/pattern comparison

- Proximity Displacement



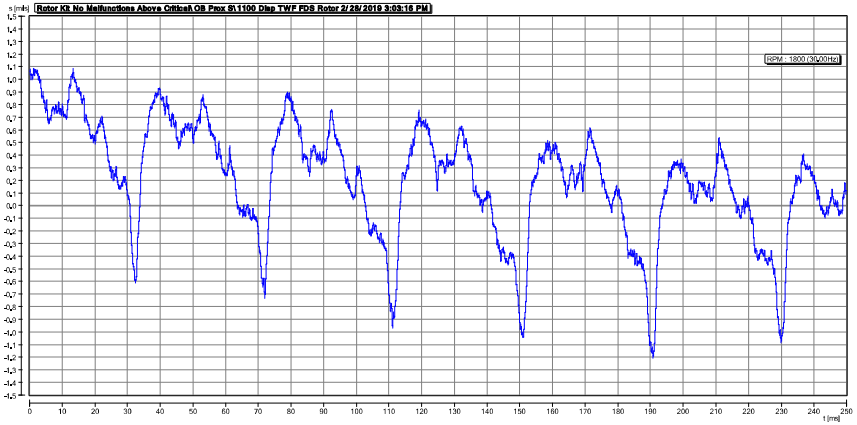
- Dynamic Strain



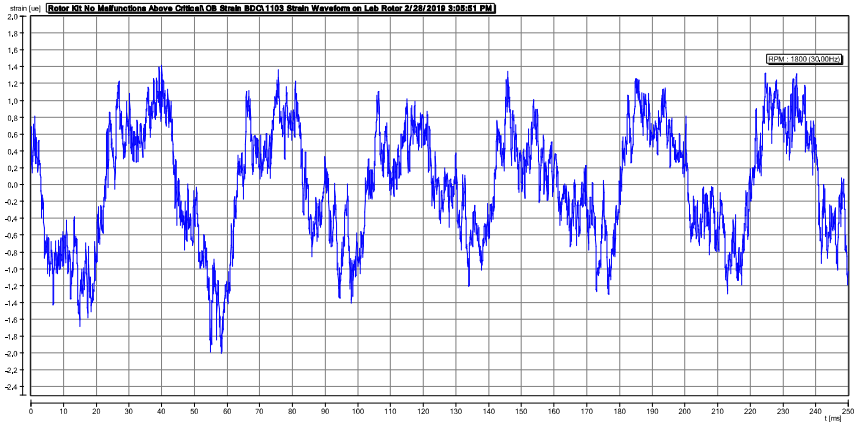
Lab Data

Amplitude/pattern comparison

- Proximity Displacement



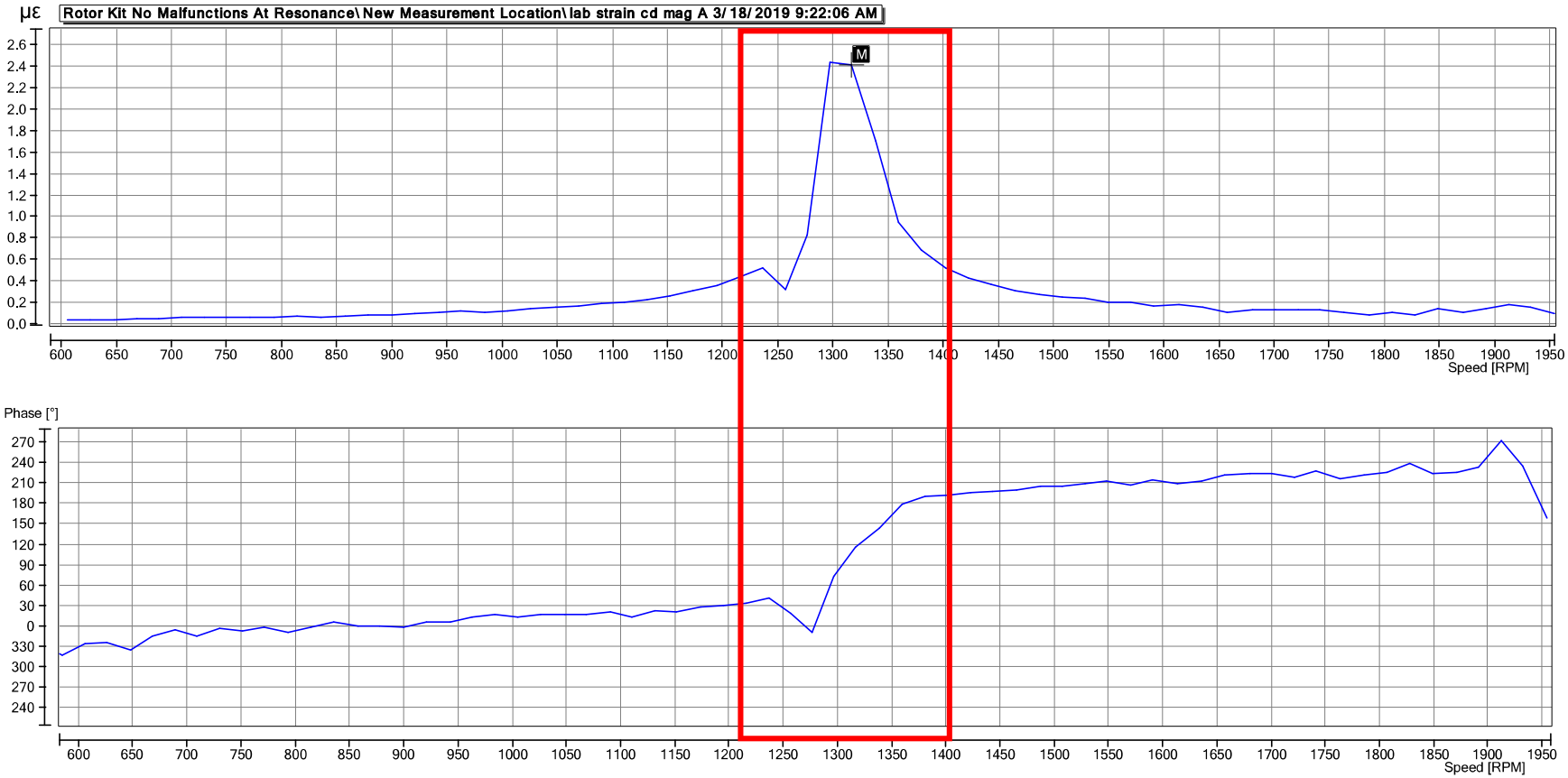
- Dynamic Strain



Lab Data

Coast Down – Bode Plot

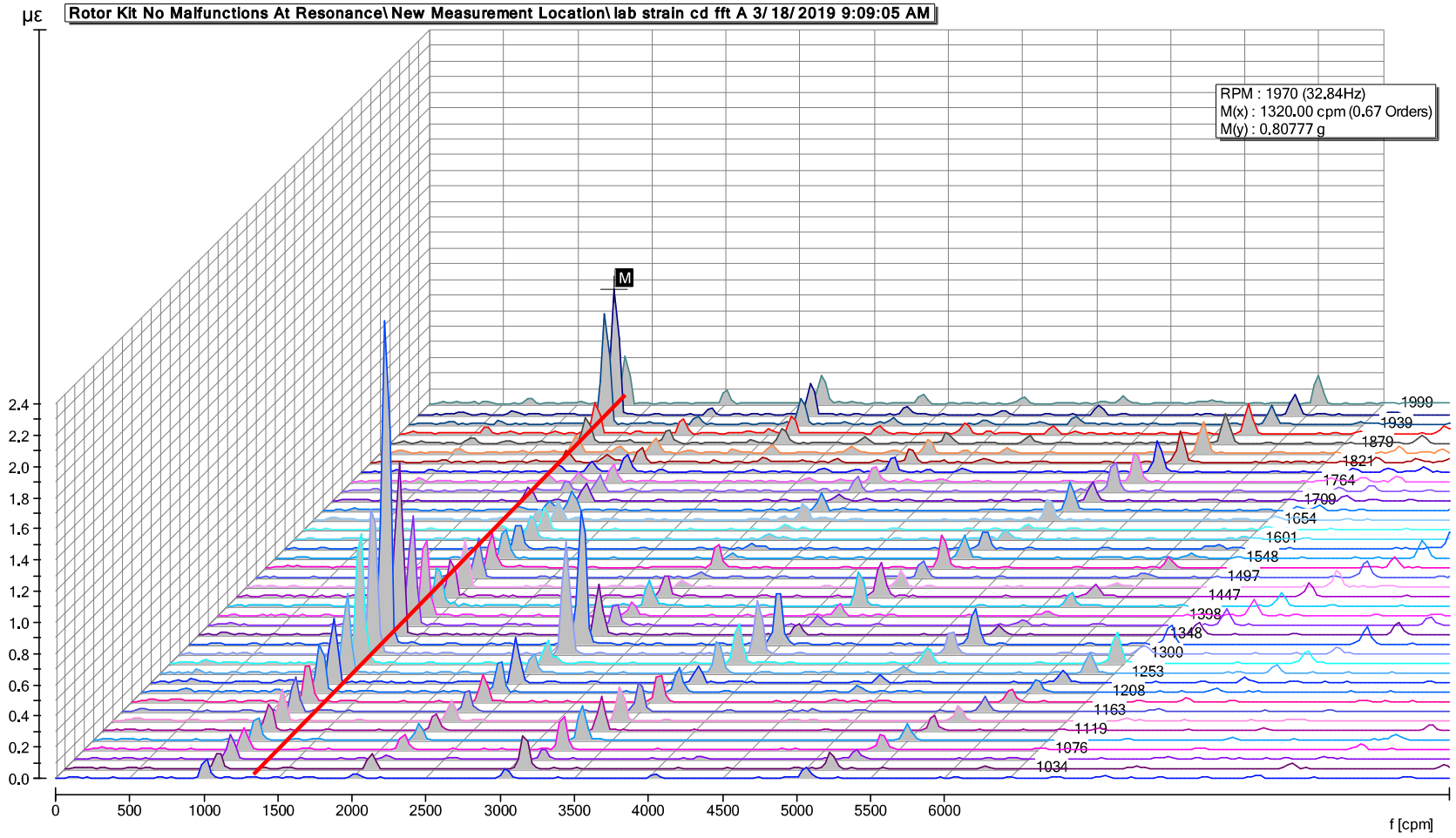
- Critical Speed
- Phase shift



Lab Data

Coast Down – FFT Waterfall

- 1x harmonic – resonance
- Oil Whip



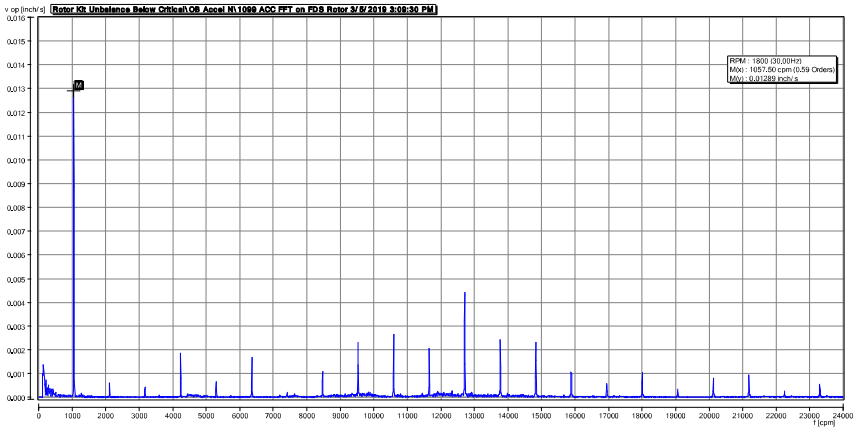
Lab Data

- **Unbalance**
  - Calculated to ISO G8.4 Unbalance
  - Applied Evenly to all Four Disks
  - Spinning at 70% of 1st Critical
    - Remains a Rigid Rotor

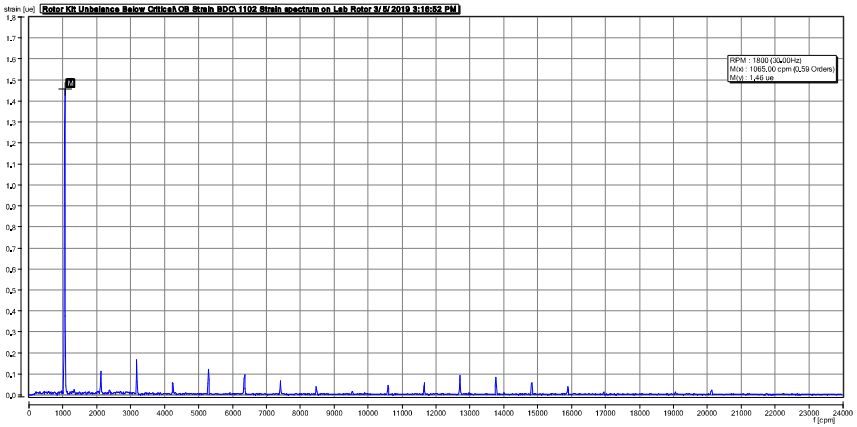
Lab Data

Unbalance

Velocity Data – 1x = 0.0128 ips



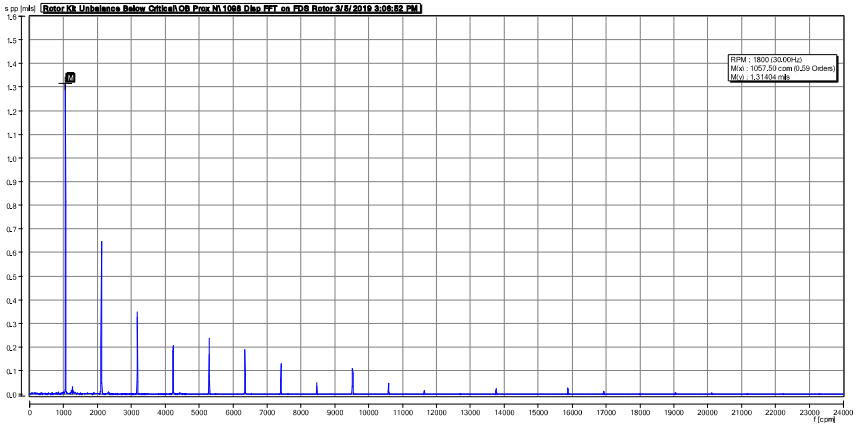
Insight FDS Data – 1x = 1.46με



Lab Data

Unbalance

Proximity Displacement - 1x 1.31mils



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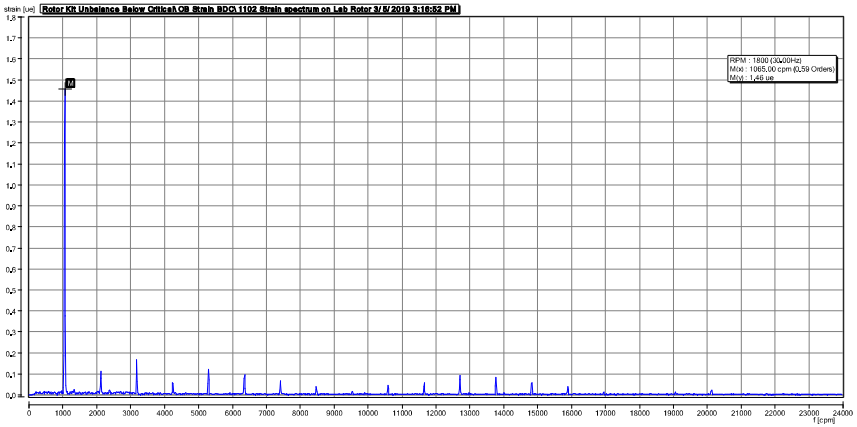


Lab Data

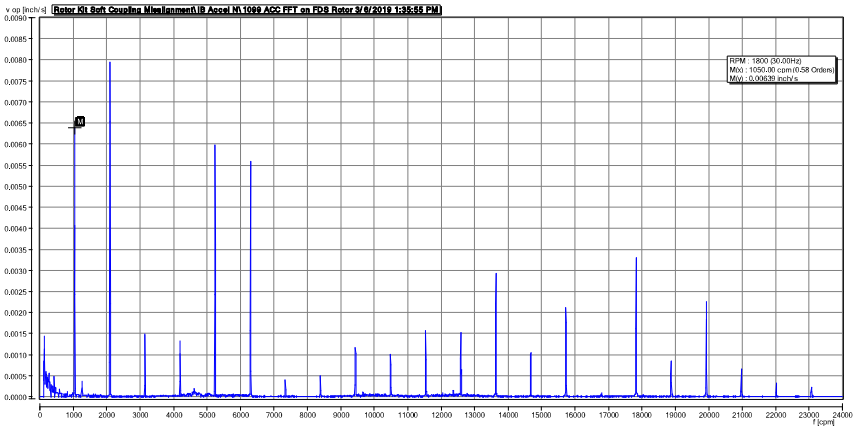
- **Misalignment**
  - Tire Element Coupling
    - Allowable 0.0625” Misalignment
    - Set with severe Misalignment
  - Used Pruftechnik Shaft Alignment Tool
  - Both Proximity Probes and FDS Sensors Reflect the Malfunction Better Near the coupling
    - Similar Frequency Content

Lab Data

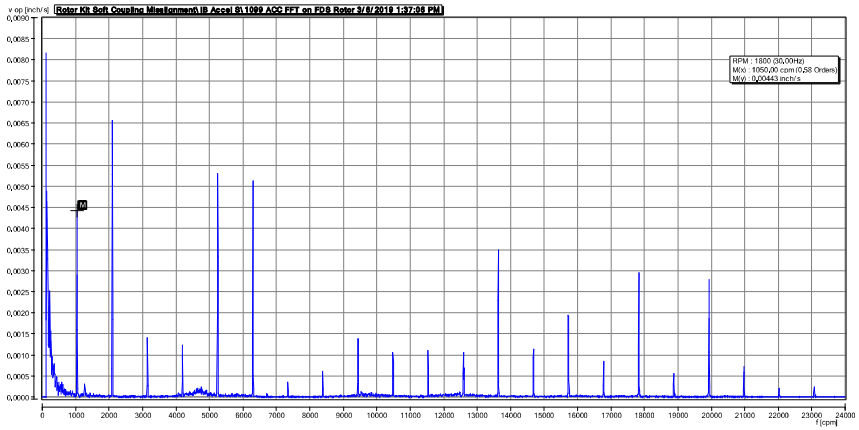
Misalignment

Velocity

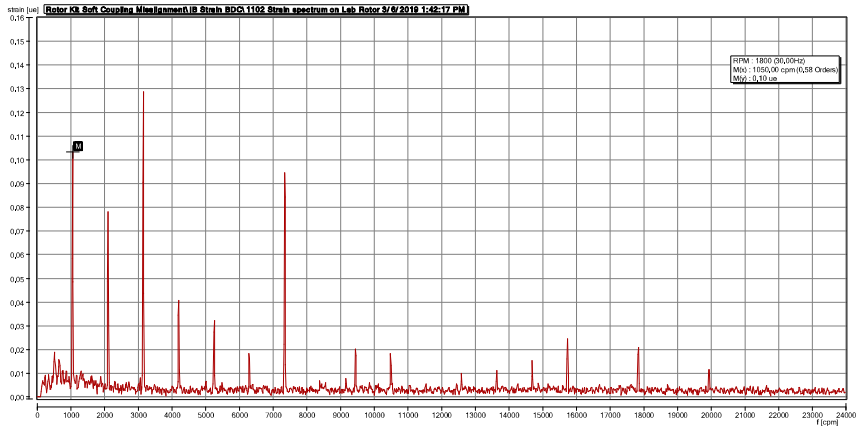
X

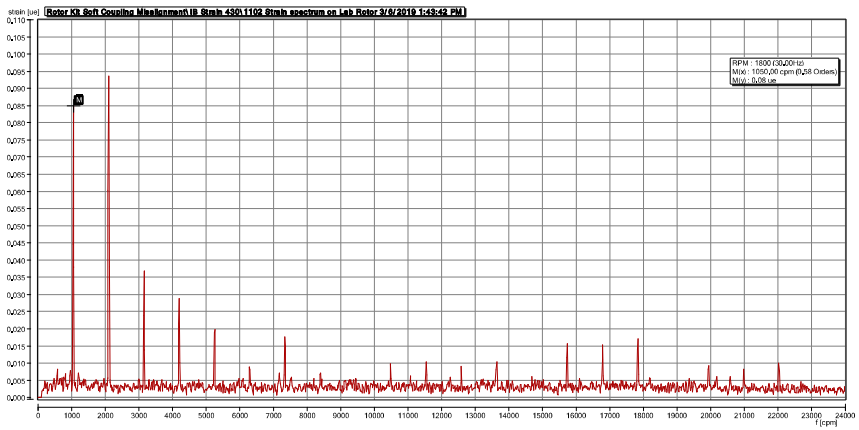


Y



Insight FDS Data



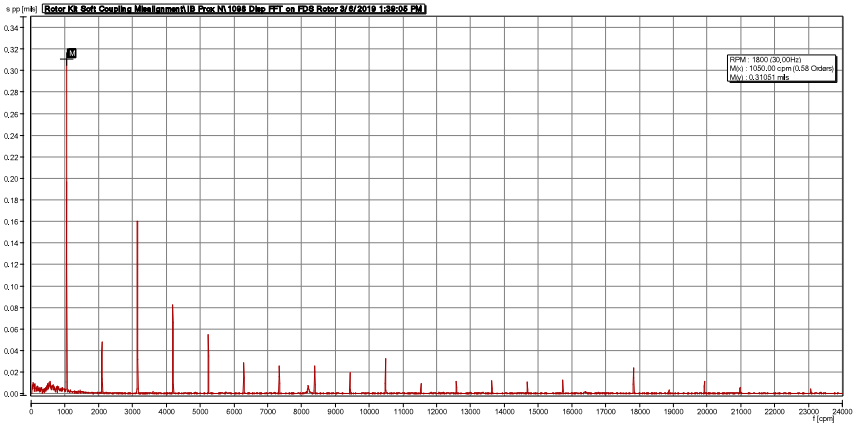


Lab Data

Misalignment

Proximity

X



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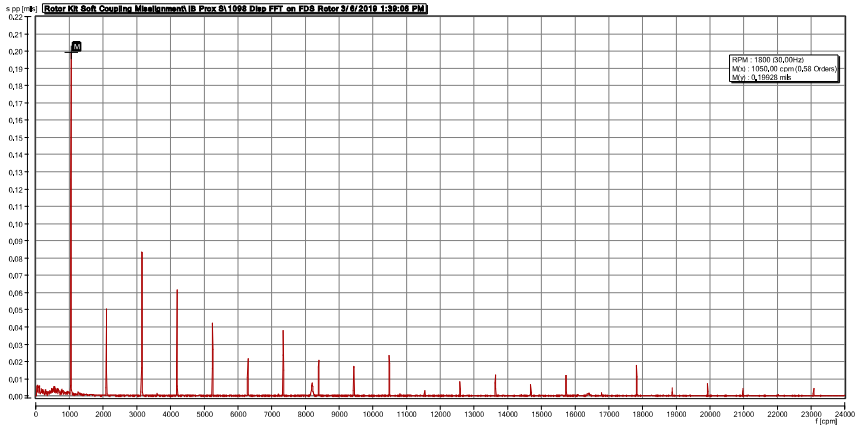

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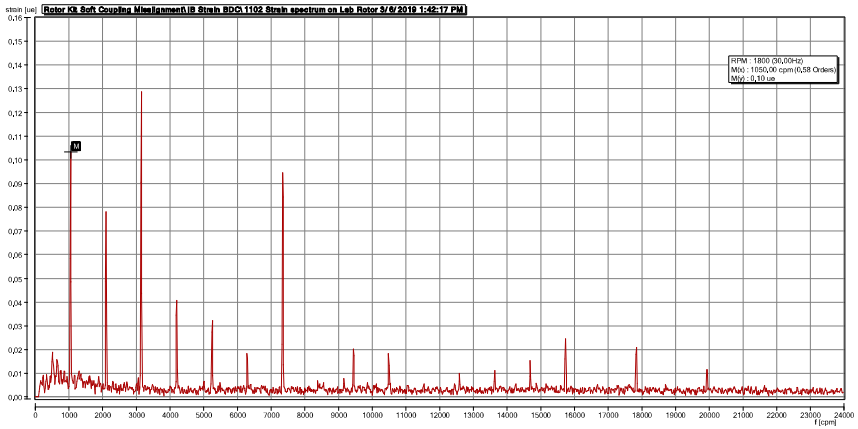
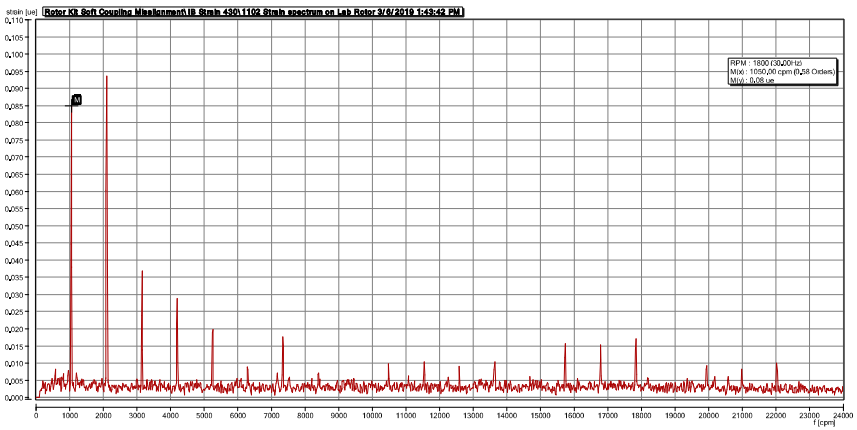
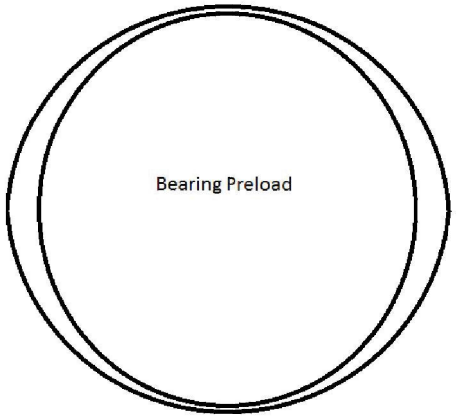


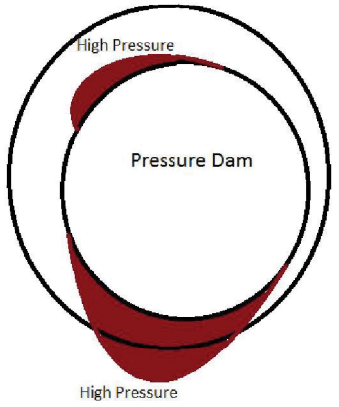


Oil Whirl

- Occurs in Plain Bearings at Higher Speeds and Low Eccentricity
  - Sub-synchronous
  - L/D ↑ Whirl ⟹ ½ x RPM
  - Caused by Tangential Forces

- Whirl frequency varies with eccentricity
  - Low eccentricity: whirl closer to 50%
  - High eccentricity: whirl closer to 20%
- Can be higher than 50% with pre-swirl
- Much lower than 50% with anti-swirl
- Correct by increasing eccentricity

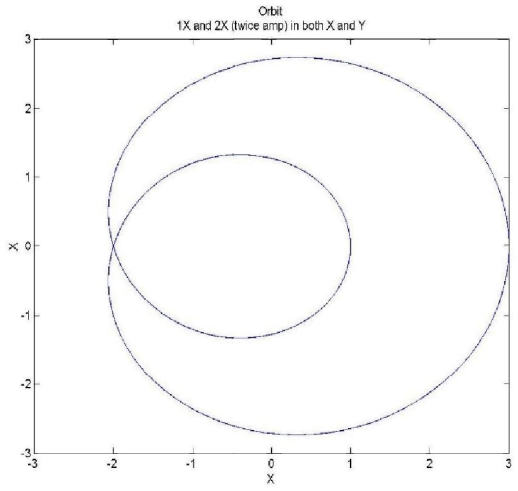


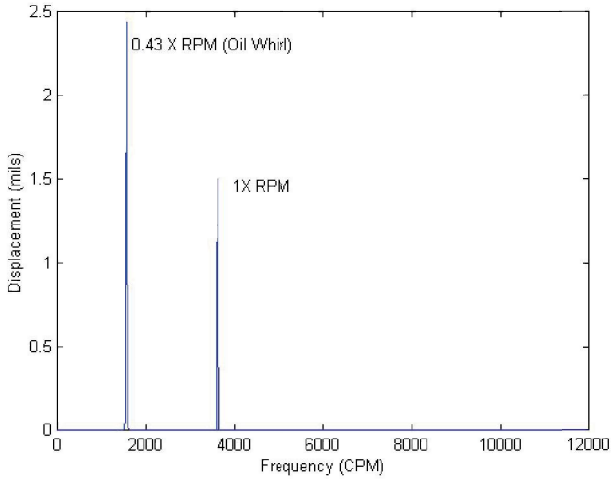


Lab Data

Oil Whip

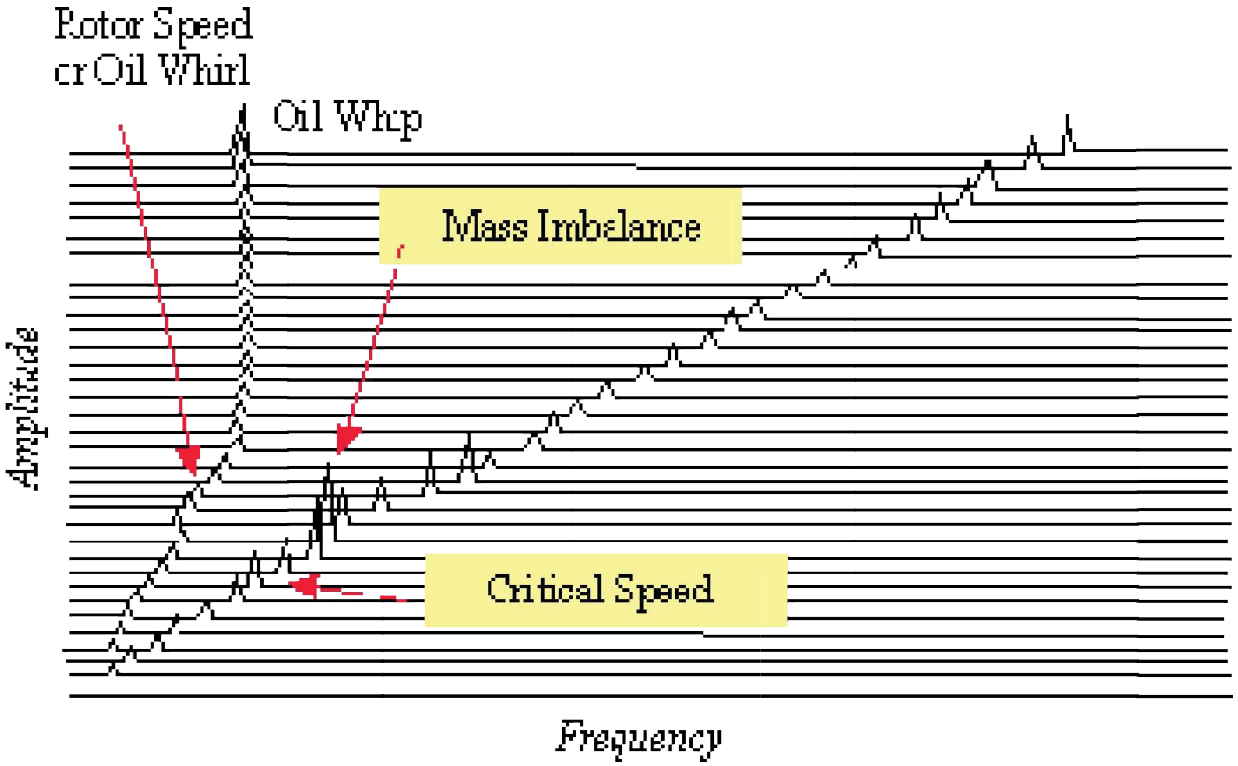
- Occurs when shaft vibrates at a natural frequency regardless of shaft speed
  - Most commonly excited by whirl
  - Can initiate without whirl
  - Influenced by Viscocity, Temp, Load
  - 0.42 - 0.48 X RPM





Oil Whip

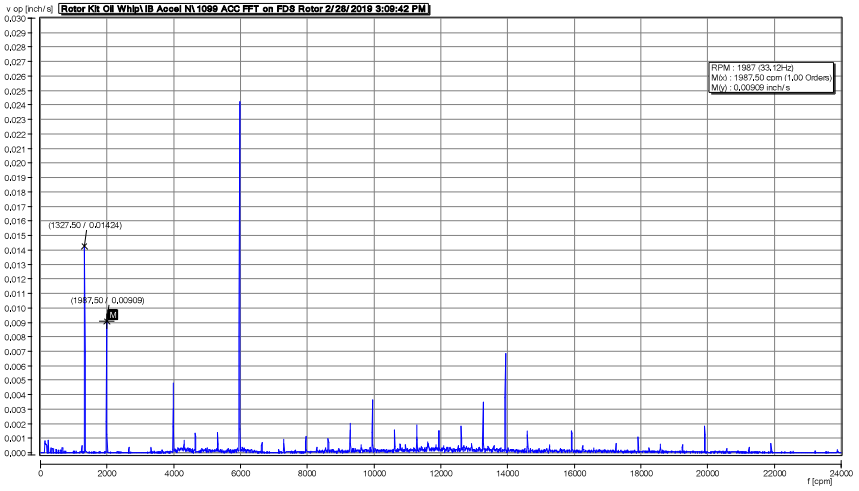
- When Oil Whirls resonates



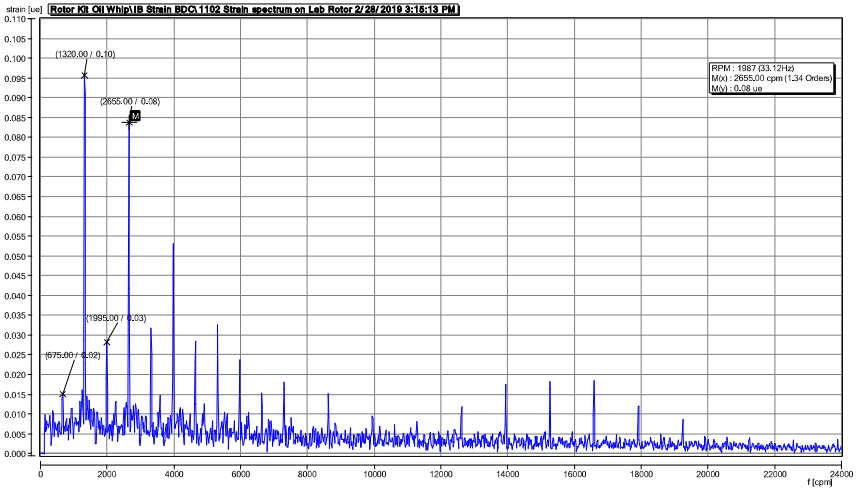
Lab Data

Oil Whirl / Whip

Velocity Data



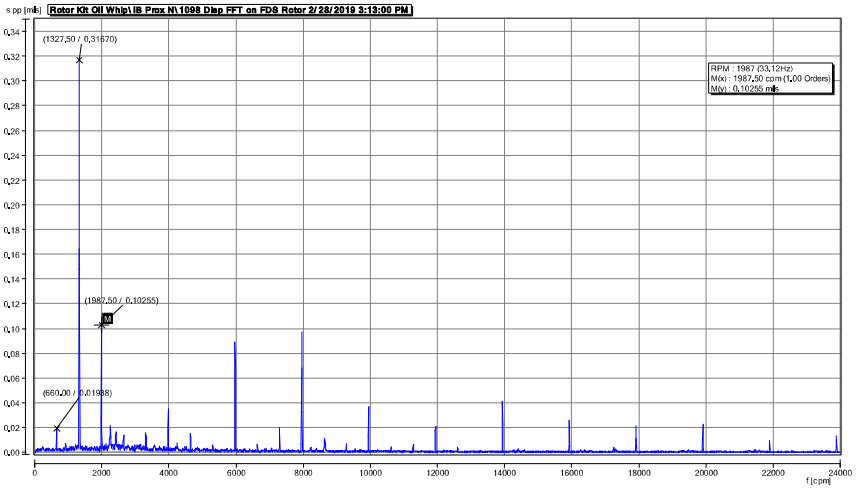
Insight FDS Data



Lab Data

Oil Whirl / Whip

Proximity Data



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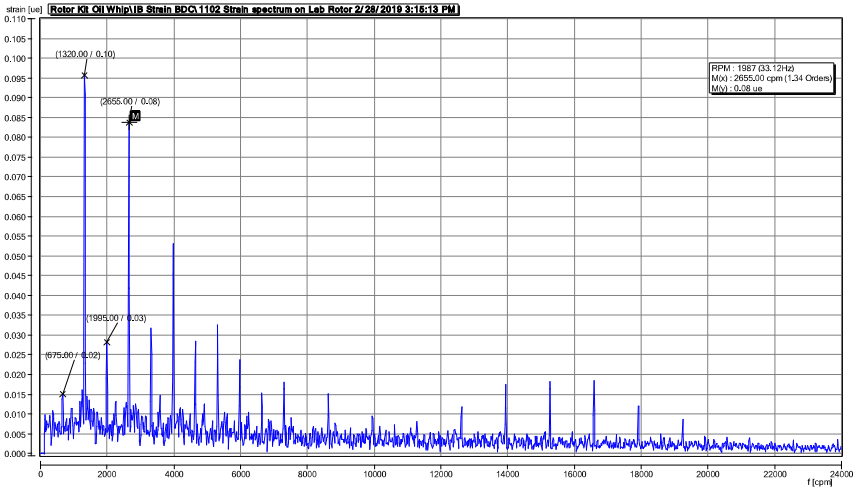


Lab Data

Loss of pressure wedge

- Hydrodynamic Bearings Make Internal Pressure for Lift from the Babbitt
  - Function of Static Load, Dynamic Viscosity, Shaft Speed
- Lose Hydrodynamic Pressure Wedge If
  - High Static Load

    Likely Constant
  - Low Viscosity

    High Temperatures Most Likely Cause
  - Slow Shaft Speed

    During Startup and Coast down

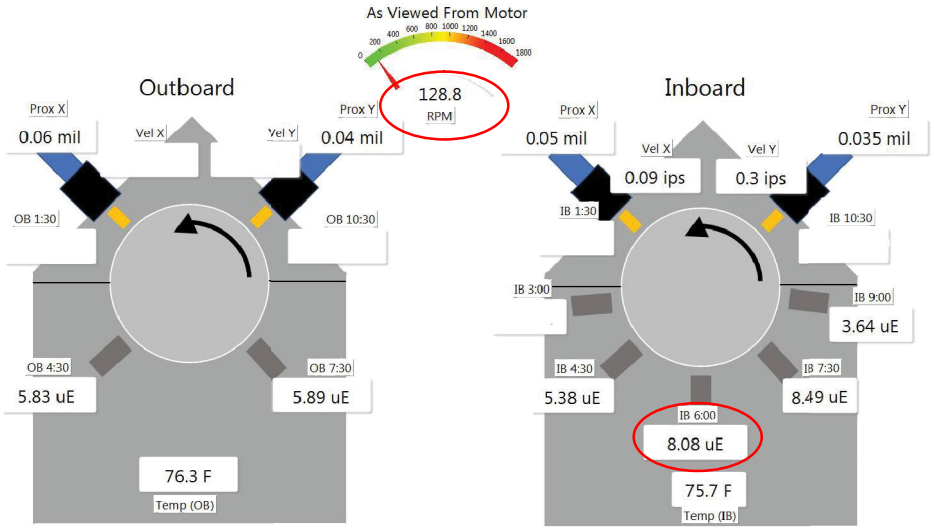
Lab Data

- **Loss of pressure wedge**
  - Next Slide Demonstrates Losing Pressure Wedge
    - Slowing Shaft Speed
  - Note Large Increase in Strain at Bottom Dead Center
  - Note Slight Decrease in Strain at Other Sensors
    - The Shaft is No Longer Lifted
    - Most of Strain is from Gravity Load

Lab Data

Loss of pressure wedge

Before



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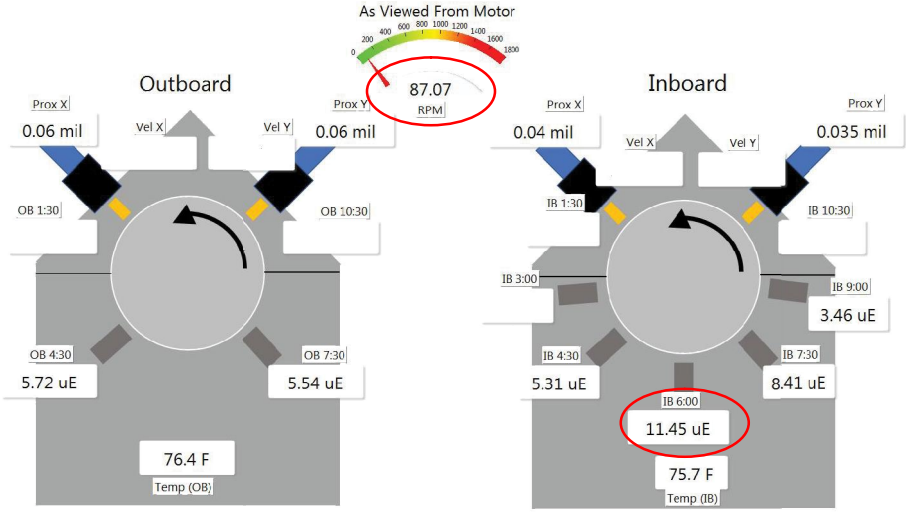


Lab Data

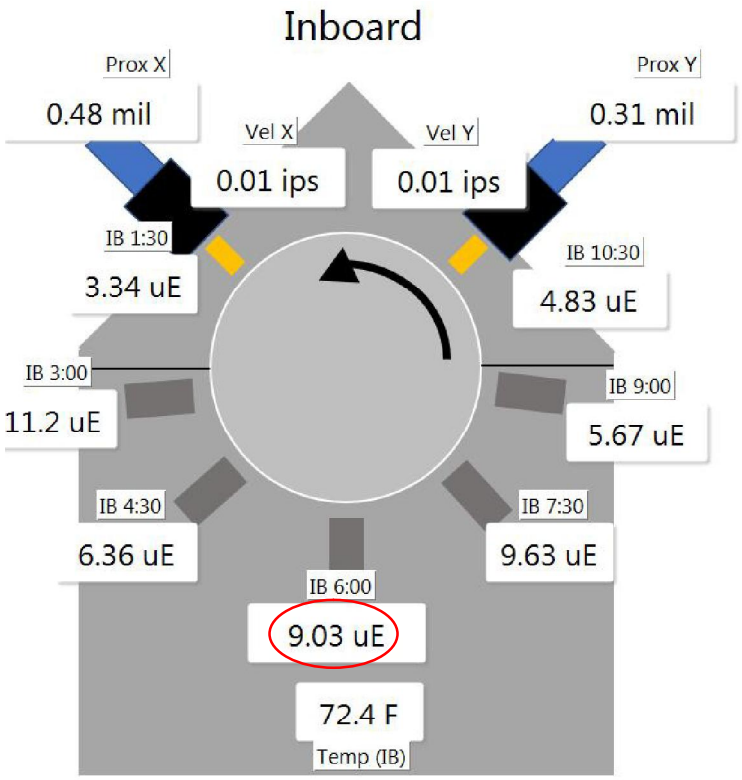
Loss oil feed

- Hydrodynamic and hydrostatic bearings require constant oil supply to flood the bearing
- Losing oil feed can quickly lead to catastrophic failure
- Using strain gives immediate detection and shutdown options
- Note the bottom dead center strain amplitude which rises (262%) instantly with loss of feed
- Note insignificant change (10%) in proximity probe displacement

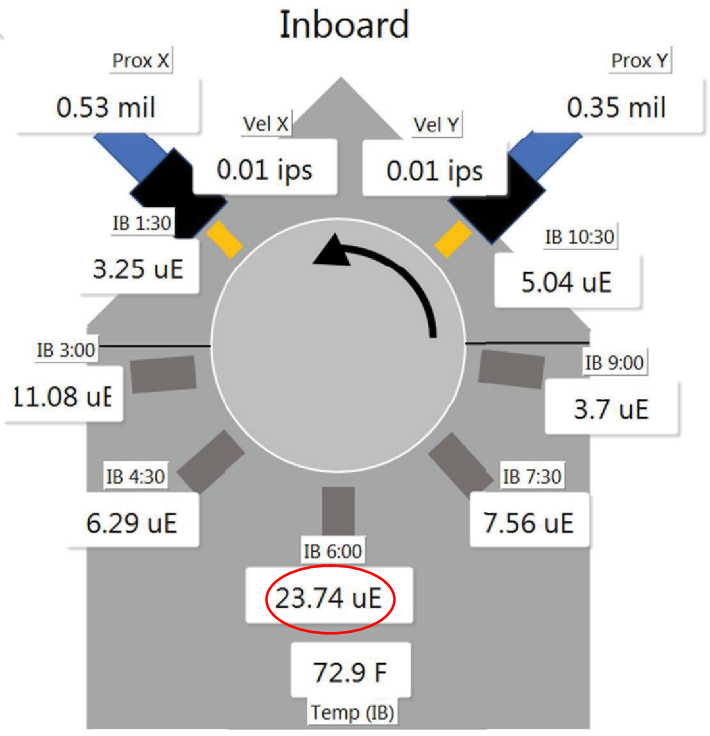
Lab Data

Loss of oil feed

- Before



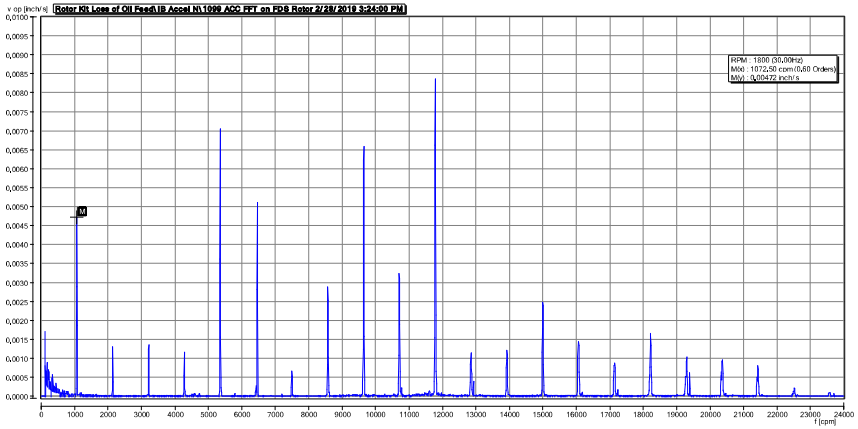
- After Cutting Feed



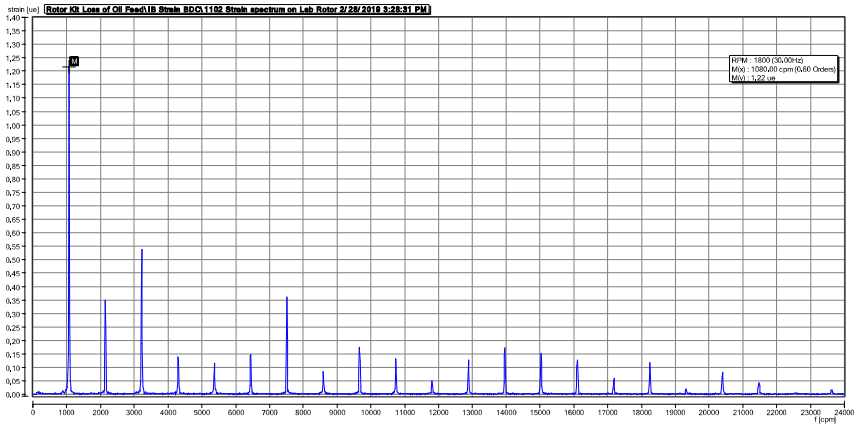
Lab Data

Loss of oil feed

Velocity Data (1x from 0.003ips to 0.00472ips)



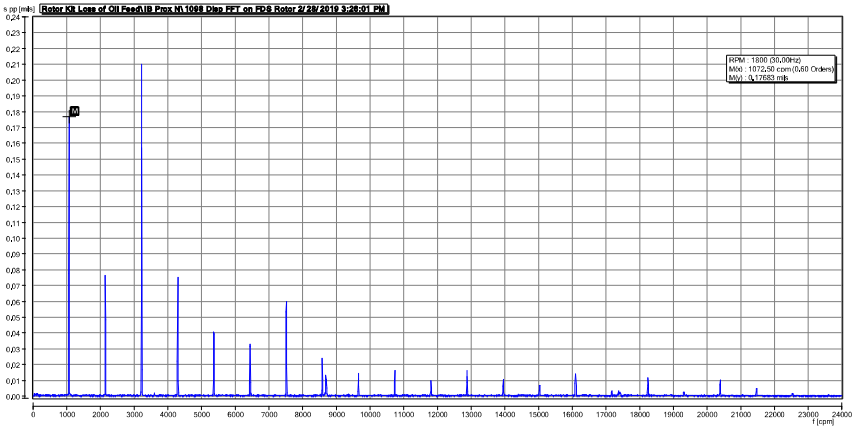
Insight FDS Data (1x from 0.32με to 1.22με)



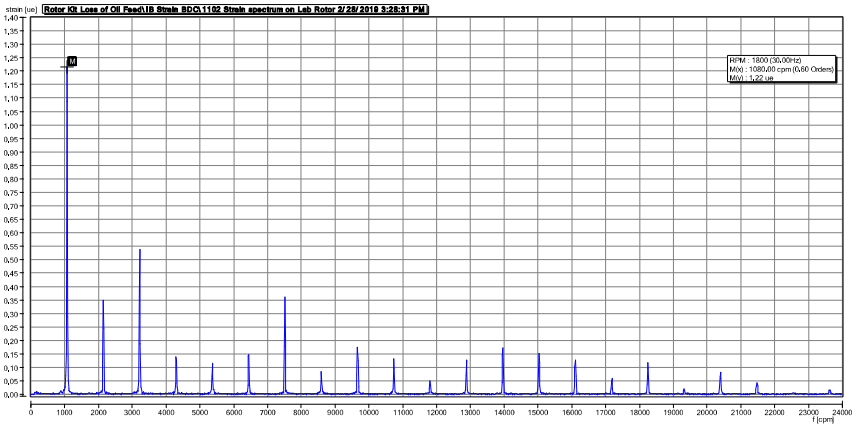
Lab Data

Loss of oil feed

Proximity Data (1x from 0.19mils to 0.177mils)



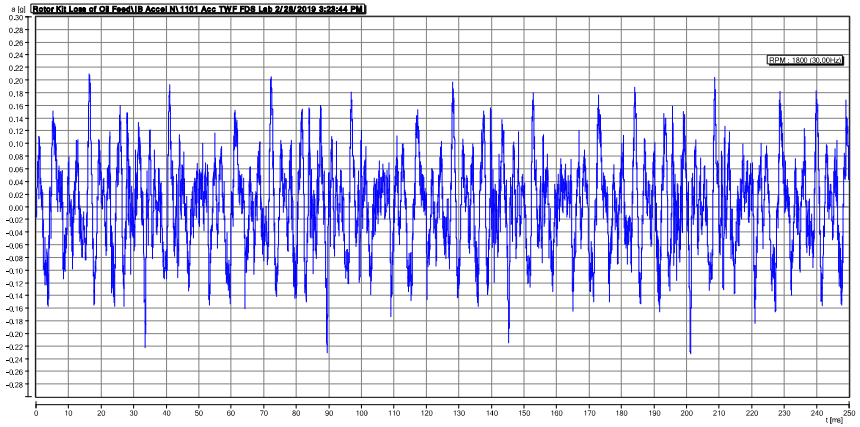
Insight FDS Data (1x from 0.32με to 1.22με)



Lab Data

Loss of oil feed

Acceleration Data



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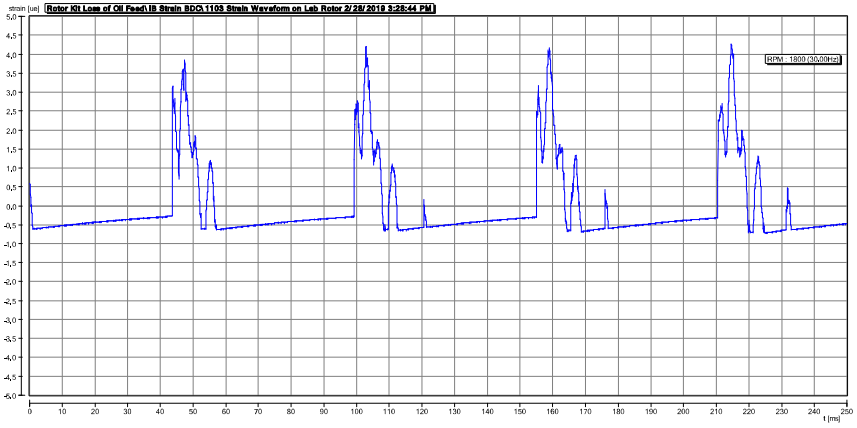
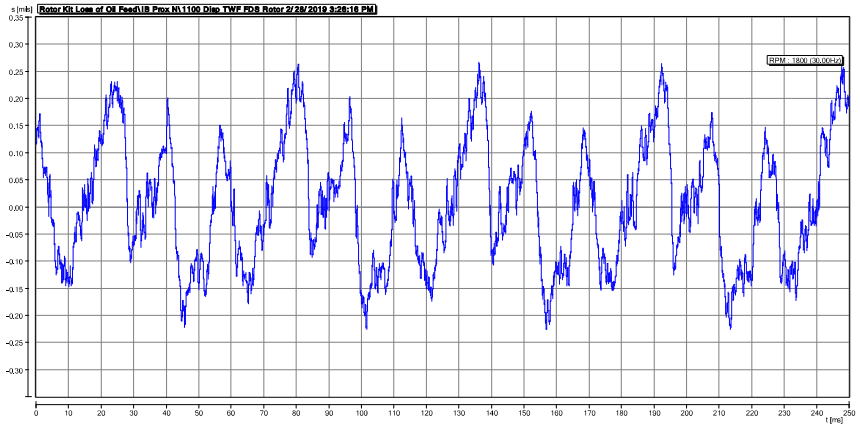


Lab Data

Loss of oil feed

Proximity Data



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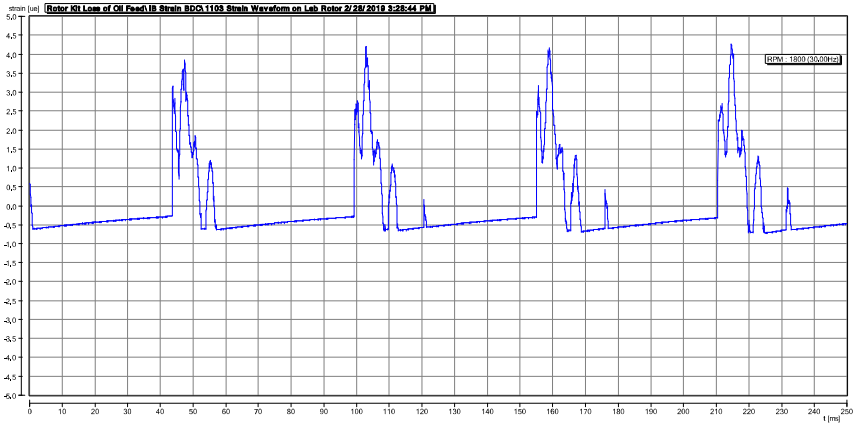
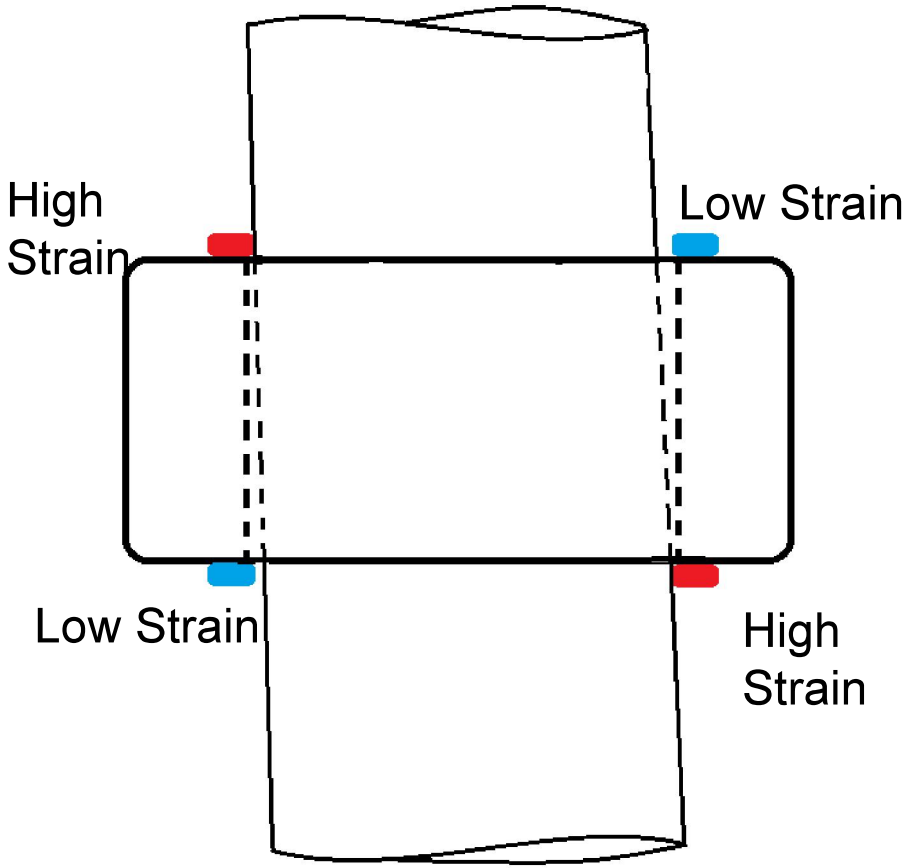


Cocked Bearing Details

- Mounting strain sensors on both faces on the bearing can indicate a cocked bearing during slow roll
  - At higher speeds, many malfunctions can influence these values so only applicable at slow roll (or even turning by hand)
- Lab rotor bearing to bearing alignment checked and adjusted this way

Cocked Bearing Details



Note: Strains should be similar on both faces of the bearing during slow roll

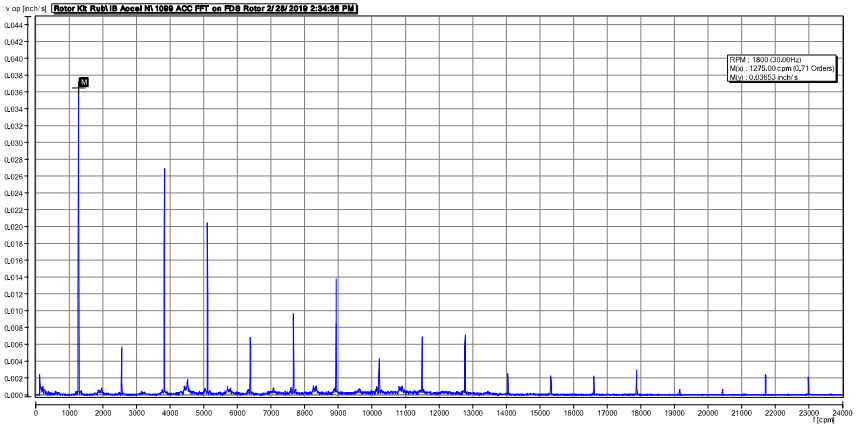
Lab Data

- **Rub between shaft and Babbitt**
- Dwelling Near Resonance to Force a Rub
  - Mode Shape Bends the Shaft Causing the Rub
- Slide Shows Outboard Bearing (High Clearance)
  - Strain in Upper Half and Displacement in Lower Half
  - Displacement Waveform Hints at Rub
  - Strain Waveforms Clearly Present the Rub

Lab Data

Rub between shaft and Babbitt

Velocity Data



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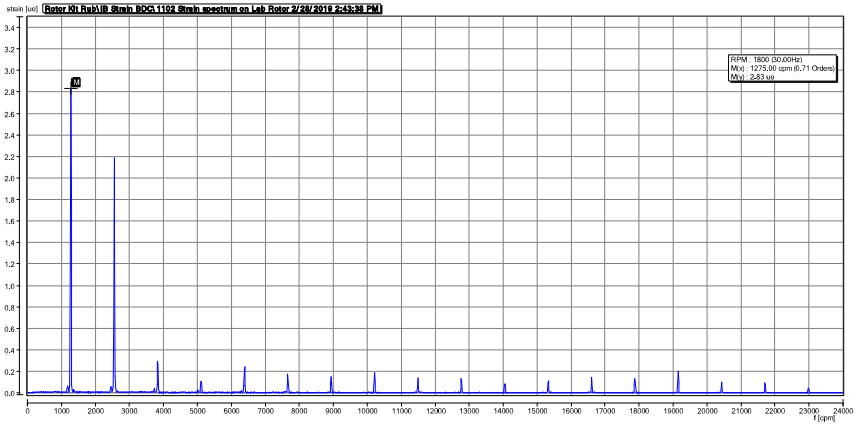
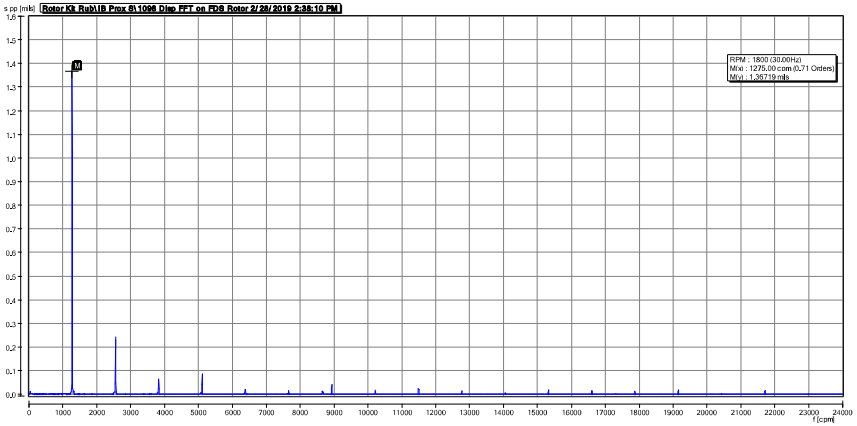


Lab Data

Rub between shaft and Babbitt

Proximity Data



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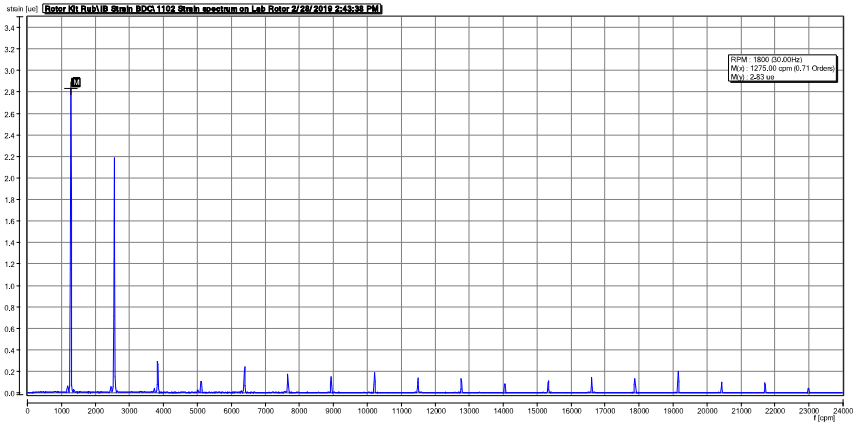
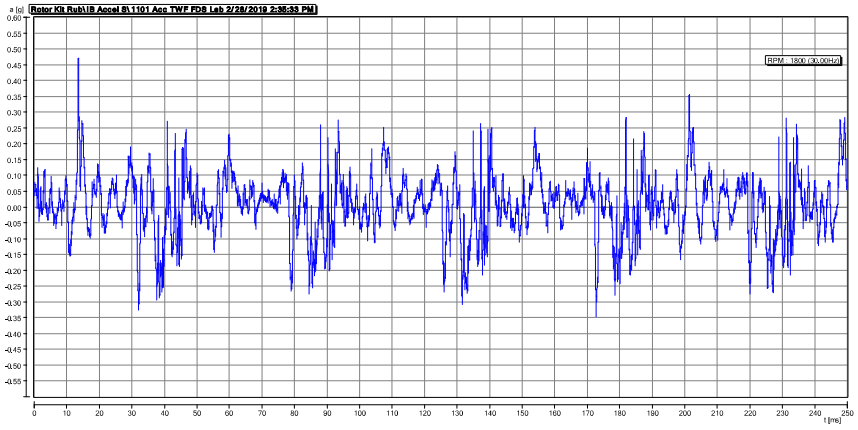


Lab Data

Rub between shaft and Babbitt

Acceleration Data



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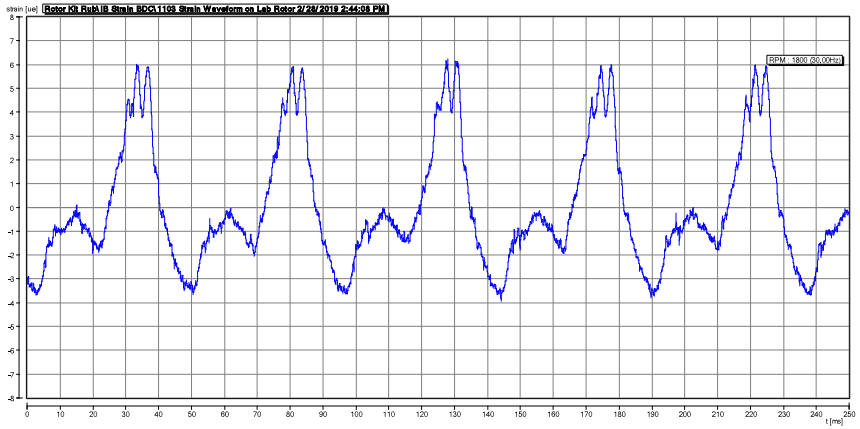
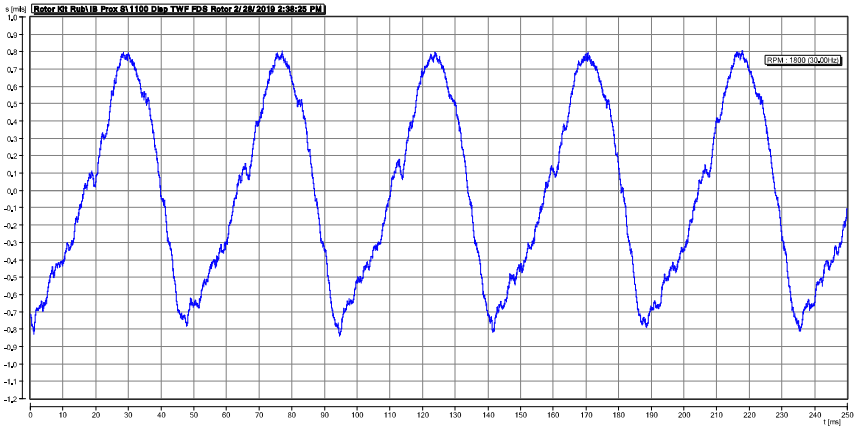


Lab Data

Rub between shaft and Babbitt

Proximity Data



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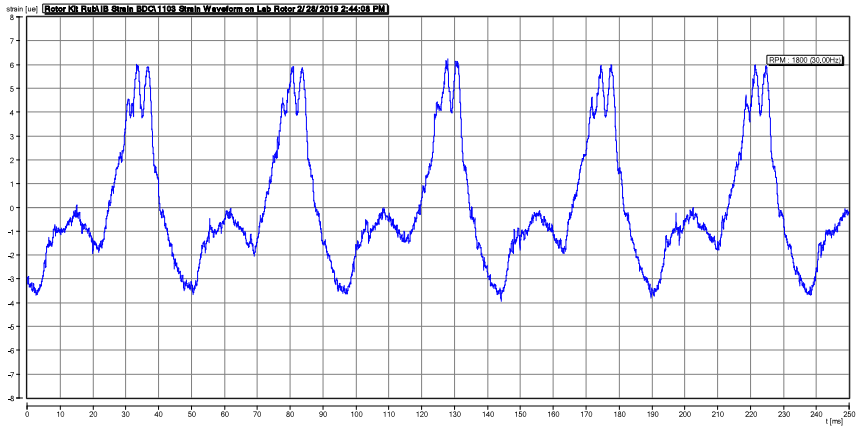


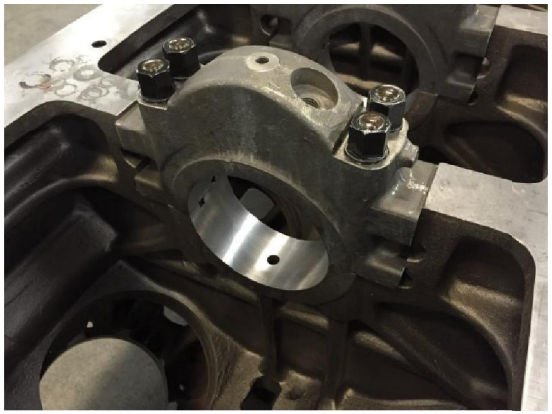
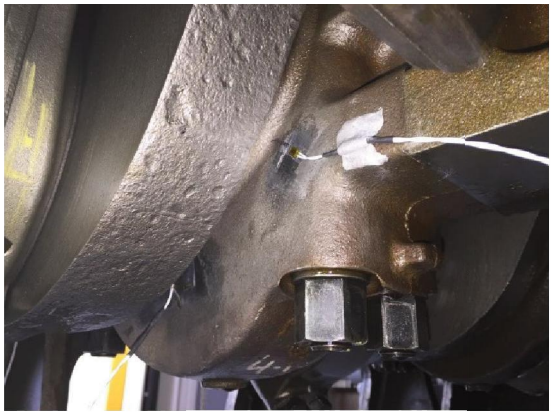
Field Data

- **Waukesha engine – (BP Oil)**
  - Waukesha Natural Gas Engine
  - 1st Ever Test of Dynamic Strain on Main Bearings by Pioneer Engineering
  - Used old style metal foil strain gauges for proof of concept
    - Now use IEPE powered piezoelectric strain sensors
  - No malfunctions noted
    - Examples of Clear Waveforms from Engine Main Bearings

Field Data

➢ Waukesha engine – (BP Oil)

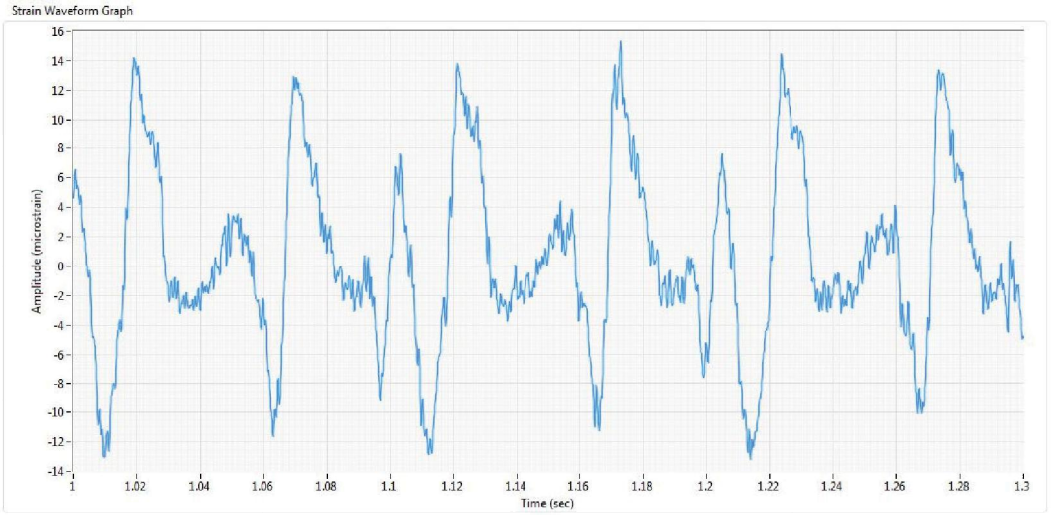
Installation pictures

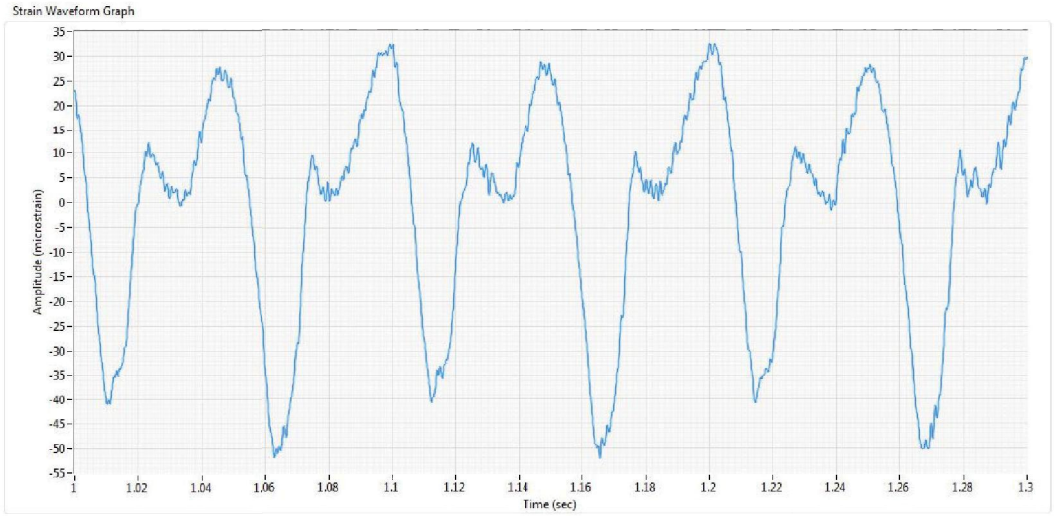





Field Data

➢ Waukesha engine – (BP Oil)

Insight FDS

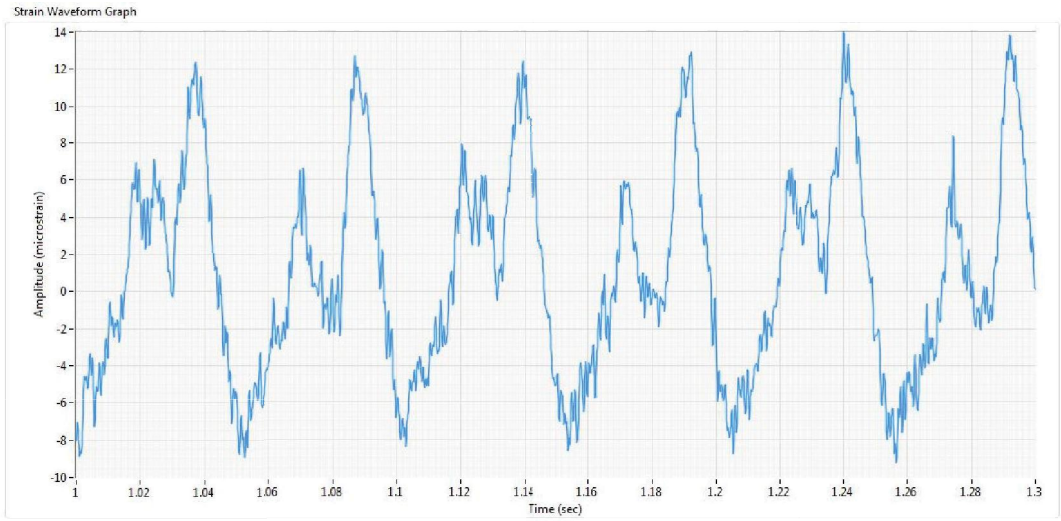


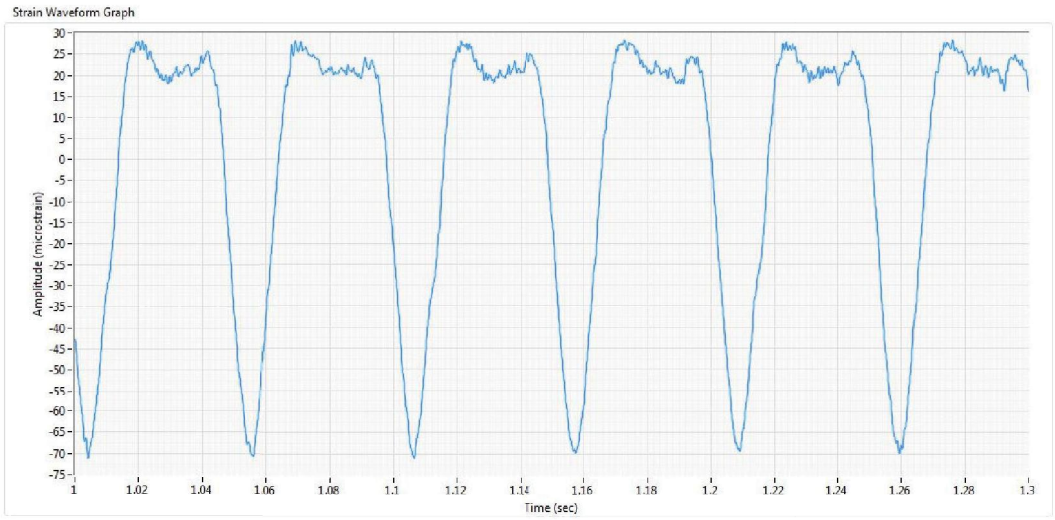


Field Data

➢ Waukesha engine – (BP Oil)

Insight FDS

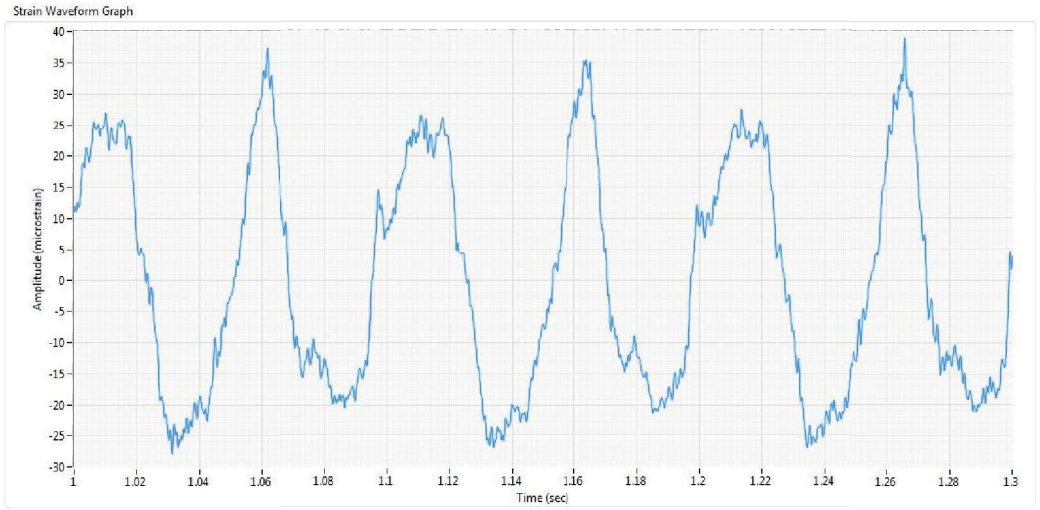


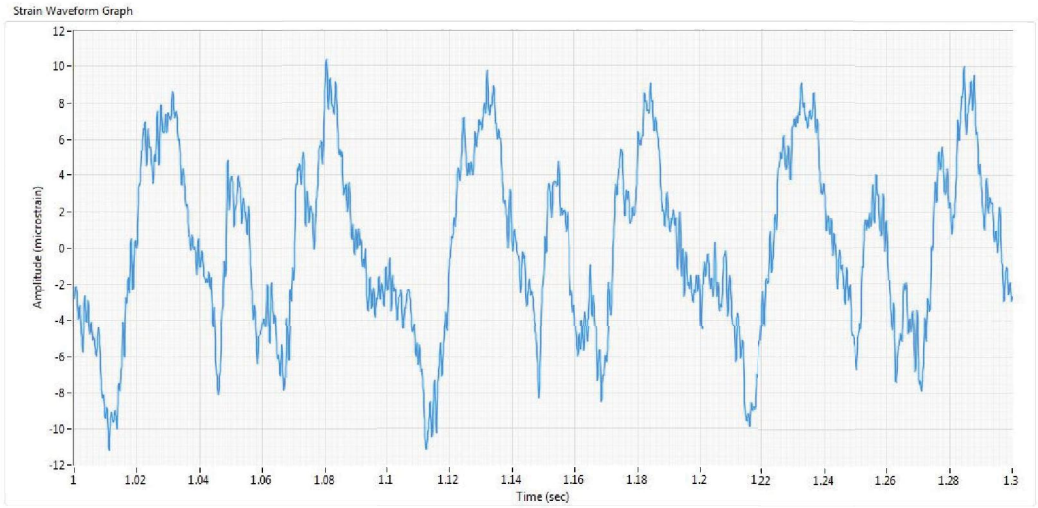


Field Data

➢ Waukesha engine – (BP Oil)

Insight FDS

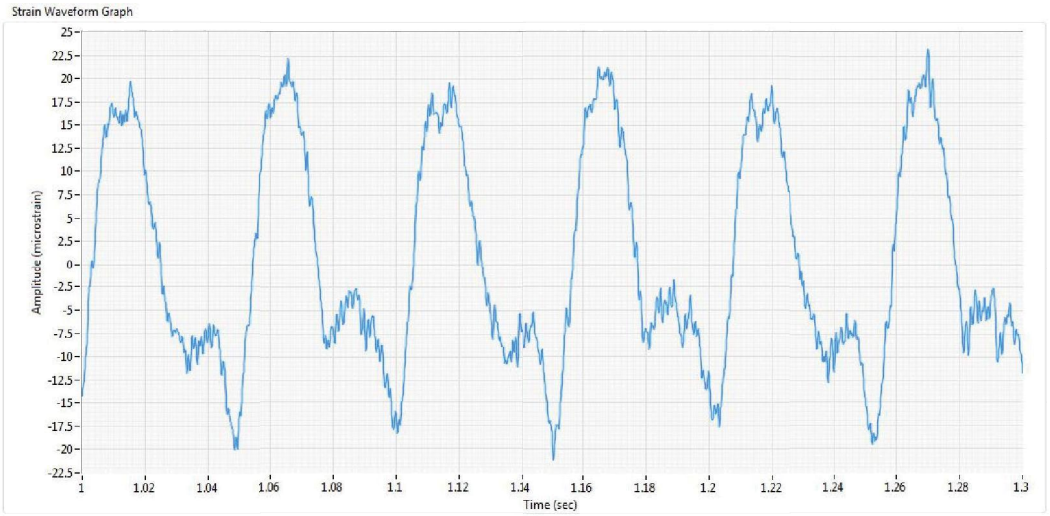


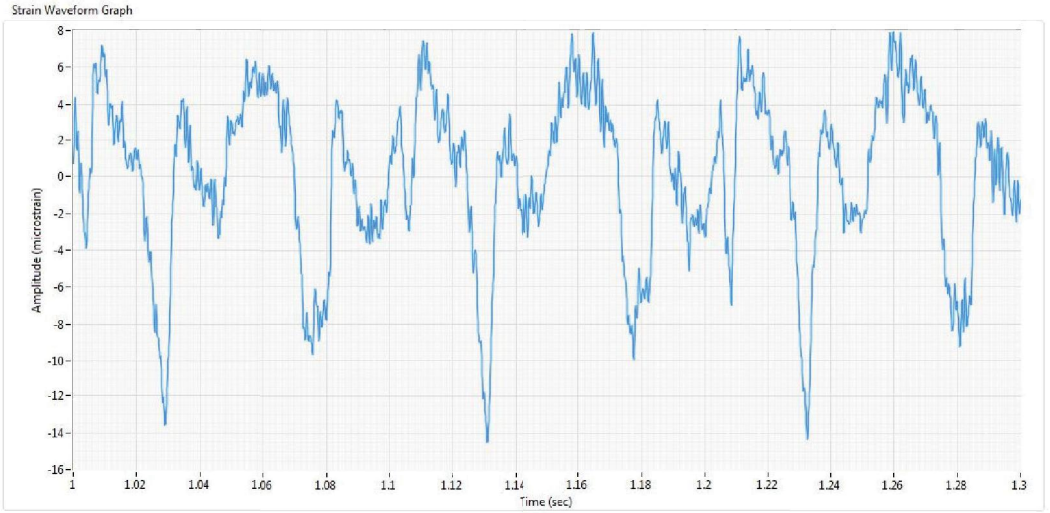


Field Data

➢ Waukesha engine – (BP Oil)

Insight FDS





Field Data

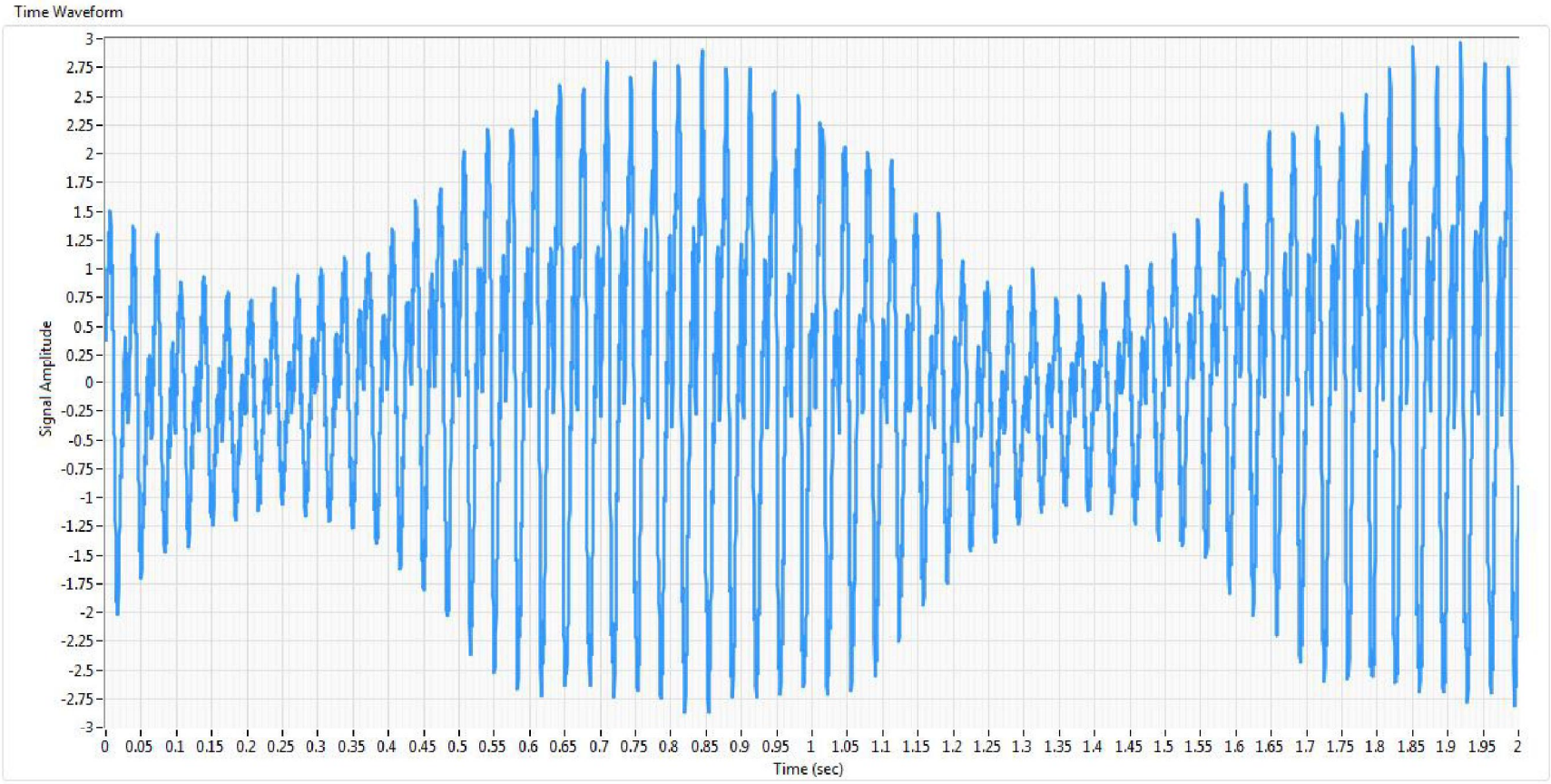
PA Fan Motor - Rotor Fault (Basin Electric)

- 4 pole AC induction motor (1500HP)
- 2 Stage vane axial fan
- Motor has a known rotor bar fault
- Data taken on motor outboard bearing with
  - Insight FDS
  - Case mounted accelerometer
  - Proximity probes
- Prox probe data was not slow roll compensated

Field Data

PA Fan Motor - Rotor Fault

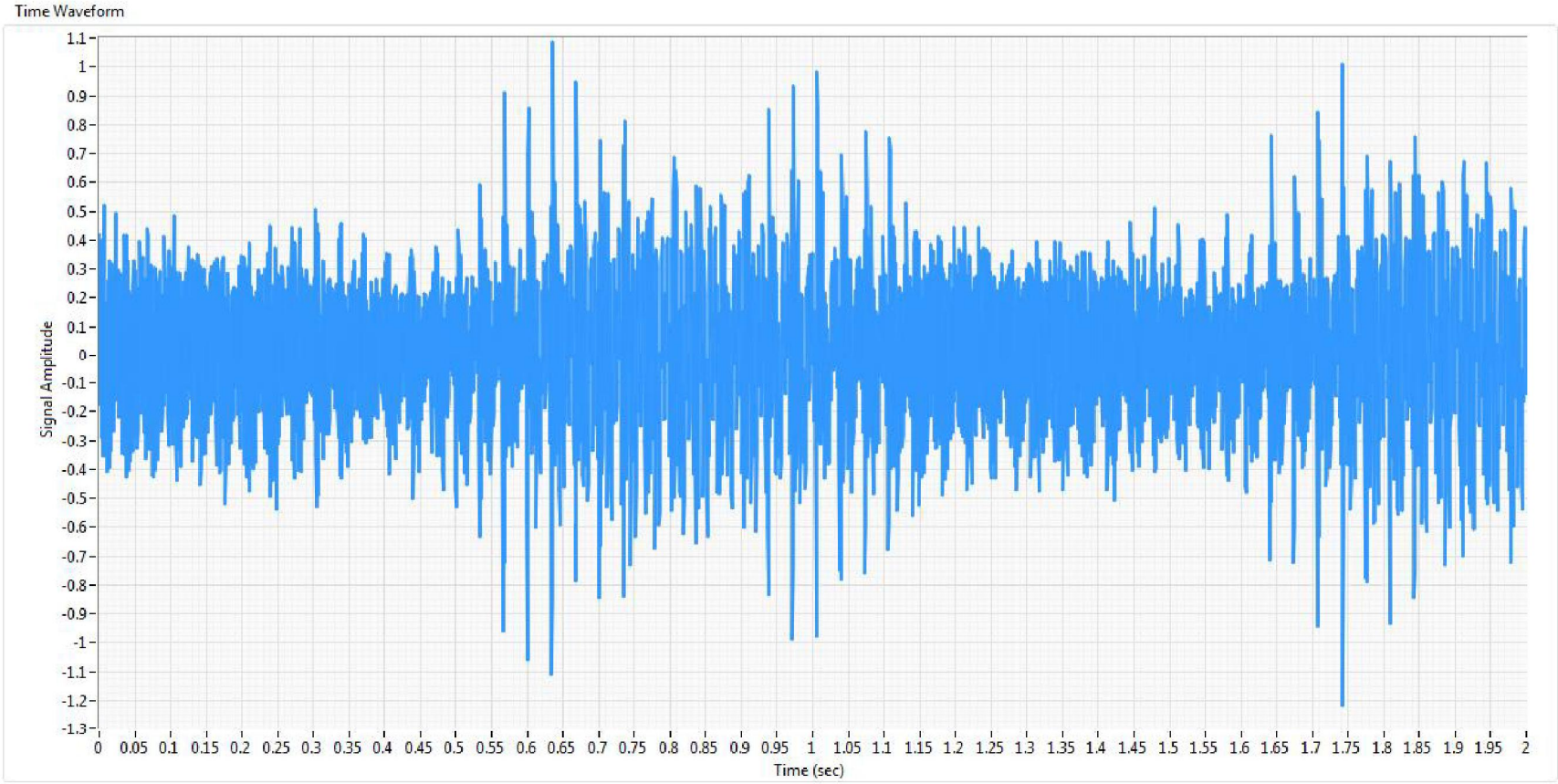
Unfiltered TWF - Insight FDS



Field Data

PA Fan Motor - Rotor Fault

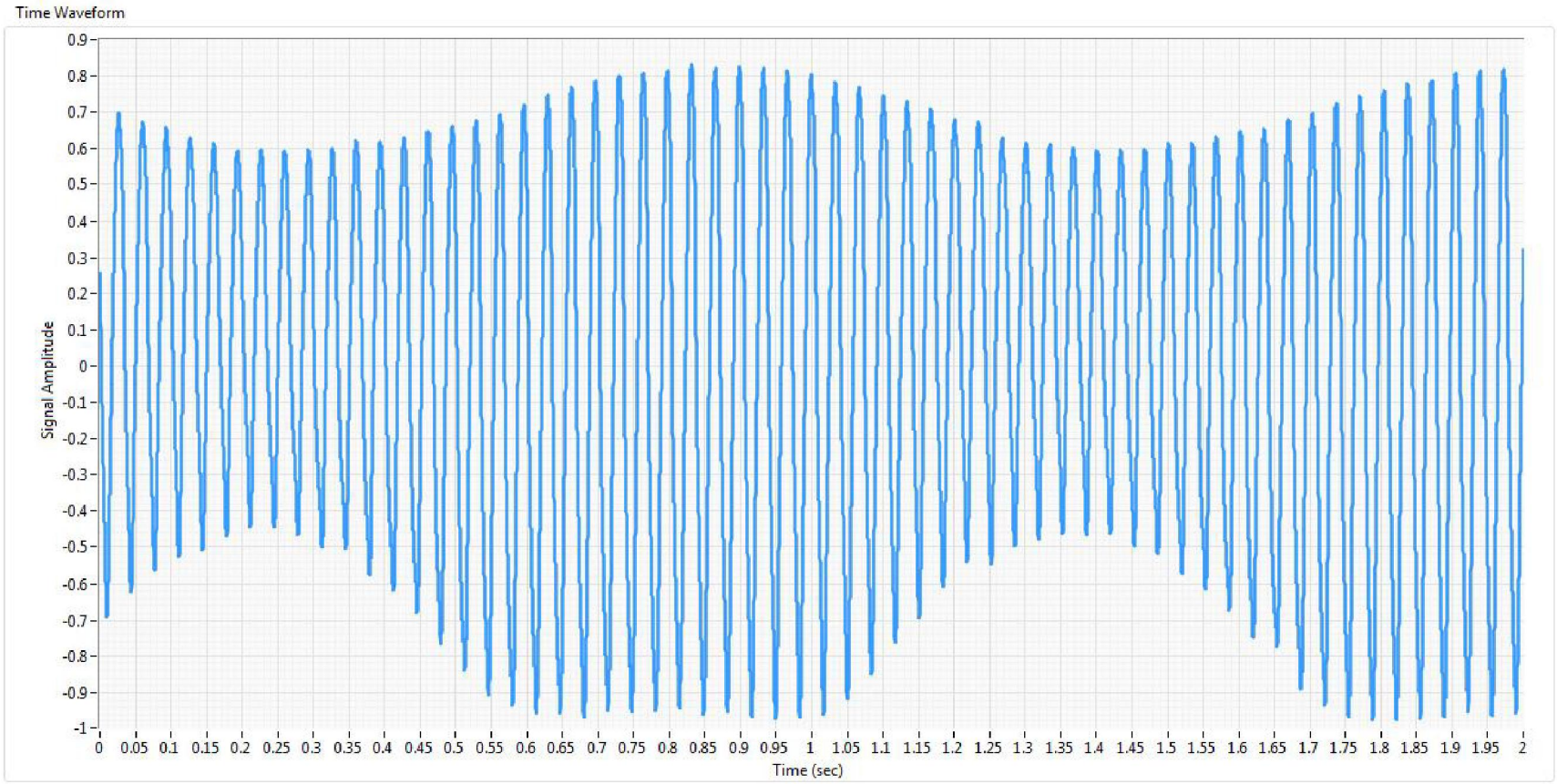
Unfiltered TWF - Accelerometer



Field Data

PA Fan Motor - Rotor Fault

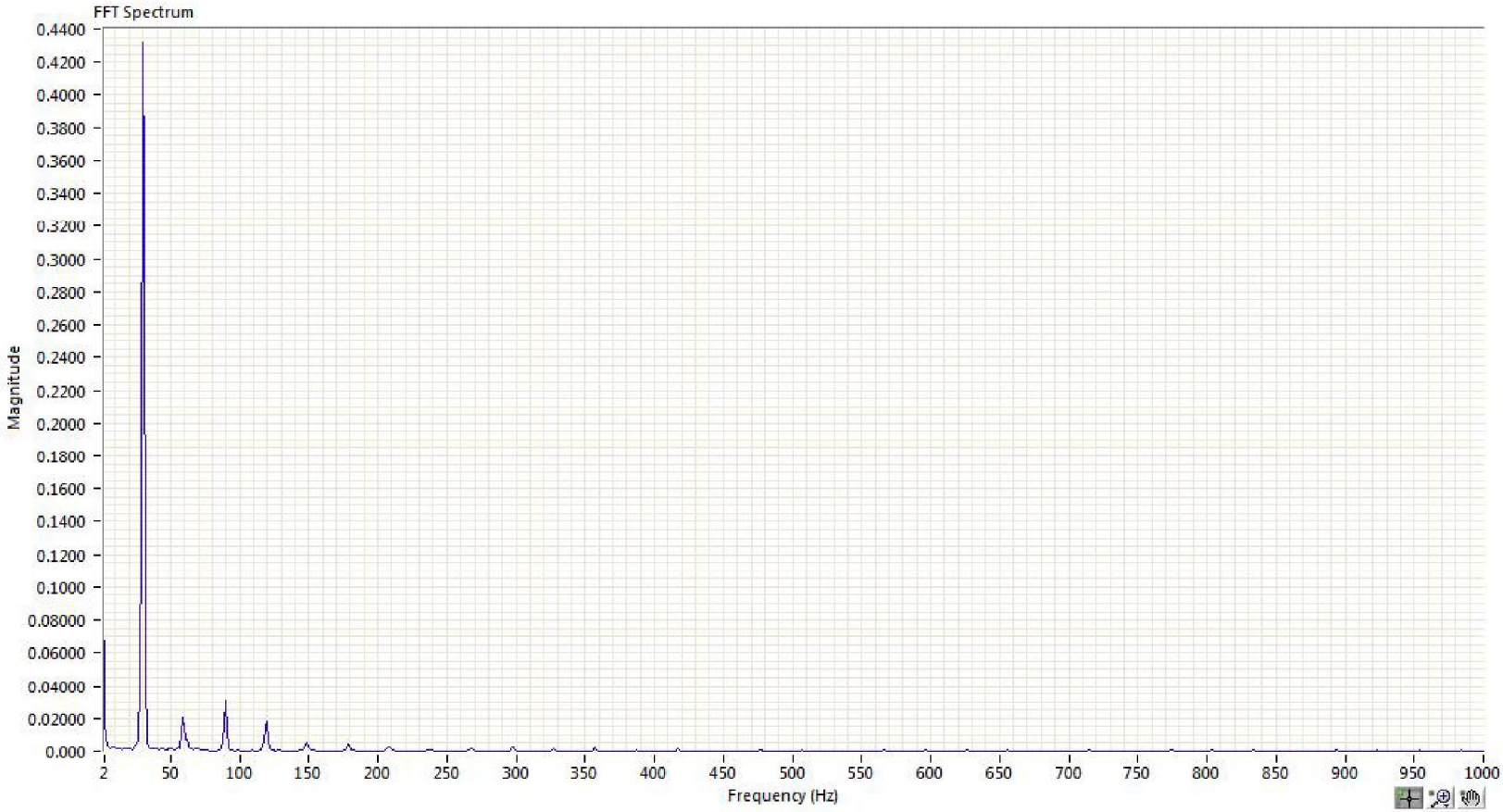
Unfiltered TWF - Prox Probe



Field Data

PA Fan Motor - Rotor Fault

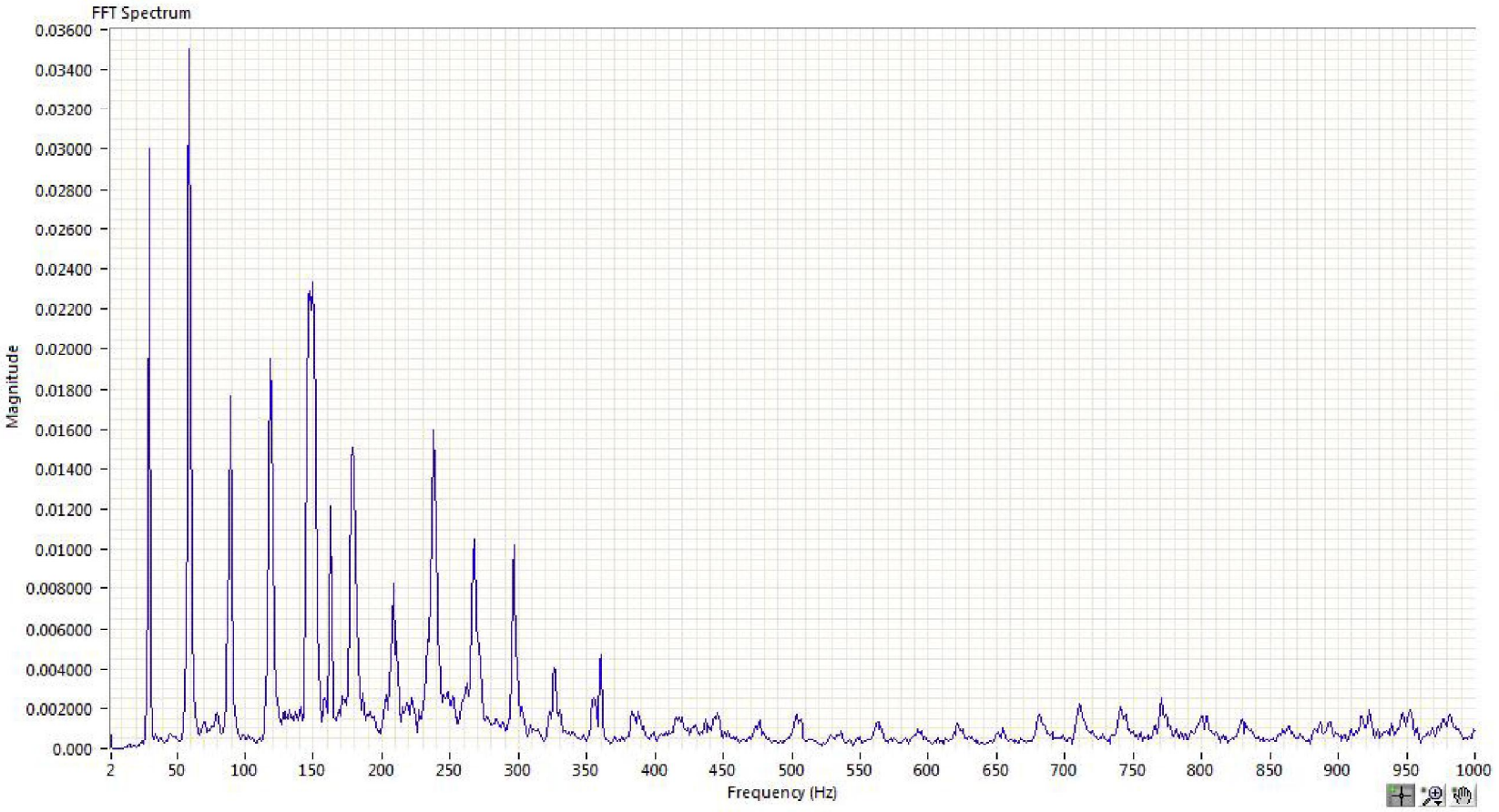
FFT - Insight FDS



Field Data

➢ PA Fan Motor - Rotor Fault

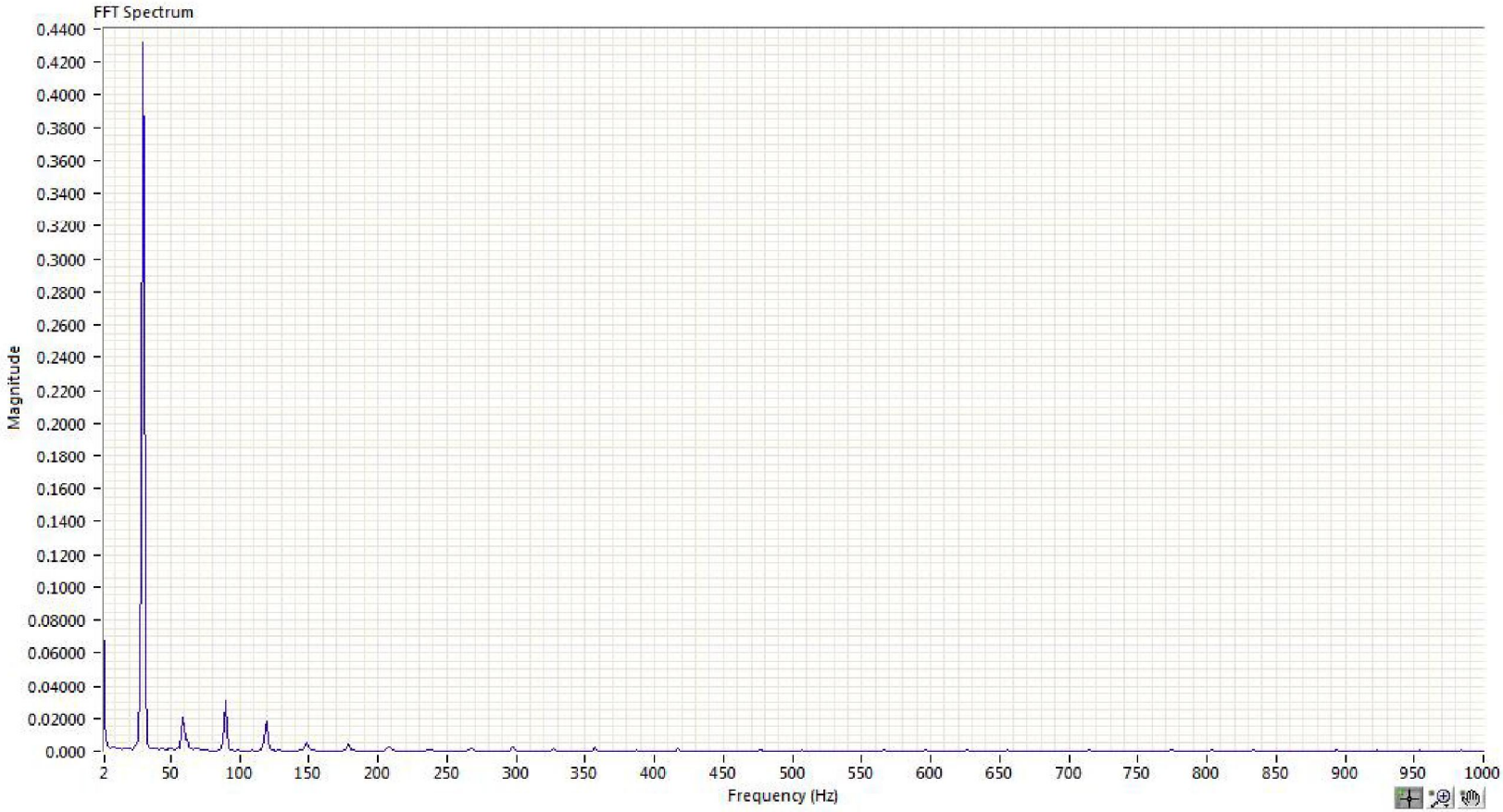
FFT - Accelerometer



Field Data

PA Fan Motor - Rotor Fault

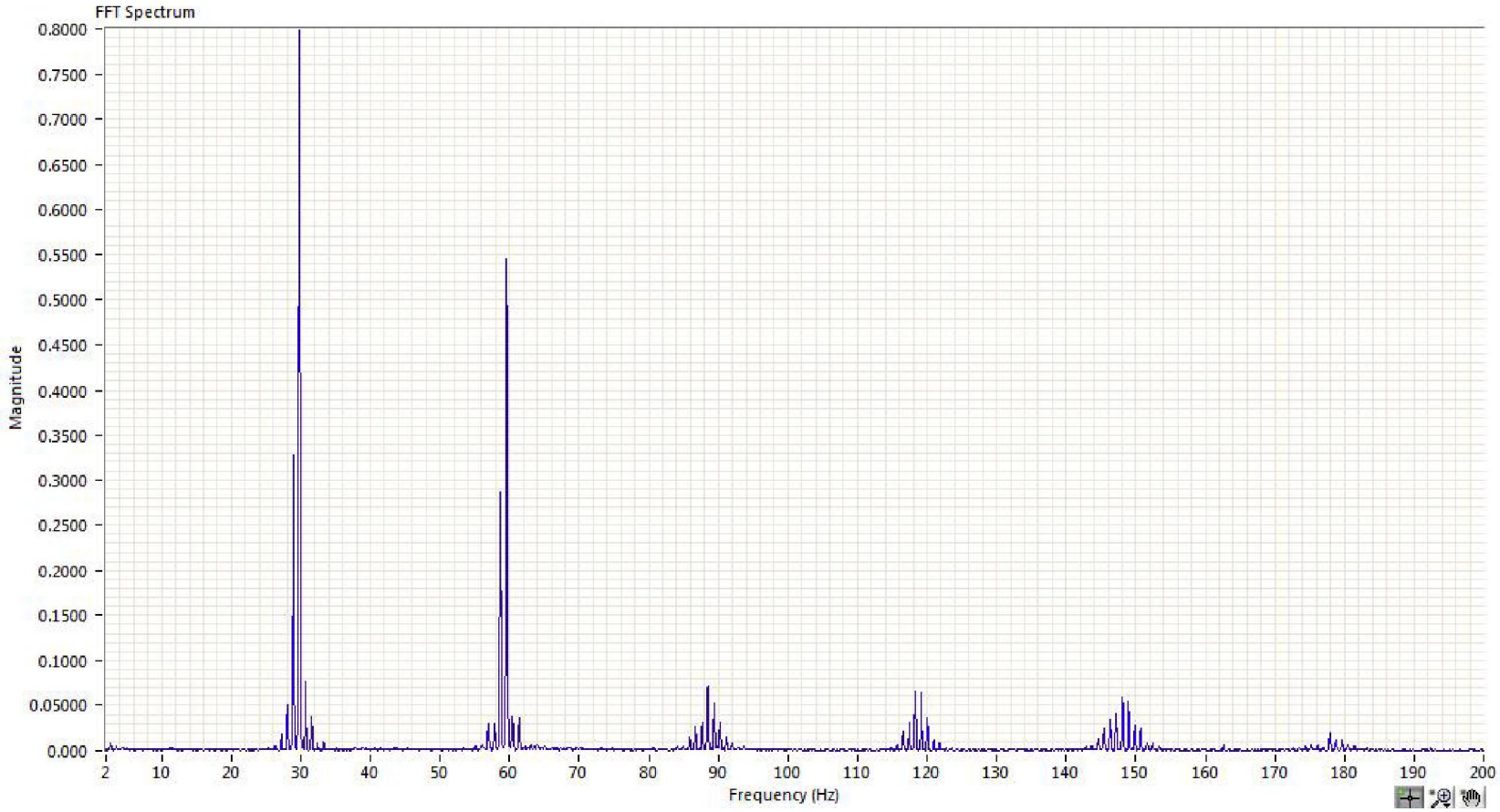
FFT - Prox Probe



Field Data

PA Fan Motor - Rotor Fault

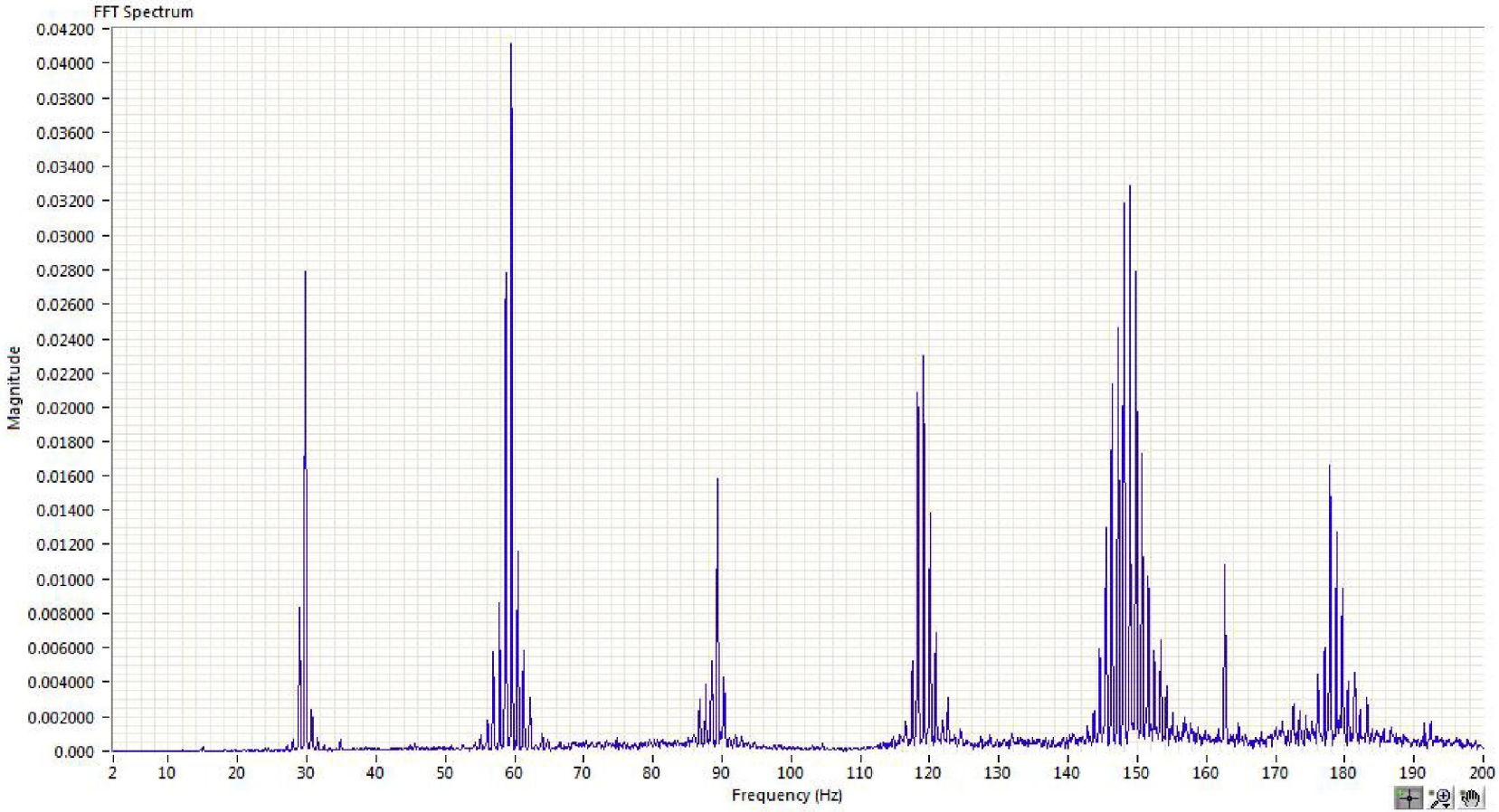
High Res. FFT - Insight FDS



Field Data

PA Fan Motor - Rotor Fault

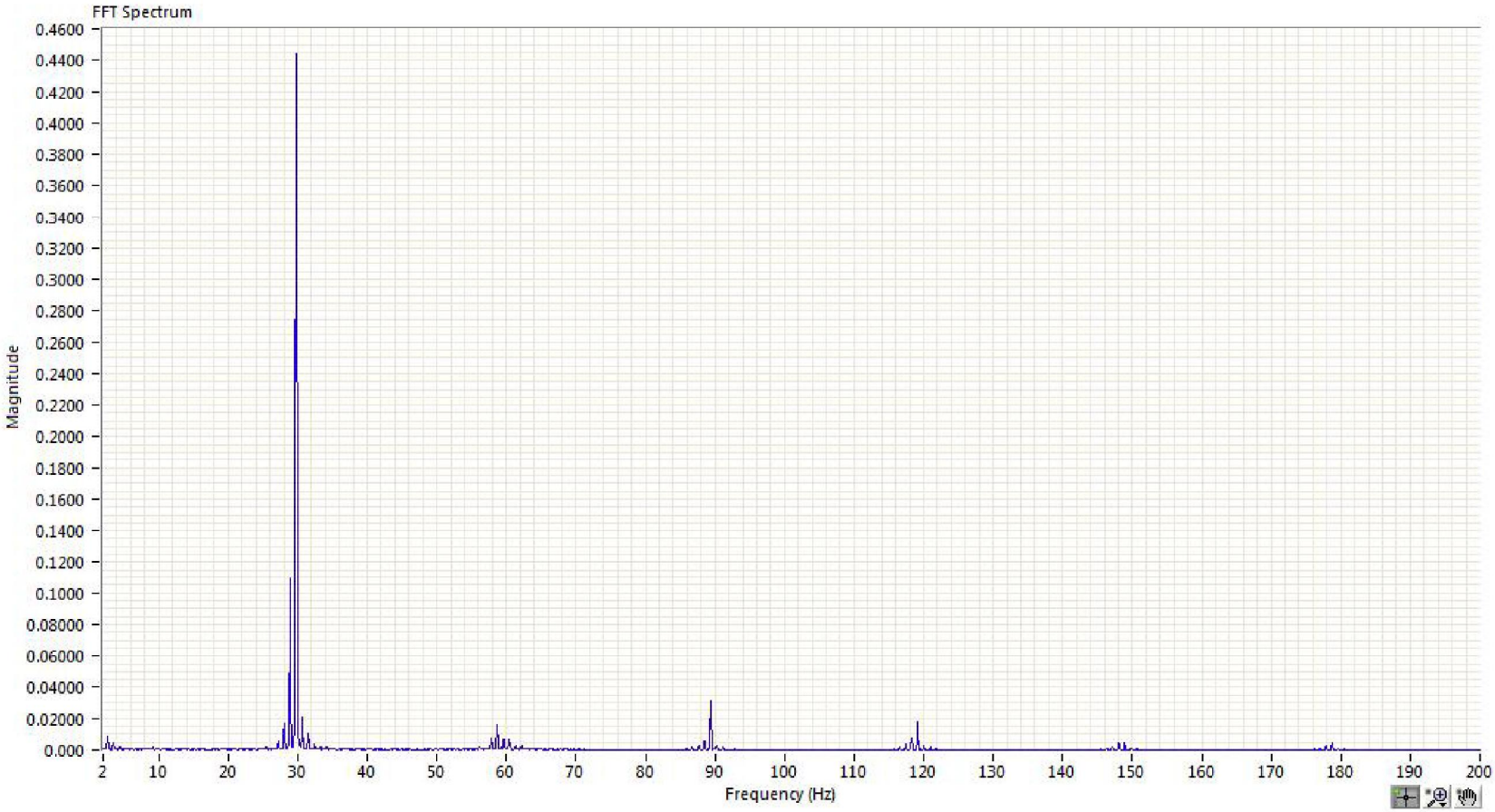
High Res. FFT - Accelerometer



Field Data

➢ PA Fan Motor - Rotor Fault

High Res. FFT - Prox Probe



Conclusion

- Fluid Film Bearings on Critical Machines
- Different monitoring technologies
  - Proximity Probes – Best but very expensive
  - Temperature – To late warning
  - Case Mounted Accelerometers – Better than nothing
  - Not at all?? – Expensive
- Insight Force Detection Sensor
  - Strain indirectly representing bearing forces
  - Easy install
  - Data quality proven
- New exciting technology available today.

THANK YOU

QUALITY MEANS TO US:

TO MAKE A DIFFERENCE EVERY DAY.

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