FLUKE Reliability

Azima DLI

Vibration Analysis: Slow-Speed Machine Applications and Impact Detection

Steven Hudson

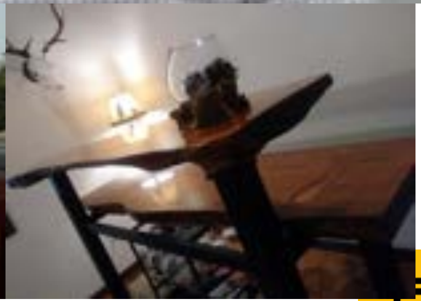
Background:

- Naval Nuclear Power (Submarines)
- 36 years in Predictive Maintenance
- ISO Cat IV Vibration Analyst
- Joined AzimaDLI in 2010

Director, Professional Services (2018-Present)

- Remote Vibration Analysis/Reporting (automation)
- Reciprocating Compressor Analysis
- Startup / Field Services

- Favorite things/Hobbies:
  - Family (11 Grandkids – 2 Great Grandkids)
  - Wood Working / Sawmill
  - Auto Restoration



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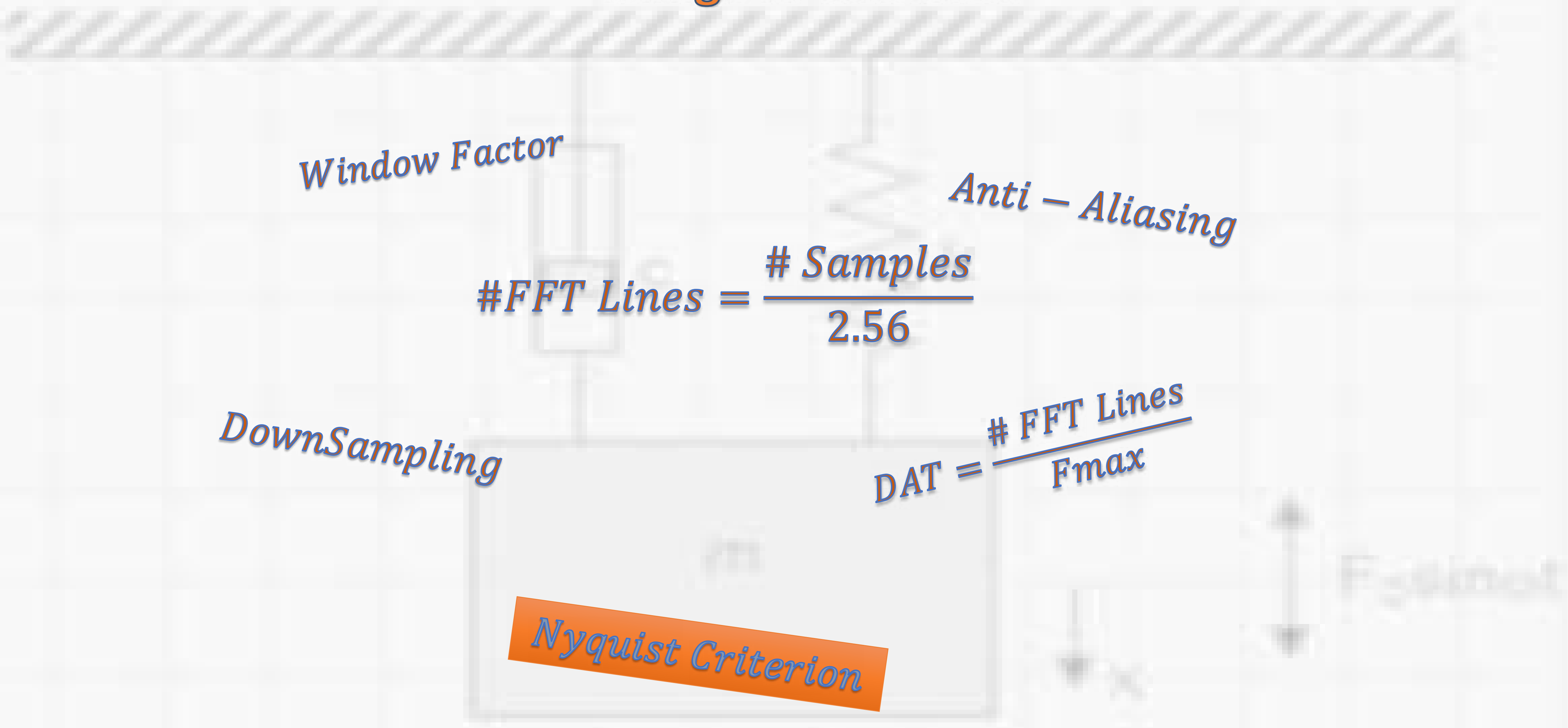
Bearing Fault Detection on Slow Speed Shafts

- Today We Are Discussing Impact Detection along with Slow Speed Shaft Vibration Techniques

Things to Consider



Window Factor

Anti – Aliasing

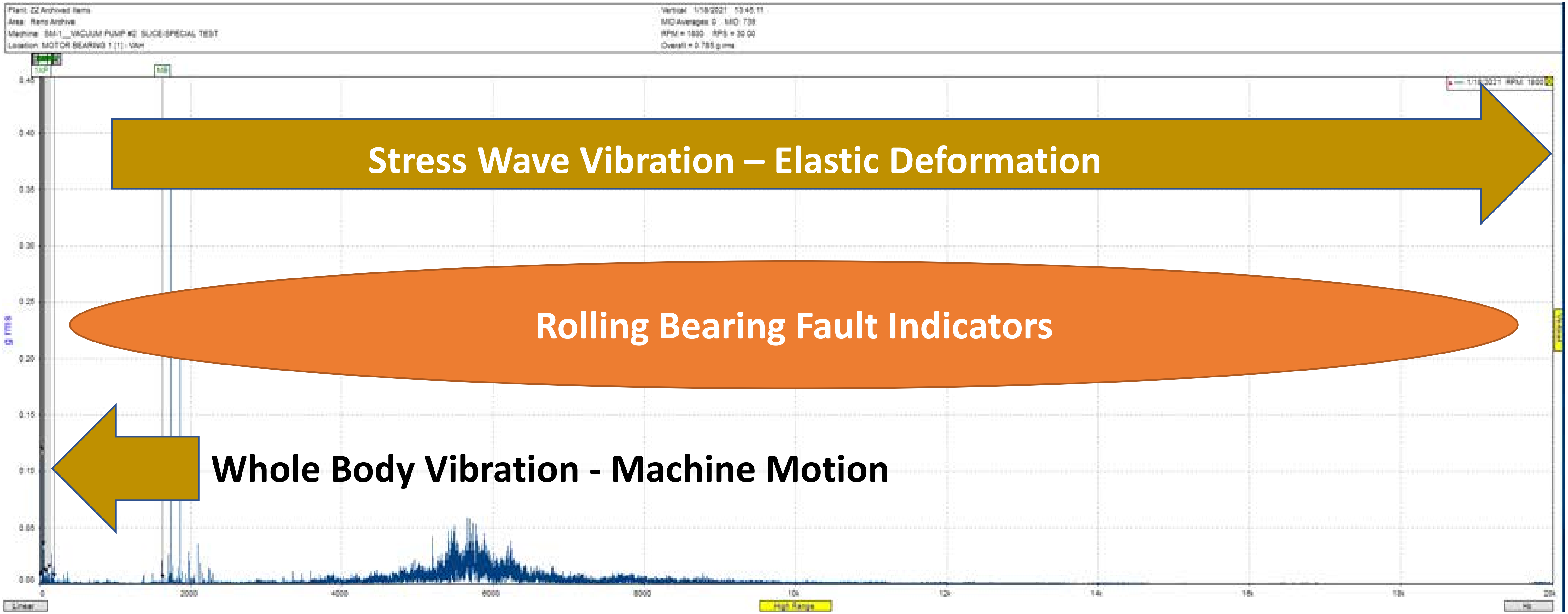
$$\#FFT\ Lines = \frac{\#\ Samples}{2.56}$$

DownSampling

$$DAT = \frac{\#\ FFT\ Lines}{Fmax}$$

Nyquist Criterion

Things to Consider



A Few words about Signal Processing

NYQUIST CRITERION

A repetitive waveform can be correctly digitized and reconstructed provided:

- The sampling frequency is greater than 2X the highest frequency to be sampled.

or

- The sample contains no frequencies higher than ½ the sampling frequency

If Nyquist Criterion is not adhered to the resulting digitized time-series data will contain distortion known as **ALIASING**

ALIASING Visualization

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Signal Processing
Anti-Aliasing Strategies

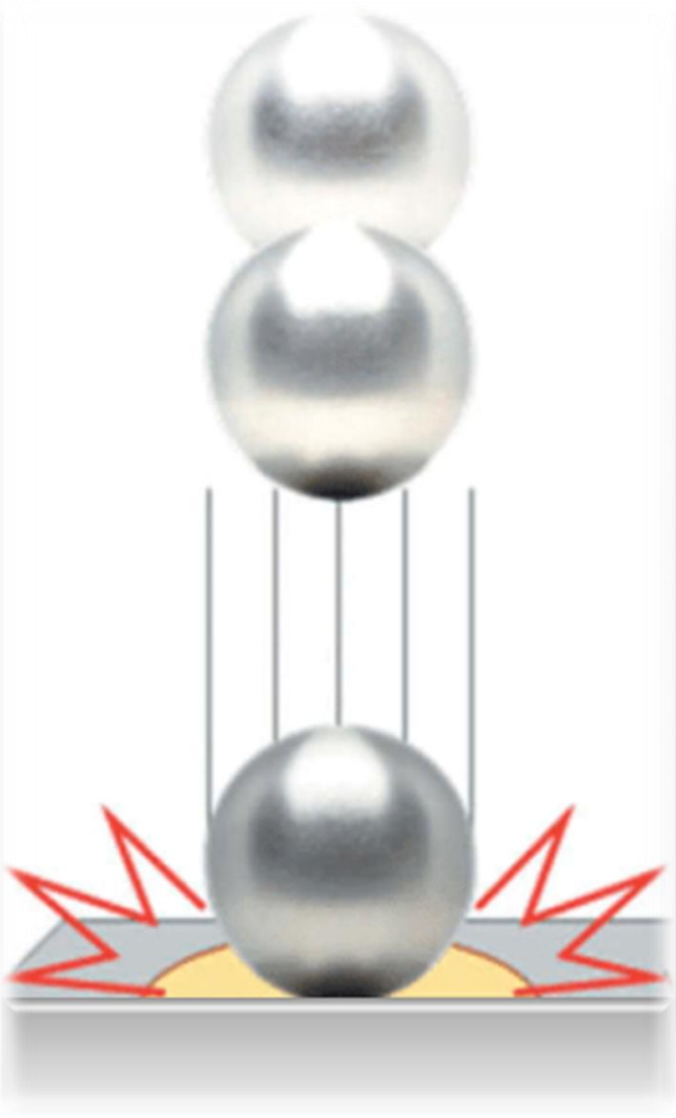
How do Digital Data Collectors comply with Nyquist Criterion

1. **Anti-Aliasing Filter:** R/C filter (or bank of filters) placed prior to A/D converter
   - Removes frequencies higher than ½ the sampling frequency

2. **Oversampling:** a strategy of sampling more than 2X faster than any plausible frequencies in the signal.

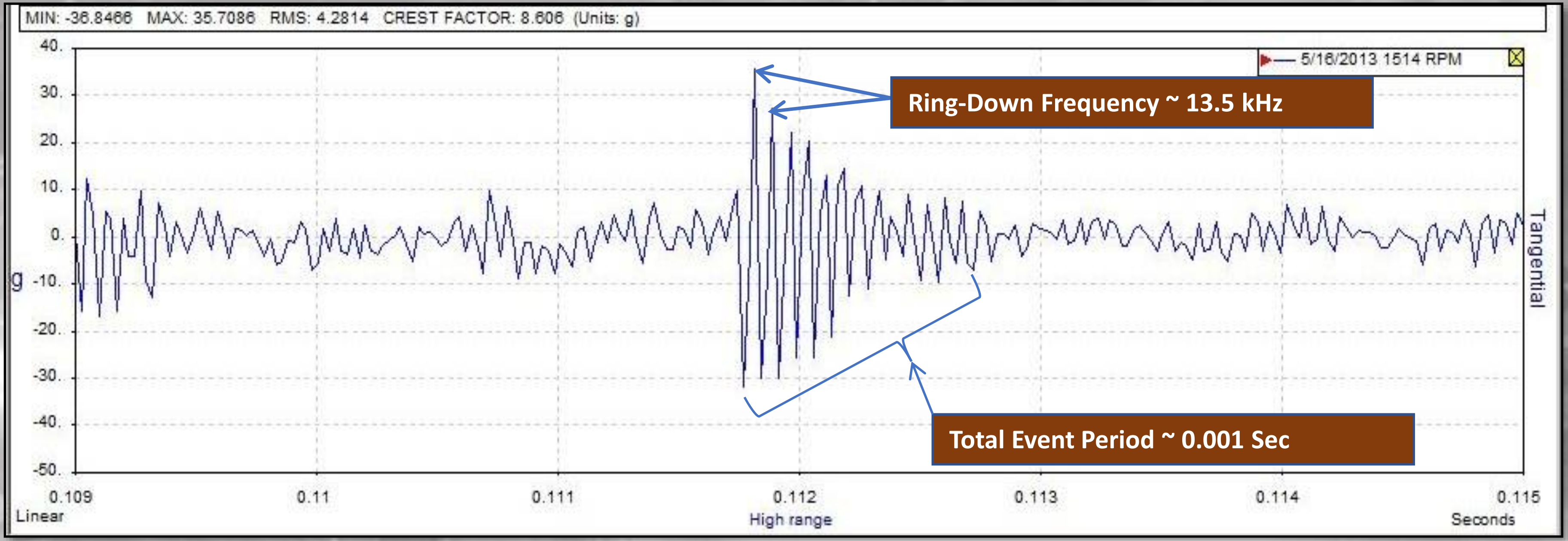
Note: Don't mistake Sensor Frequency Response as the maximum measurable frequency.

Distinguishing an Impact



Single Impact in Time Waveform

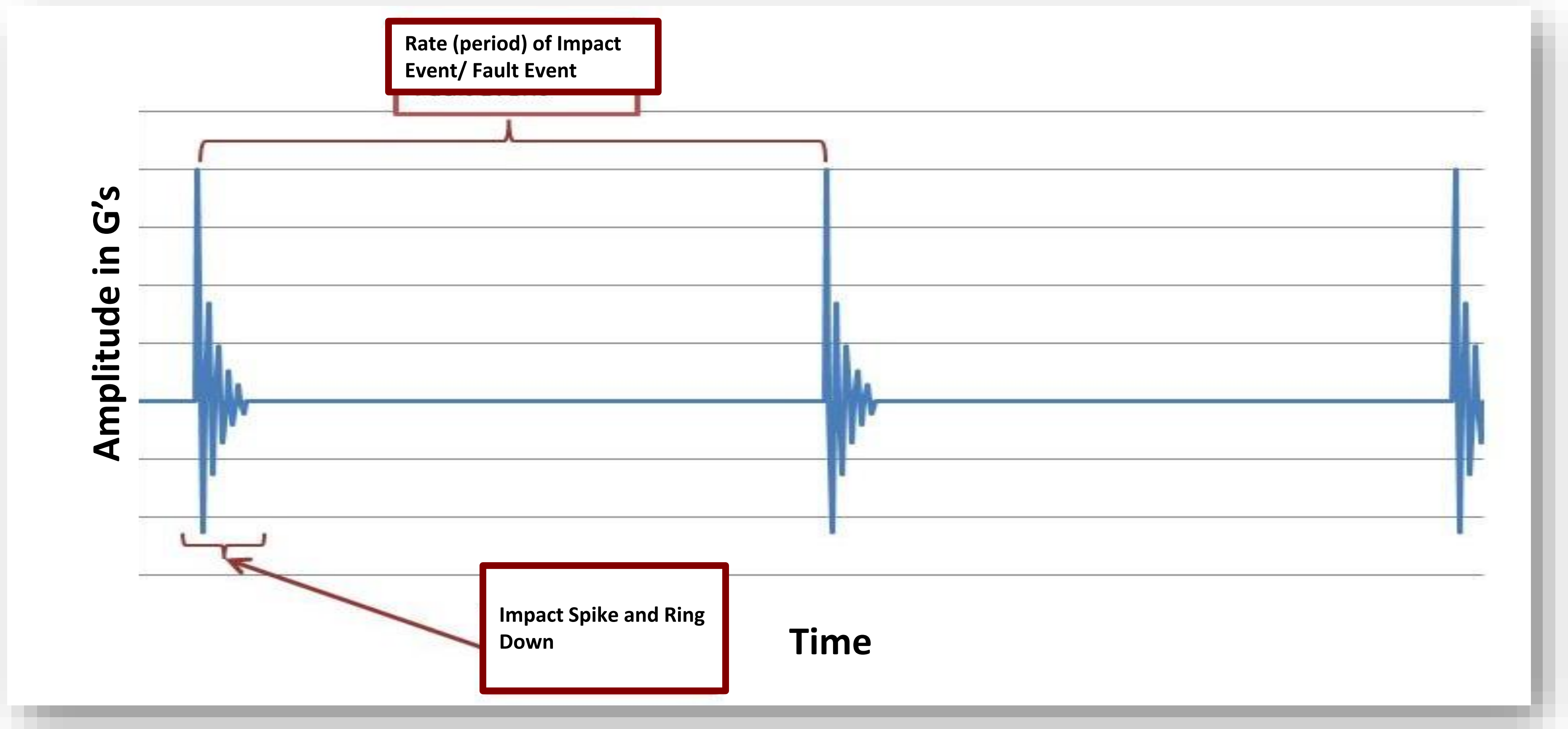
Actual Single Impact Event Example



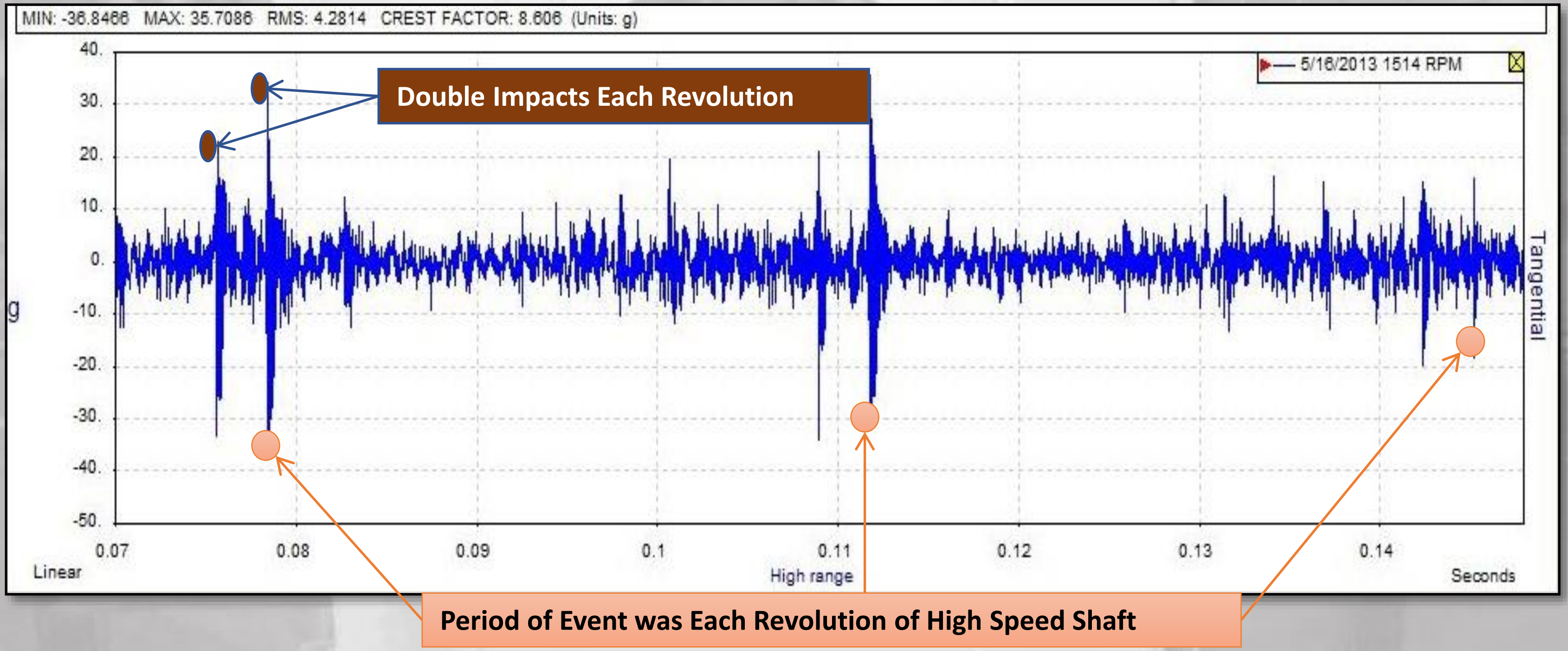
Note: Entire Event Period Must Meet Nyquist Criteria Or It Will Be Eliminated By Anti-Aliasing

Periodic Impact Spikes

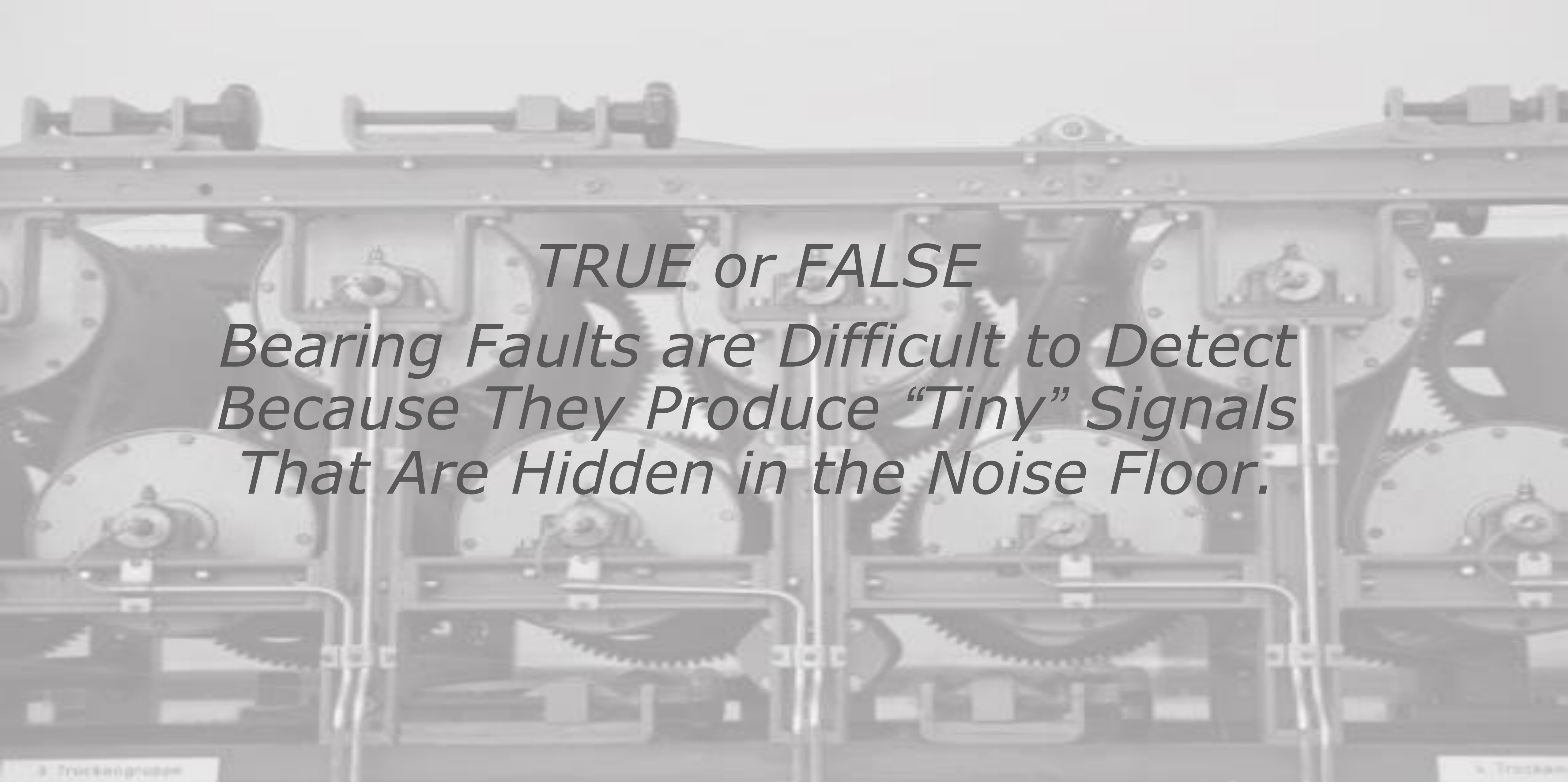
Impact Illustration in Time Waveform



Example: Periodic Impact Events



Reliability



TRUE or FALSE

Bearing Faults are Difficult to Detect Because They Produce "Tiny" Signals That Are Hidden in the Noise Floor.

TRUE or FALSE

Bearing Faults are Difficult to Detect Because They Produce “Tiny” Signals That Are Hidden in the Noise Floor.

FALSE!

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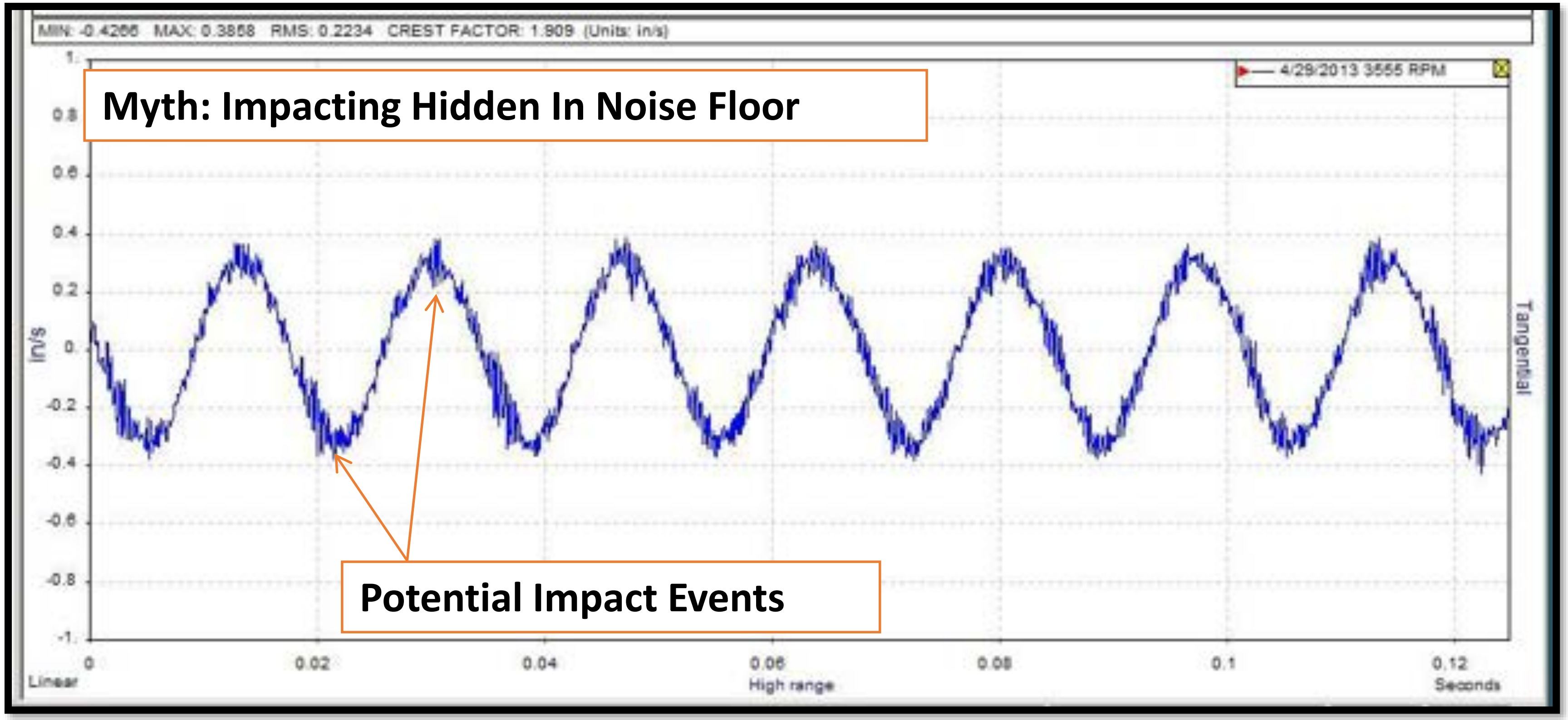
Impacting Amplitude Example - Low Impacting

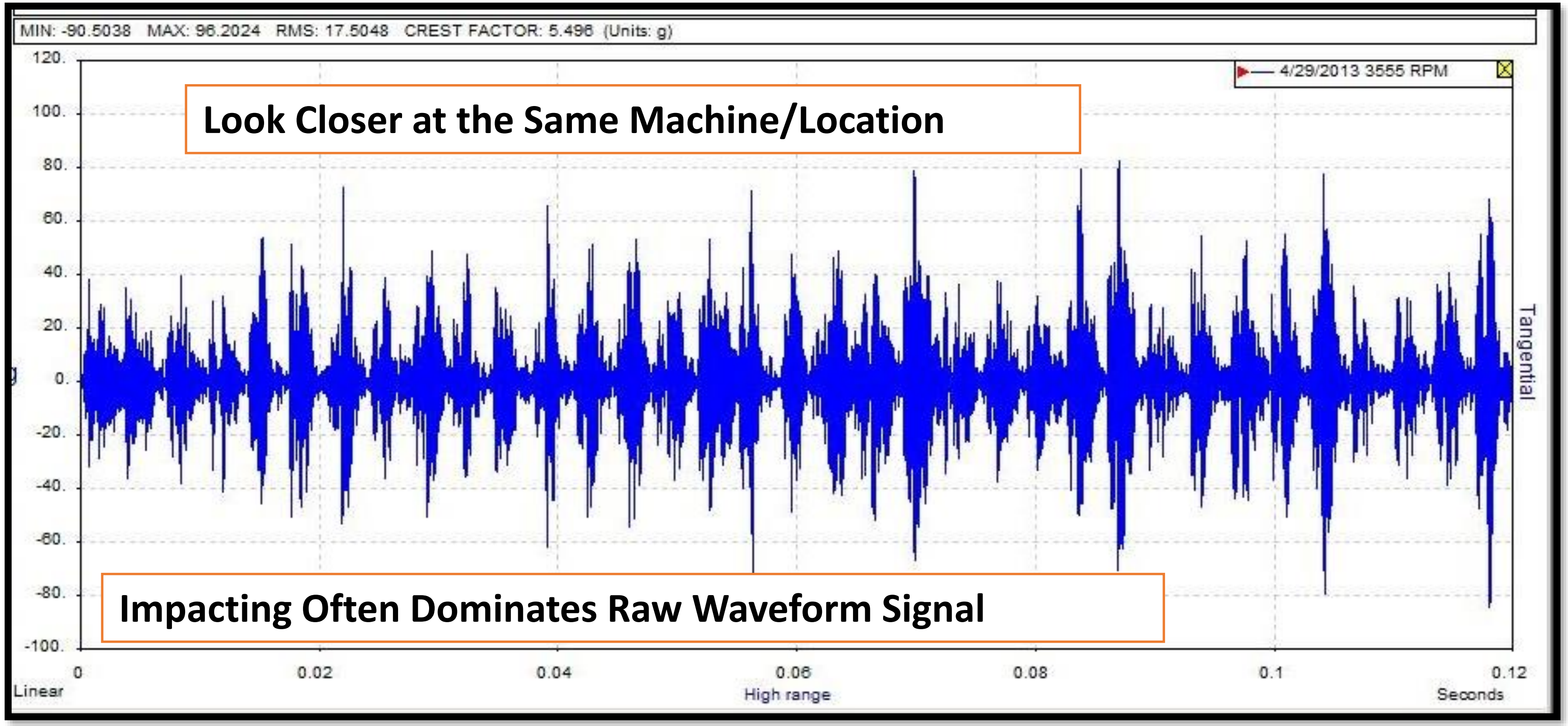
- Fmax at 6000Hz (Integrated)



Same Signal Reality!

Impacting Amplitude >180 g

- Fmax at 16,000Hz (non-integrated)



So, Why is it Difficult to Detect?

- Requires Very High Sampling Rate
  - Minimum Bandwidth (Fmax) of 10,000 Hz (~26,000 Samples/Sec)
  - SIAI Trio and Online - Fmax used is 40,000 Hz
- Requires Long Sampling Times
  - Provides Adequate Low Frequency Resolution
  - SIAI devices have a capacity to process 500k to 14M samples
- Best Practice - Capture 15 Shaft Revolutions

Results In Extremely Large Data Set

Sample Size Example

Example

Typical:

- Fmax:
  - 300Hz / 1600 Lines
- Results
  - 4096 Samples
  - 33.4 CPM Separating Frequency

High Sample Rate Equivalent

Typical:

- Fmax:
  - 40,000Hz / 215,000 Lines
- Results
  - 550,000 Samples
  - 33.4 CPM Separating Frequency

Slow Speed Example

Example

Typical:

- Fmax:
  - 30Hz / 3200 Lines
- Results
  - 8192 Samples
  - 1.7 CPM Separating Frequency

Note: 15Rev of 8.5RPM – 107 Sec

High Sample Rate Equivalent

Typical:

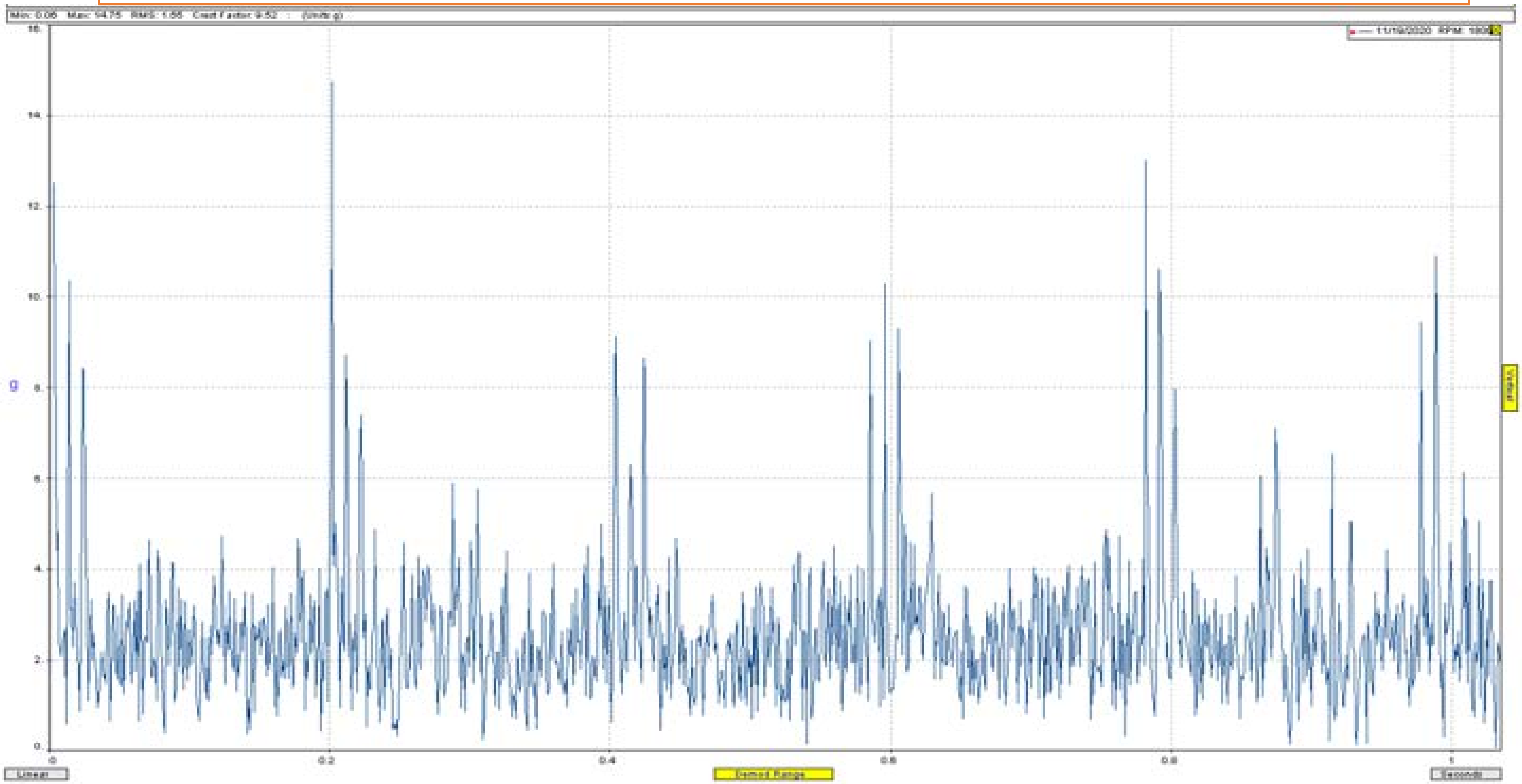
- Fmax:
  - 40,000Hz / 4,250,000 Lines
- Results
  - 10,880,000 Samples
  - 1.7 CPM Separating Frequency

Demodulation => Data Compression

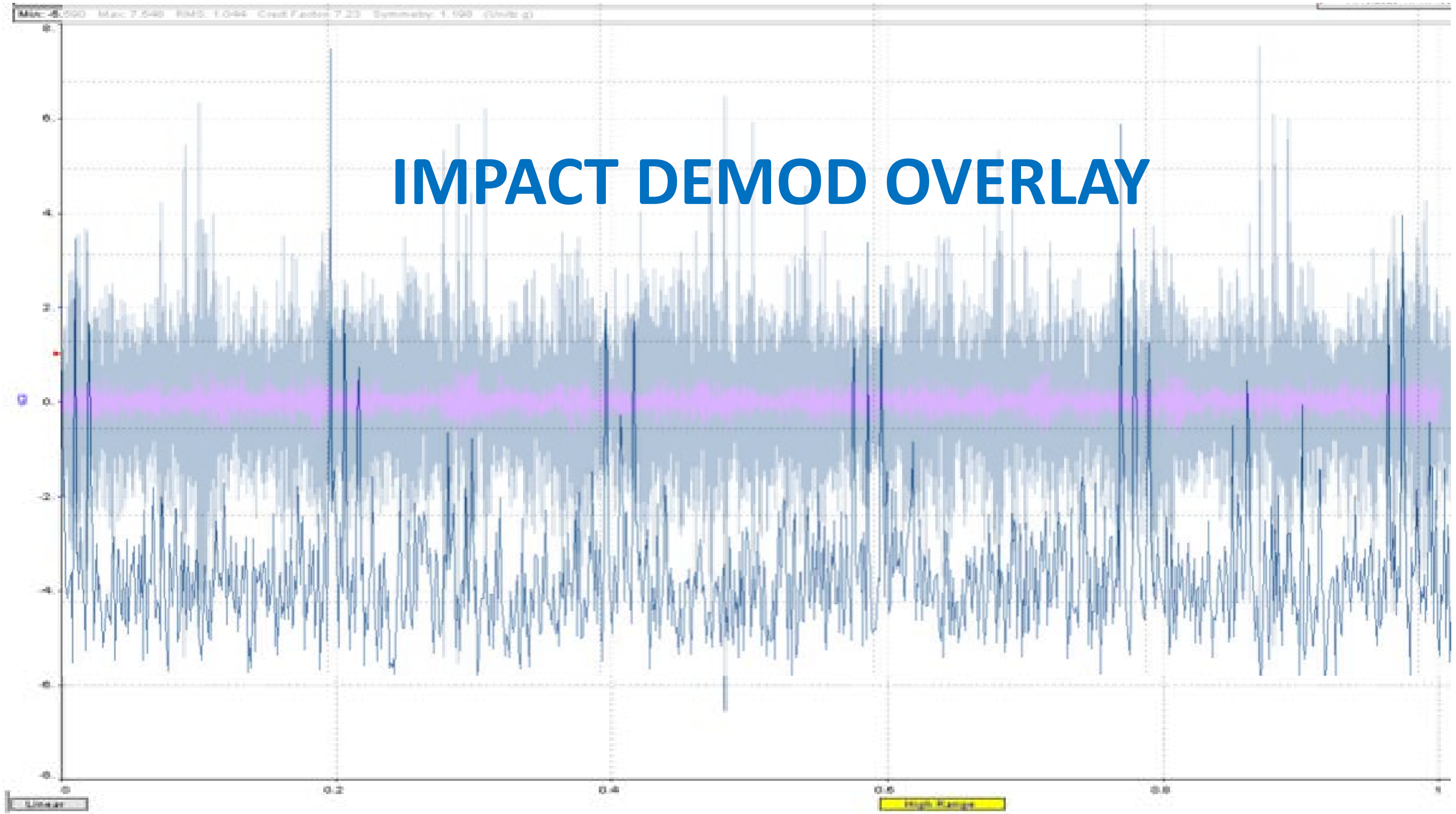
Example

Impact Demod Detected: 14.7g

Compressor Bearing Inner Race Frequency Modulated by Cage Rate



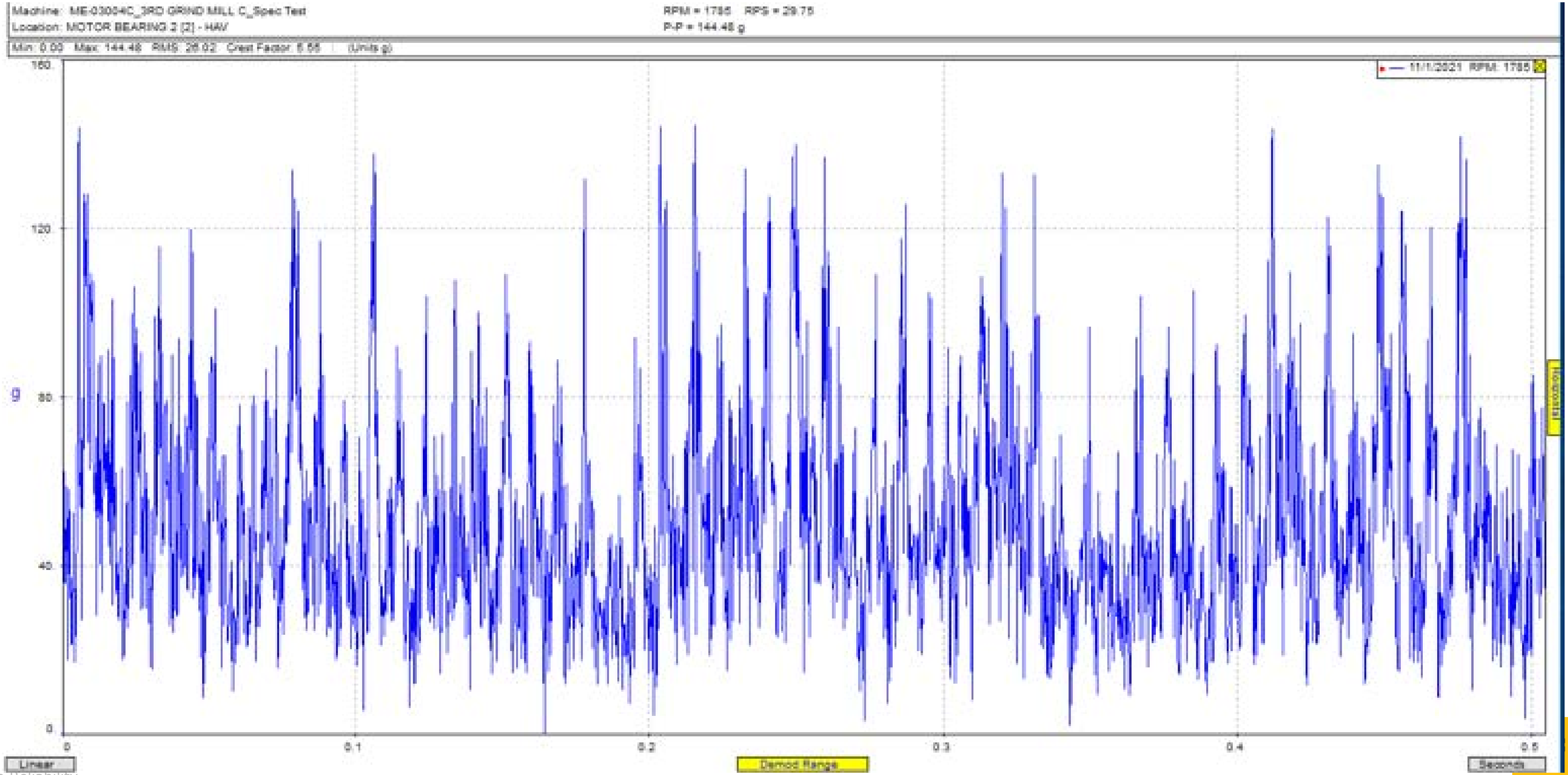
IMPACT DEMOD OVERLAY

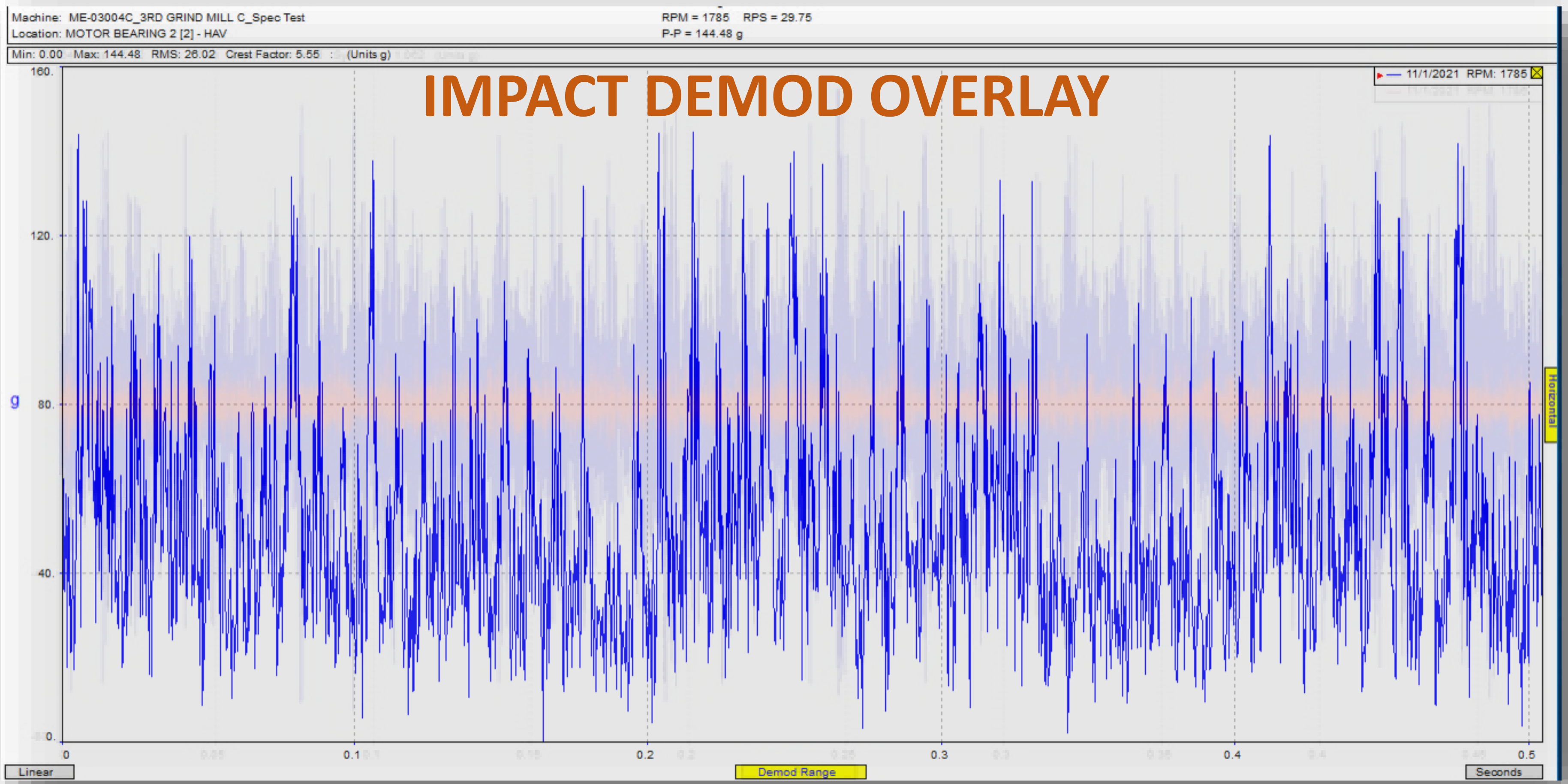


Compare Samples	Standard	High Freq / High Resolution	Impact Demod
Fmax	3000 Hz	25,000 Hz	**40,000 Hz**
Max Amplitude	1.8 g	14.1 g	**14.7 g**
# of Samples	4096	25,600	**4096**

Example (New)

Impact Demod Detected: 144.5g
Motor Bearing Fault

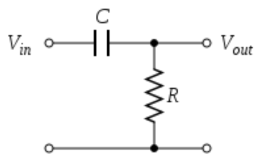




Compare Samples	Standard	High Freq / High Resolution	Impact Demod
Fmax	3000 Hz	40,000 Hz	**40,000 Hz**
Max Amplitude	29.3 g	147.8 g	**144.5 g**
# of Samples	4096	25,600	**4096**

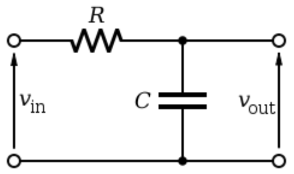
Review of Legacy Demodulation

1. Signal High Pass Filtered

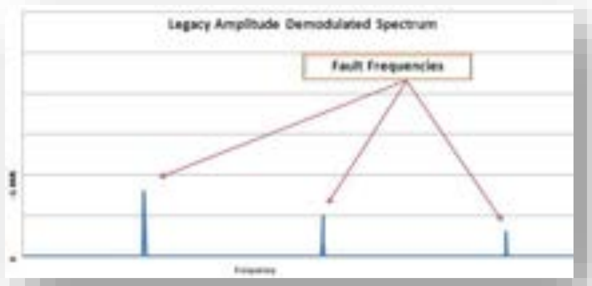


2. Rectify - Force All Peaks to be Positive

3. Signal Low Pass Filtered (Enveloped)
   - Signal Must Meet Nyquist Criterion



4. Digitize Signal
5. Perform FFT – Generate Spectrum



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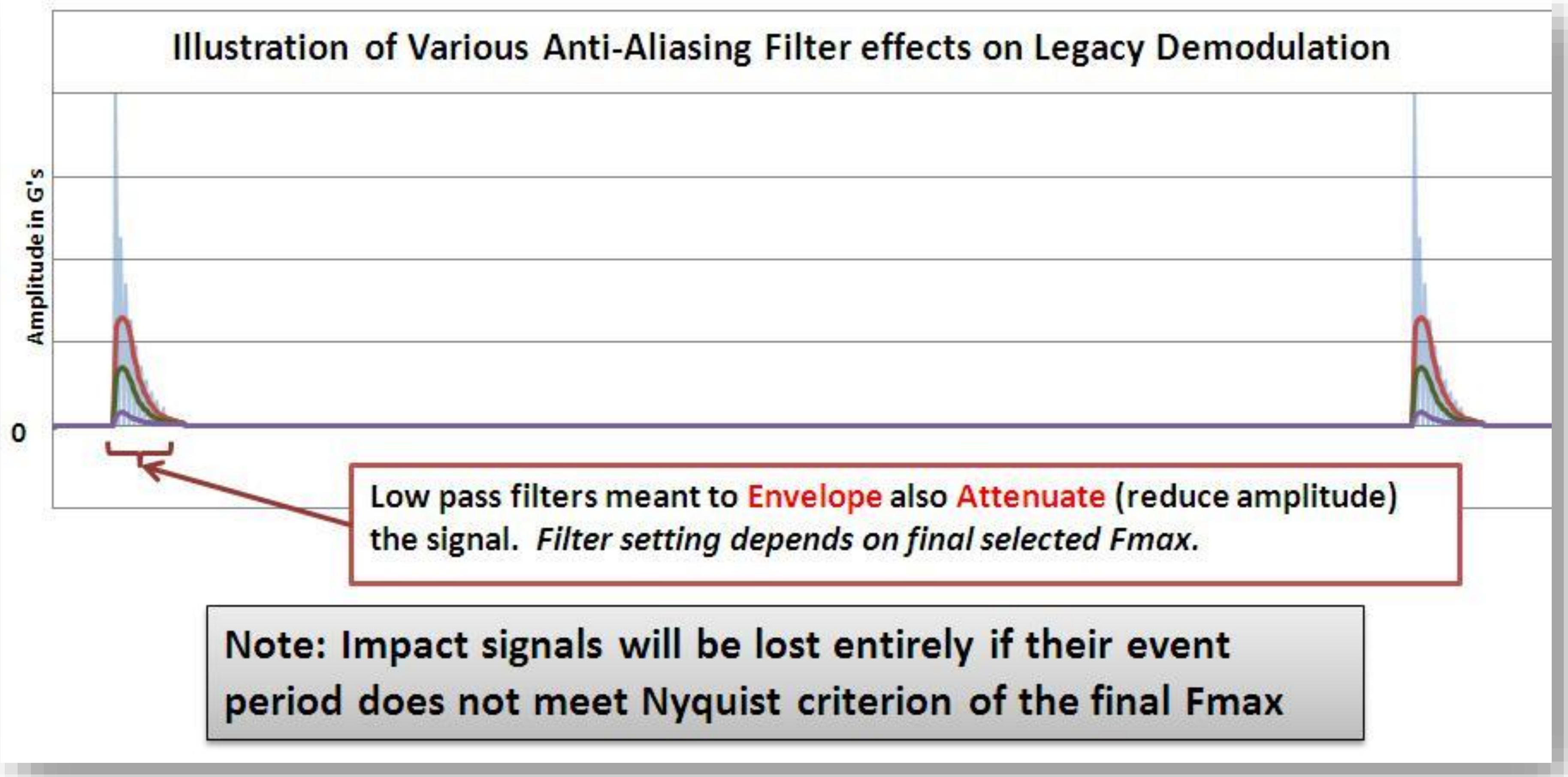
Required Low Pass Filter must meet Nyquist Criterion



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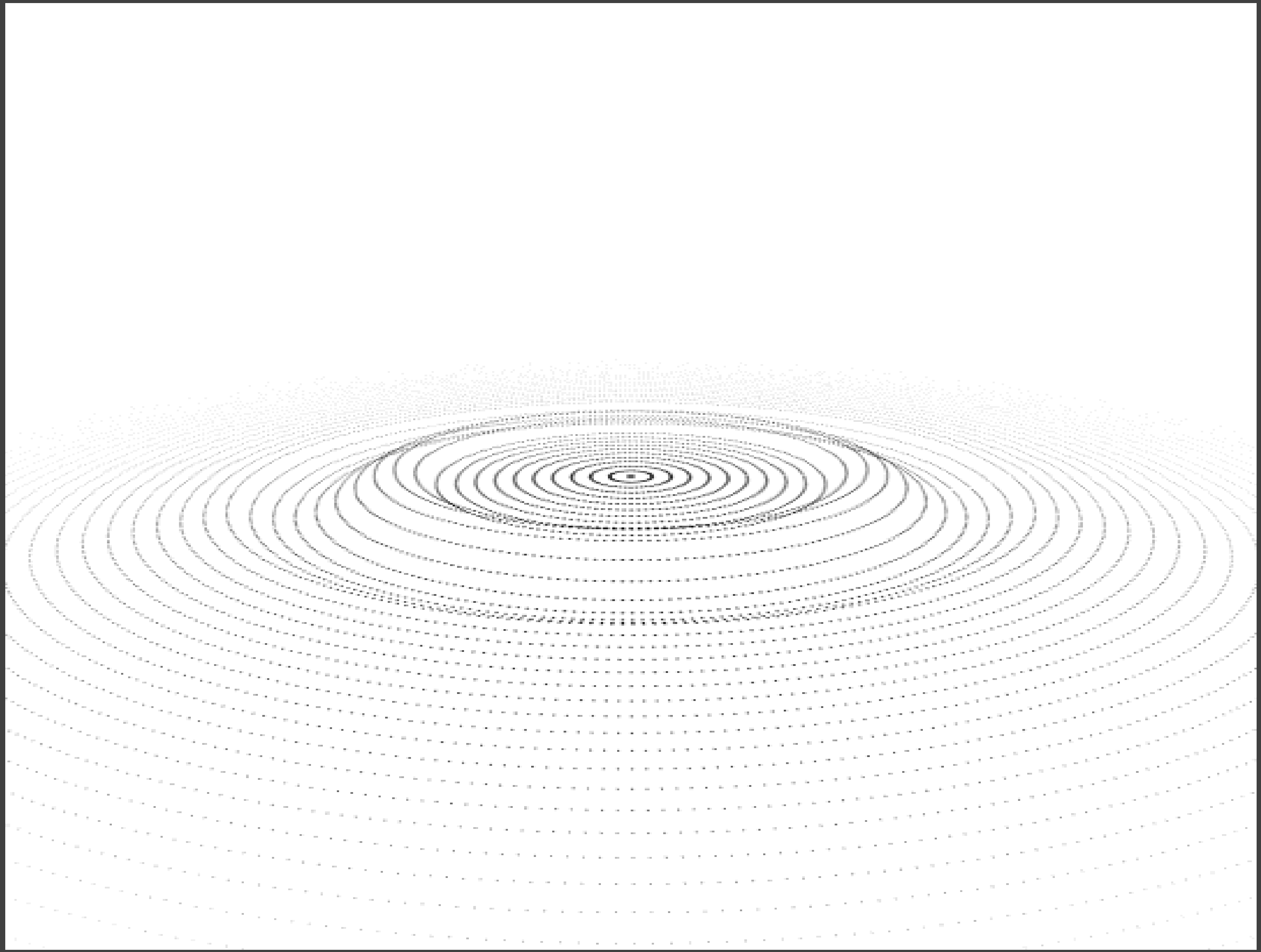
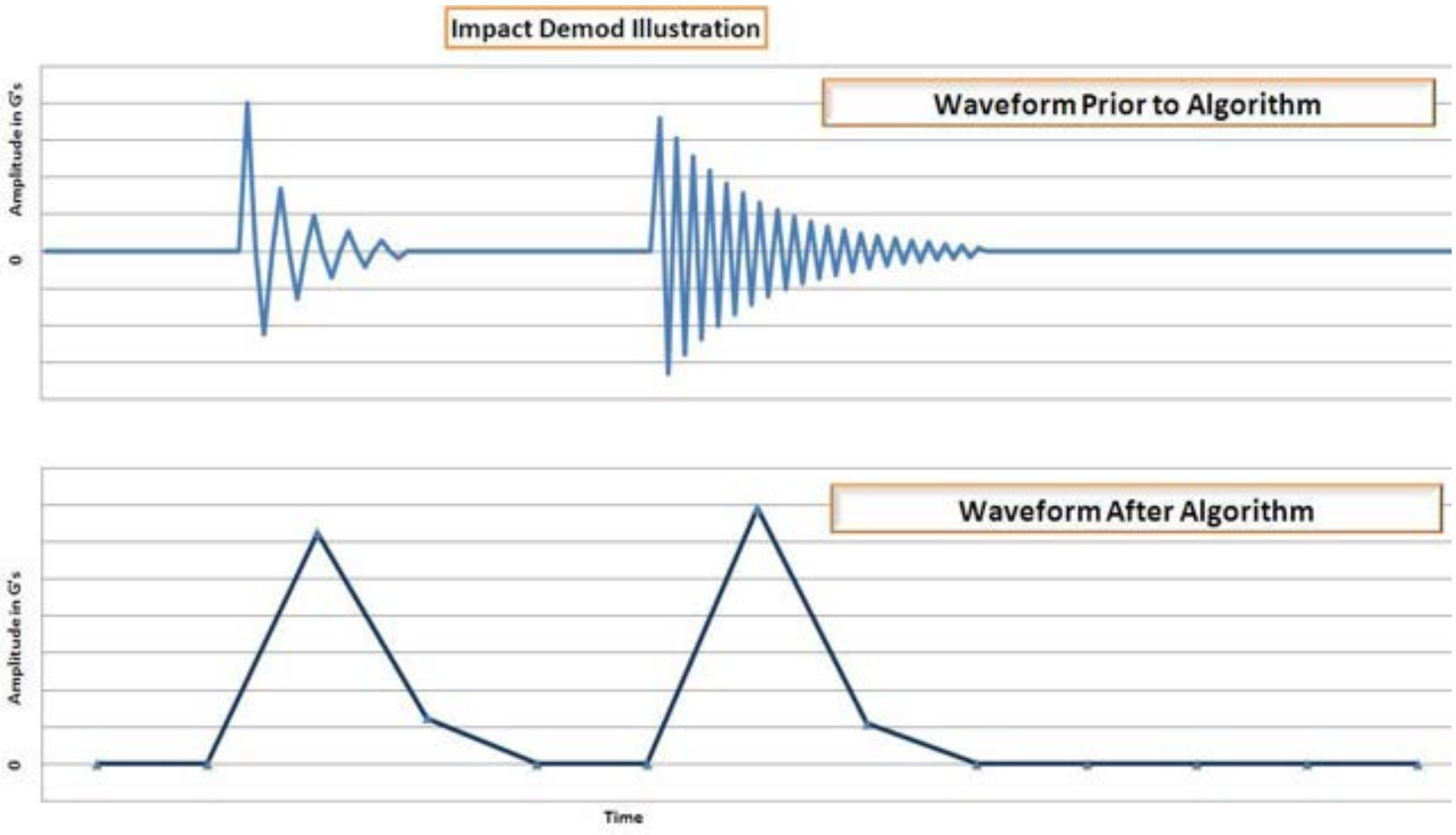
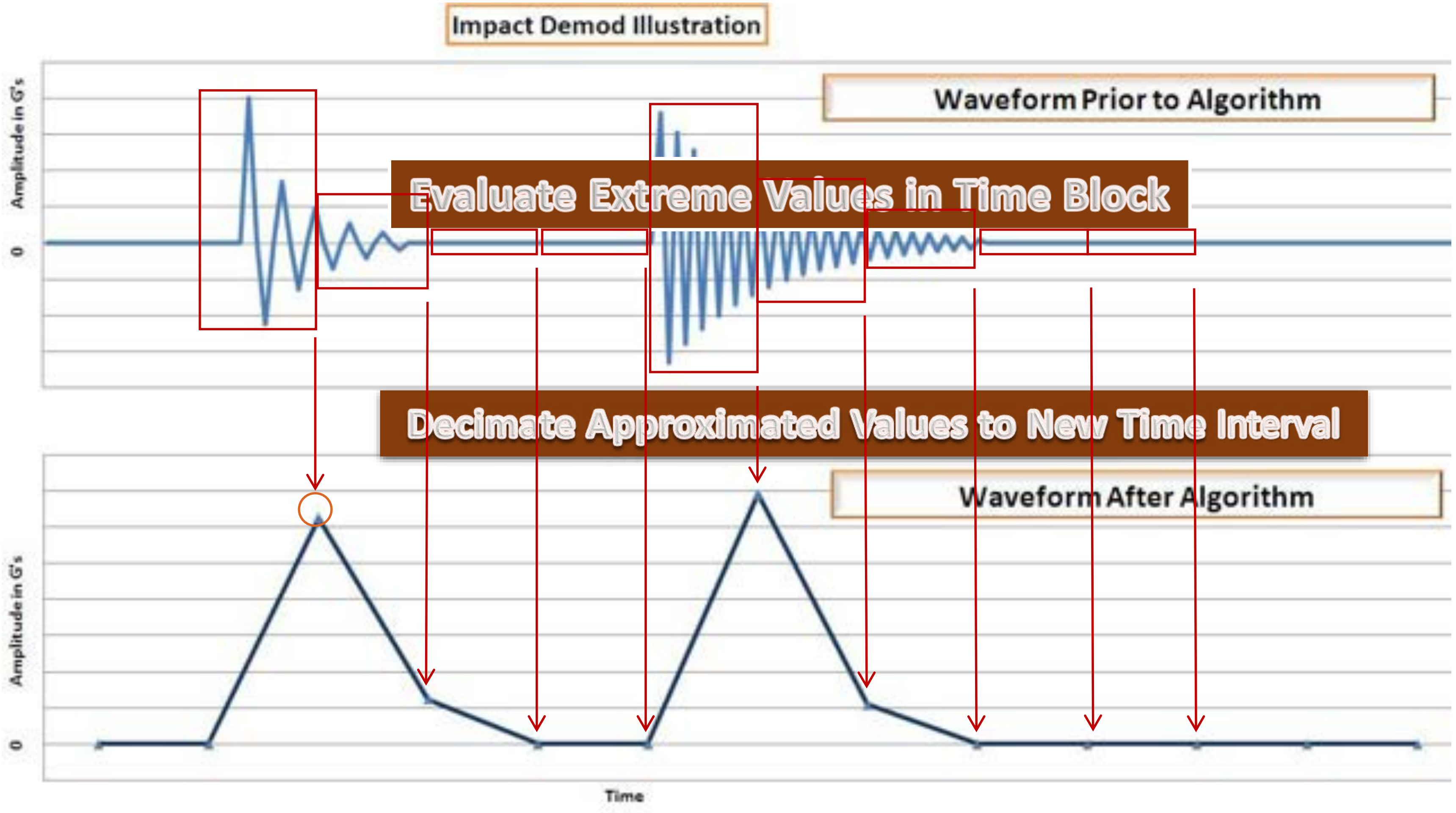
AzimaDLI Impact Detection Methodology



Impact Demod



Impact Demod Animation



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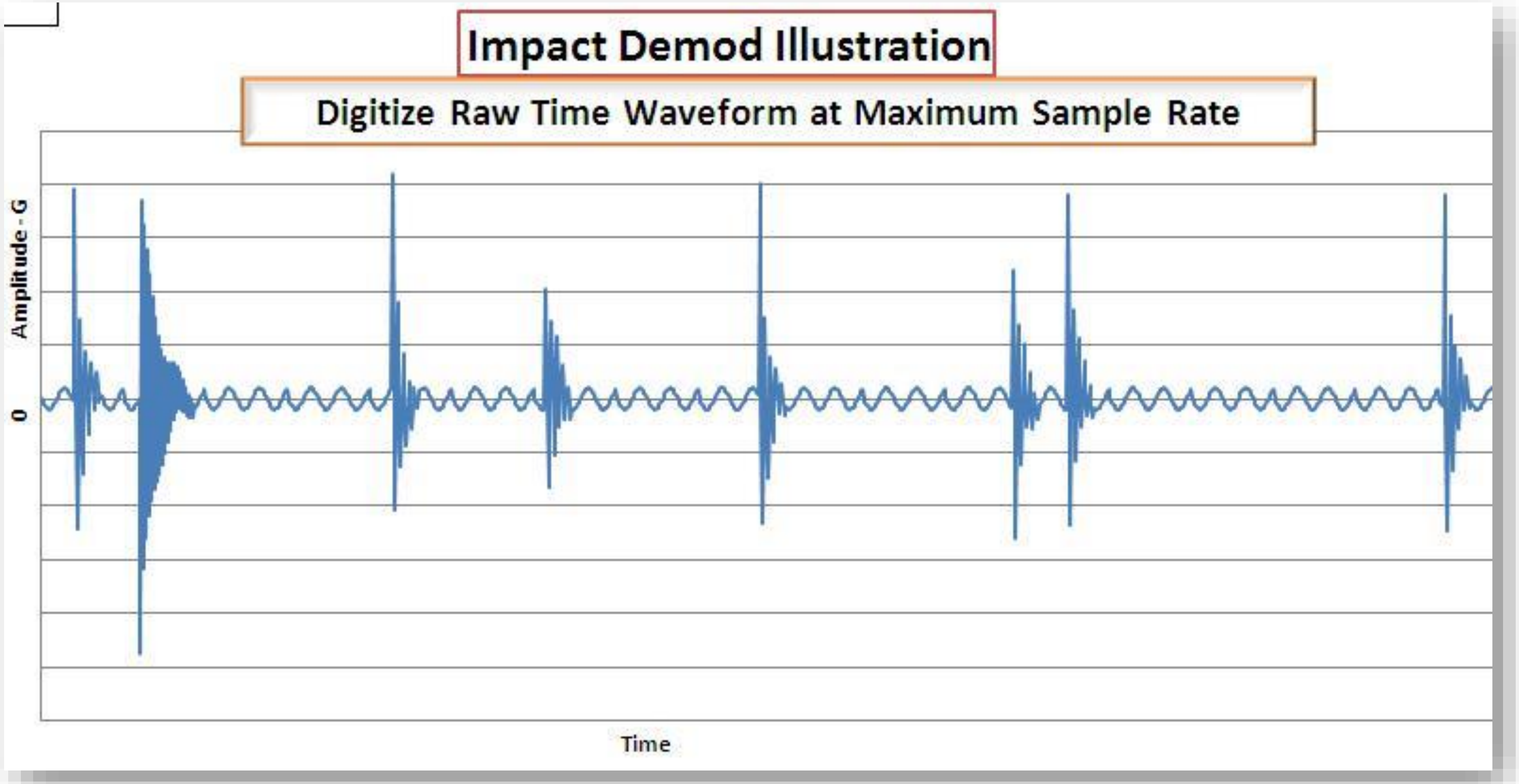
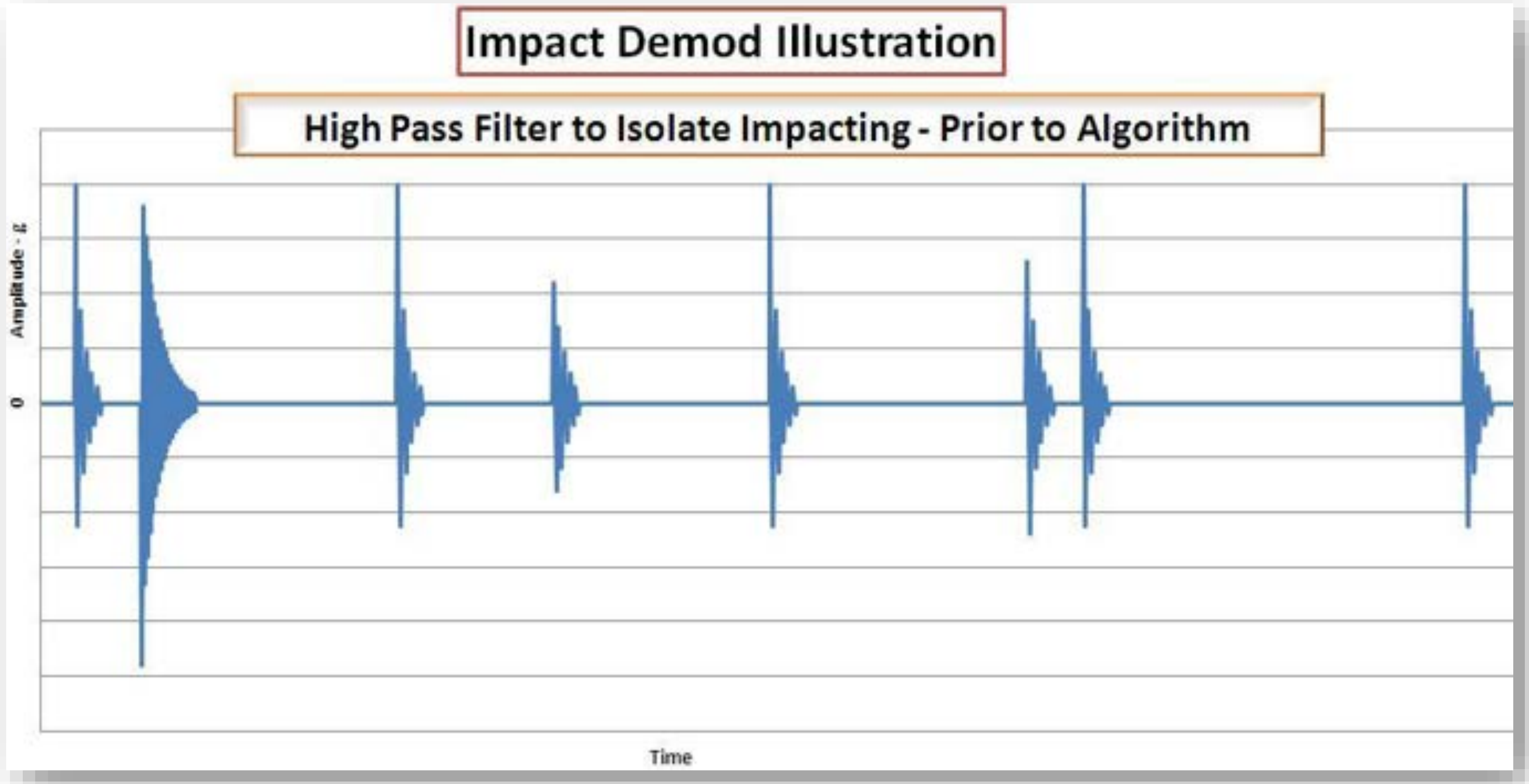
Impact Demod - Step 1

Digitize HF Acceleration Data



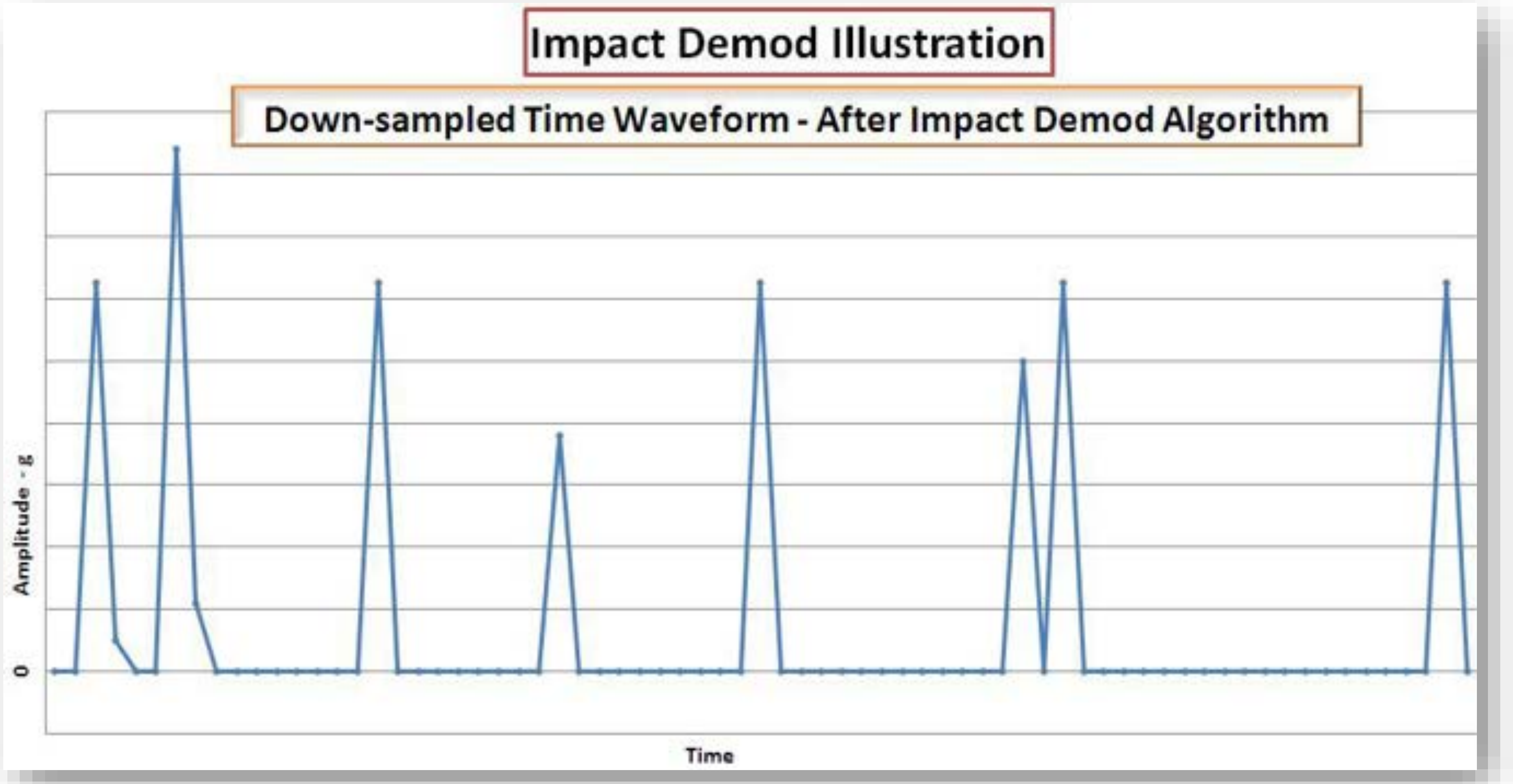
Impact Demod - Step 2

High Pass Filtering



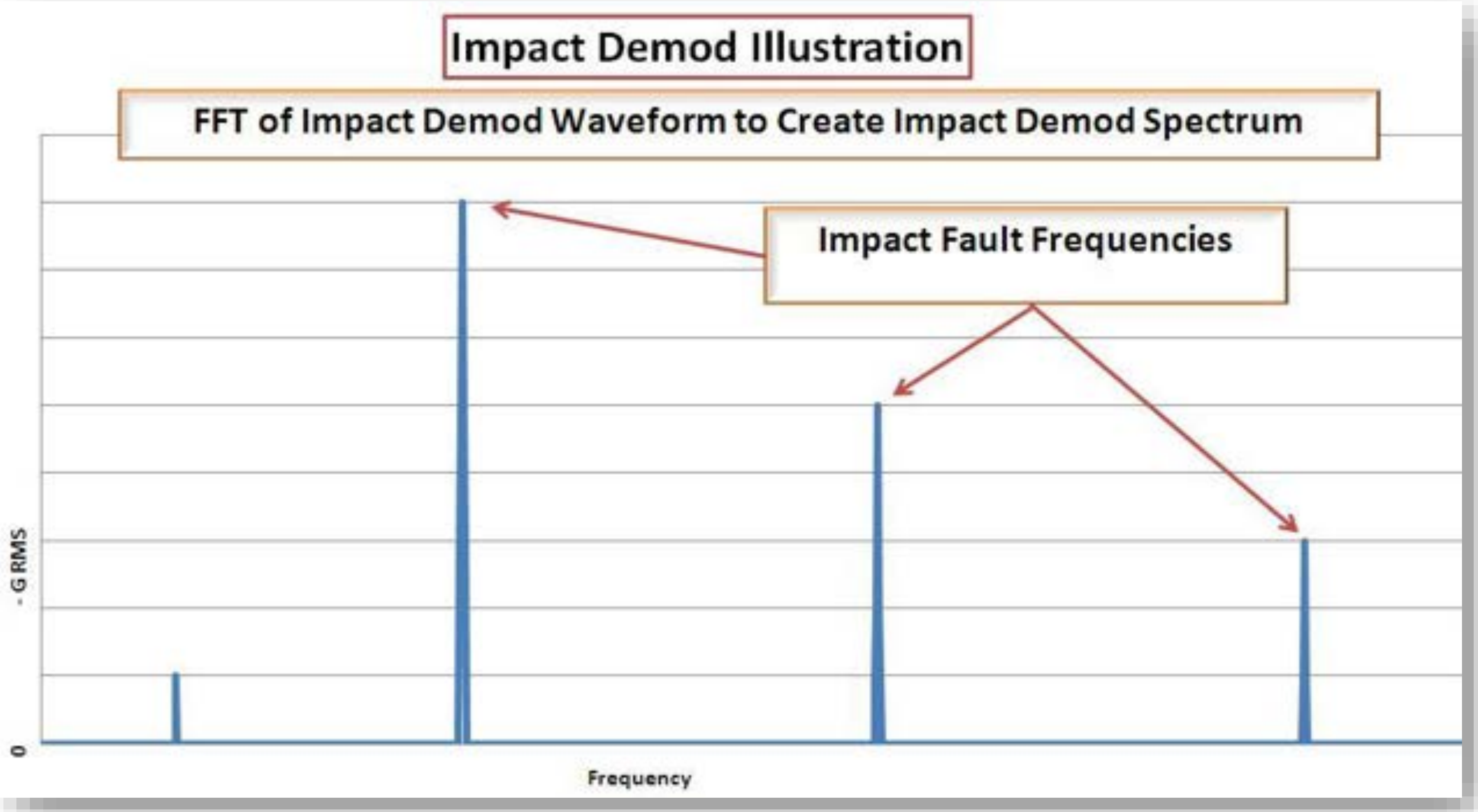
Impact Demod - Step 3

Run Impact Demod Algorithm



Impact Demod - Step 4

FFT Process – Generate Impact Demod Spectrum



Impact Demod

- Advantages
  - No Low-pass Filter Attenuation
  - Retains Maximum Waveform Amplitude Regardless Of Final Chosen Fmax
  - Simplified Filter Selection
  - Does Not Rely On Knowing Sensor Resonance Peak

Impact Demod

Setup Tips

- Use Units Of Acceleration
- Capture A Minimum Of 15 Shaft Revolutions

  (6 Revolutions of Bearing Cage)

$$\text{Number of Revolutions in Waveform} = \frac{\#\ \boldsymbol{FFT\ Lines}}{\#\ \boldsymbol{Orders}\ (\boldsymbol{Fmax})}$$

- Only One Sample (No Averaging) Is Recommended
- Use Lowest Filter That Does Not Overlap Desired Fmax
- Use In-line Axis (if Triax)

Impact Demod

Analysis Tips

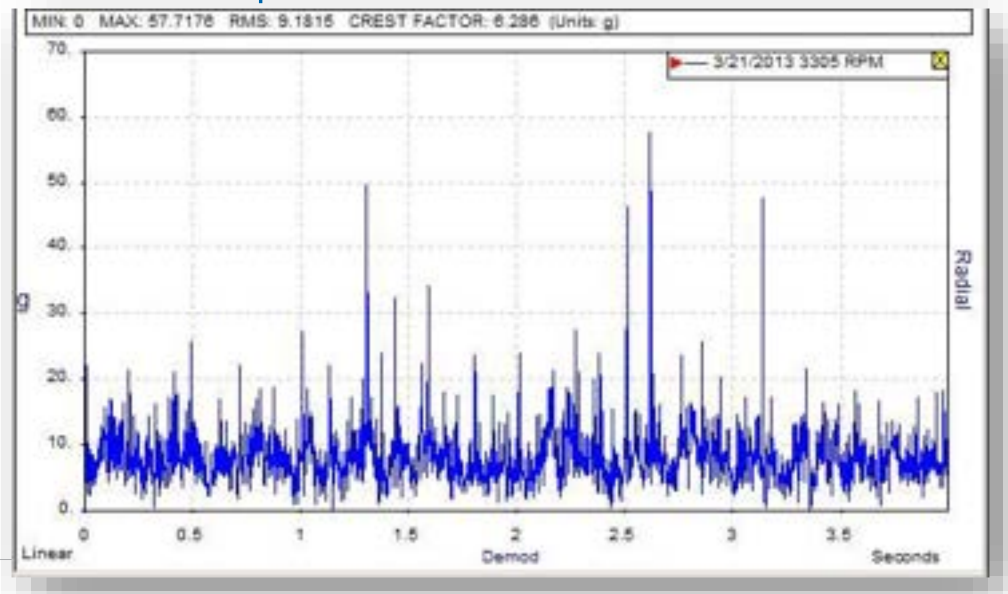
- Review The Time Waveform First
- Maximum Peak Value Determines Severity
- Compare To Other Like Machines (Statistical Average)
- Determine If Waveform Content Appears Random Or Periodic (Repetitive Pattern)
- Identify Any Harmonic Sets In Spectrum

Impact Demod

Analysis Tips (continued)

- Random impacting indicates
  - Metal to metal friction
  - Pump cavitation

Impact Demod Time Waveform

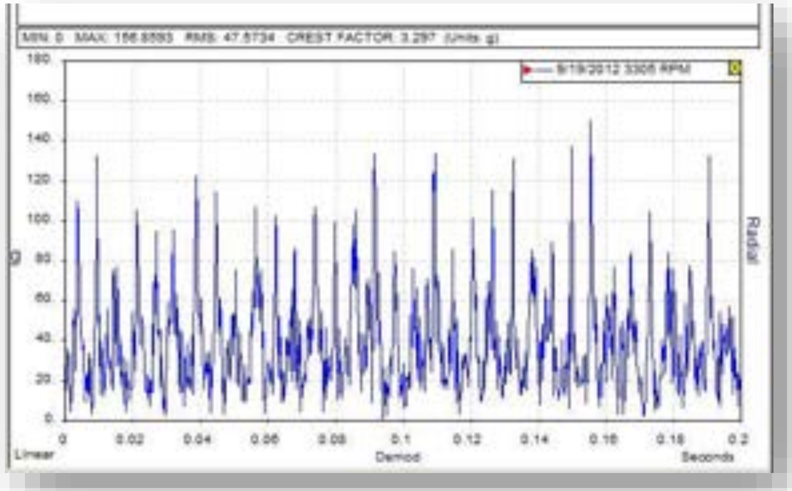


Impact Demod

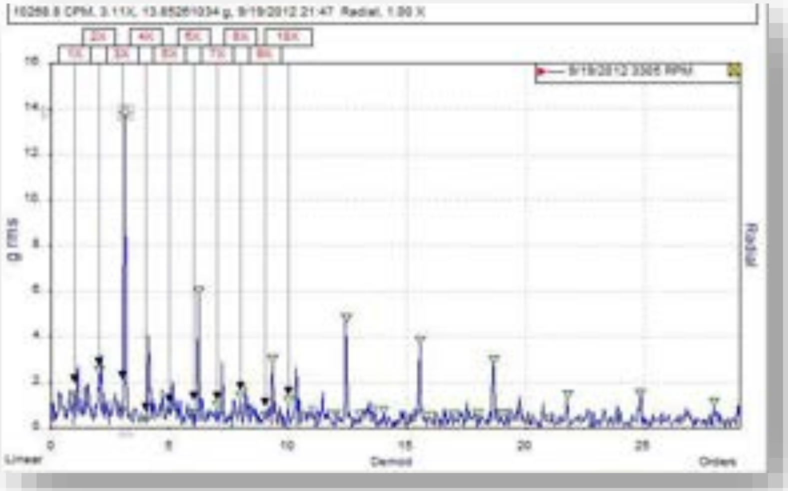
- *Analysis Tips (continued)*

- Periodic Impacting
  - Impact rate indicates faulty component
  - Review spectrum to determine fault frequency

Impact Demod Time Waveform



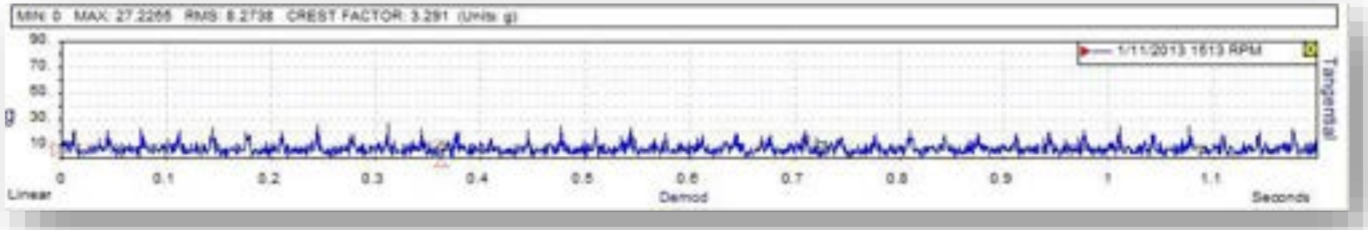
Impact Demod Spectrum

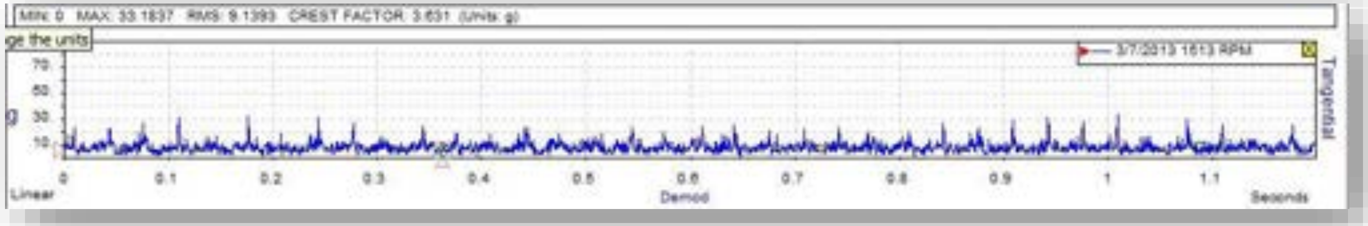


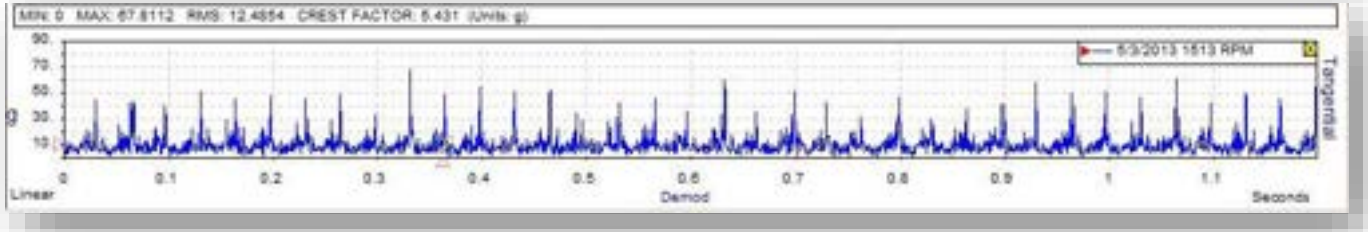
Impact Demod: *Gearbox Example*

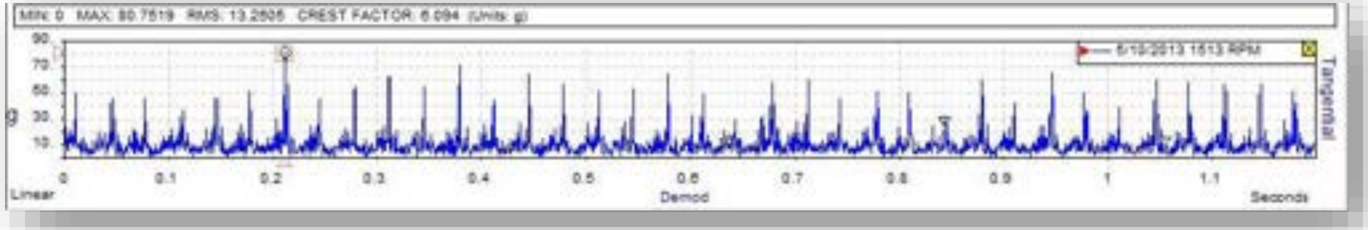
Gearbox- HS Shaft Free End

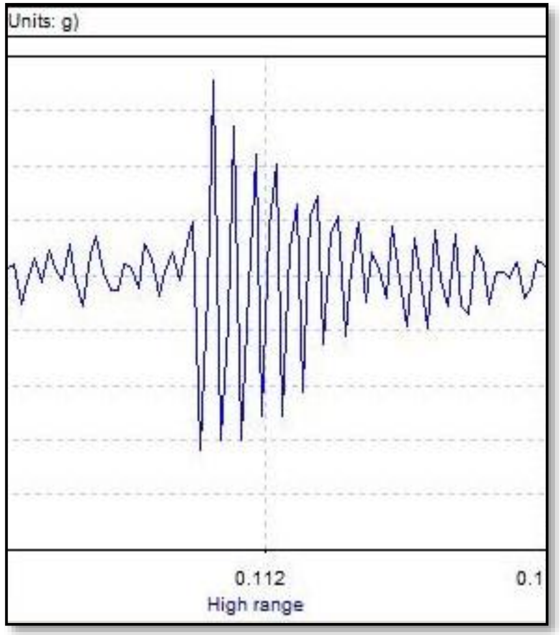
Progression of Impact Levels











May – 67g

Jun – 80g

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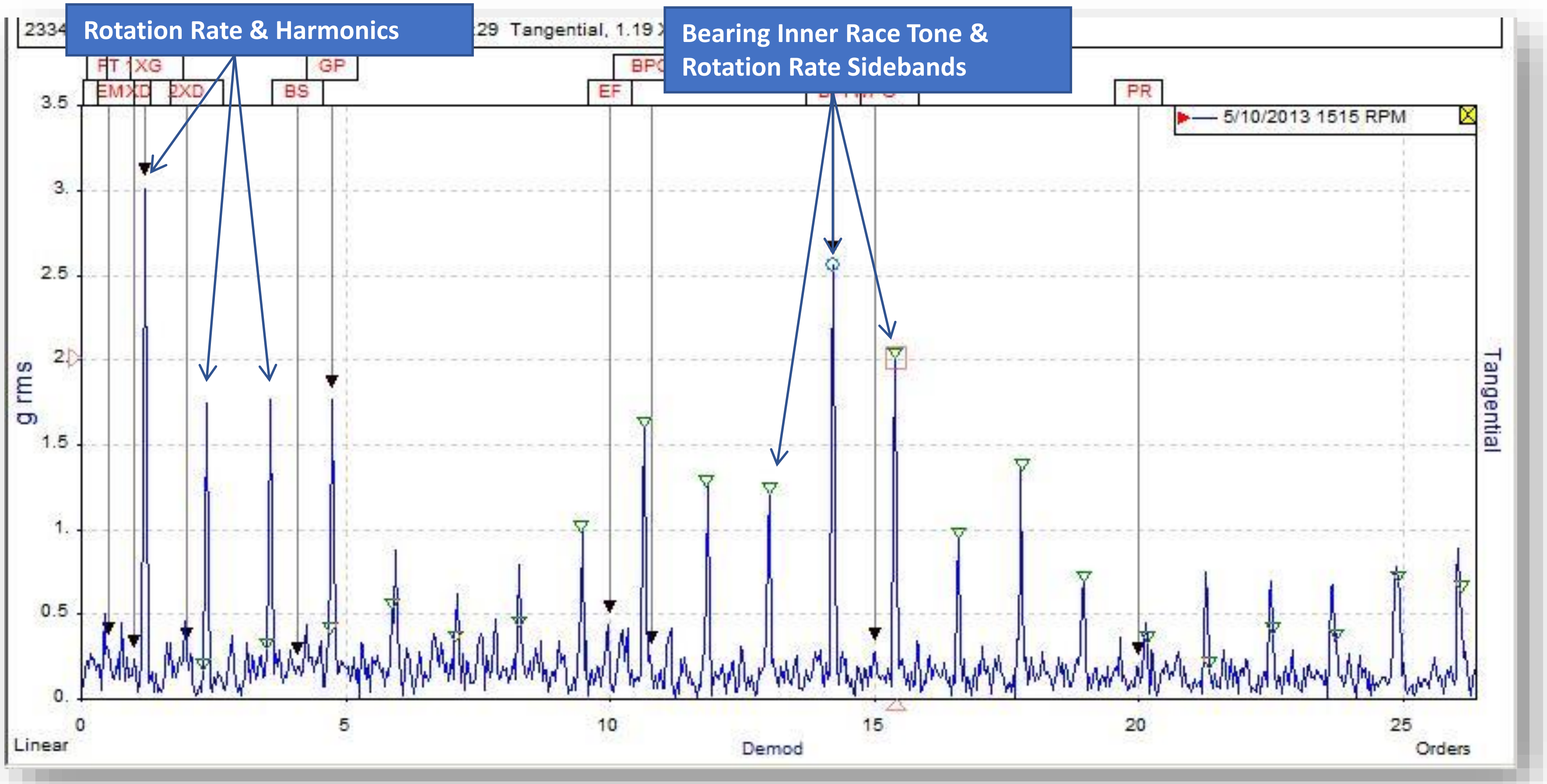
Gearbox- HS Shaft Free End

Impact Demod Spectrum



Indication of Inner Race Bearing Fault

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Gearbox- HS Shaft Free End
As Found
Inner Race
Spalling

Slow Speed Machines

Machines / Shafts below 60 RPM:

- Accelerometer signal/noise poor
- Diagnostic repeatability poor
- Reduced ROI consideration

Slow Speed Fault Detection Factors

Time

- Very Long Data Capture Times
- Highly Susceptible to Speed Variation

Sensor

- Accelerometer - Very Low Sensor Output
- Requires Large Seismic Mass
- Requires Long Settling time.
- No Analog Integration

Impact

- Legacy Demodulation Not Affective At Low Speed
- Use Impact Detection Method
- Impact Detection Is Sometimes Only Indicator

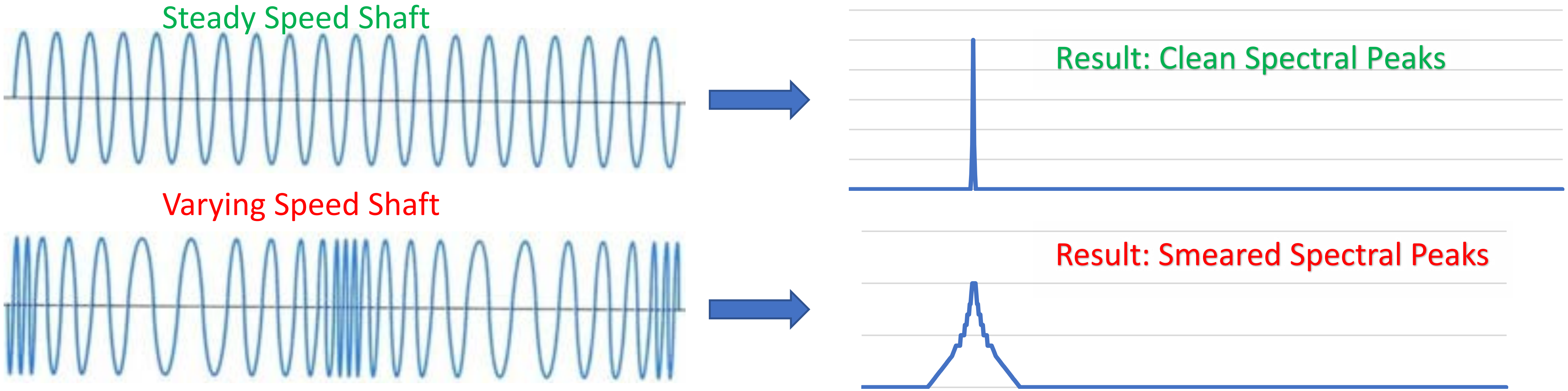
Time

- Slow Speed Machines Require Long Time Data Capture.
  - Requires More Planning
  - More Difficult To Maintain Conditions

	Typical Motor Shaft	Typical Slow Speed Shaft
Shaft Speed	1800 RPM	60 RPM
Desired Orders	10	10
Fmax	300 Hz	10 Hz
Total Sample Time (4 Avg/50% Overlap)	13.3 Sec	400 Sec

Time

- Long Capture times vulnerable to speed changes.
  - Speed Change During Sample Will “SMEAR” FFT



- Order Tracking Feature –
  - **Synchronize Sampling Rate To Pulsed Input.**
  - Requires Tachometer

Accelerometer Selection

- **Sensor Technology is - Piezo Electric Industrial Accelerometer.**
- **Direct Acceleration Measure (Not A Derivative)**
- **High Dynamic Range and Frequency Range**
- **Low Frequencies => Very Little Voltage Change**

	100 Hz (6,000 CPM)	10 Hz (600 CPM)	1 Hz (60 CPM)	0.1 Hz (6 CPM)
Displacement (mils) p-p	0.32	3.2	32	320
Velocity (IPS) p	0.1	0.1	0.1	0.1
Acceleration (g) RMS	0.115	0.0115	0.00115	0.000115
Volts (100 mV/g Accel) RMS	0.0115v	0.00115v	0.000115v	0.0000115

- 12 Bit Analyzers resolve signals to 4096 voltage steps. ~4mV
- 16 Bit Analyzers resolve signals to 65,536 voltage steps. ~0.3mV
- 24 Bit Analyzers can resolve signals to 16,777,216 voltage steps ~0.0000012mV

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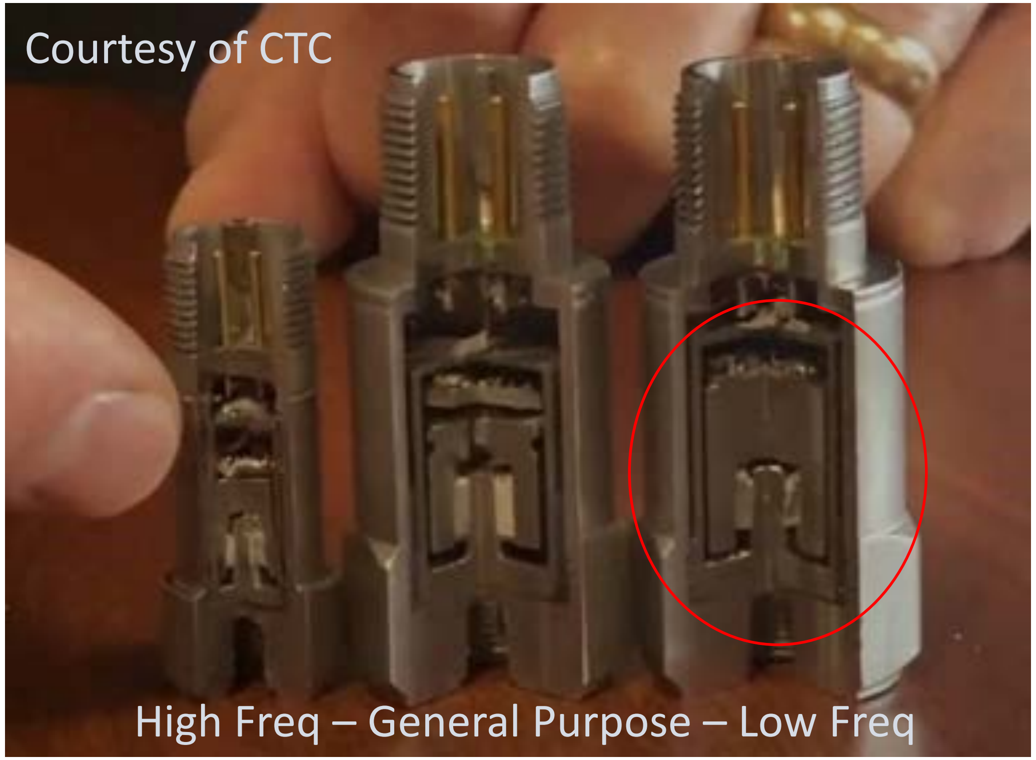
Accelerometer Selection

- Lowest Measurable Signal - Two Factors:
  - Electrical Noise of the Internal Amplifier
  - Mechanical Gain Of The Mass/Piezoelectric System.
- The Larger The Seismic Mass, The Larger The Output Of The Piezo Electric Crystal (Prior To Amplification).
- Don’t confuse Sensor Amplification with Low Frequency Capability.
- 500mv/g sensor Generally Unnecessary with 24 Bit Analyzers
- Be cautious when using 500mv/g sensors.
  - Swamp Easily Creating Non-function
  - Avoid Use In Gearboxes

ALL 3 - 100mv/g Sensor Designs



F=MA Principal Applies

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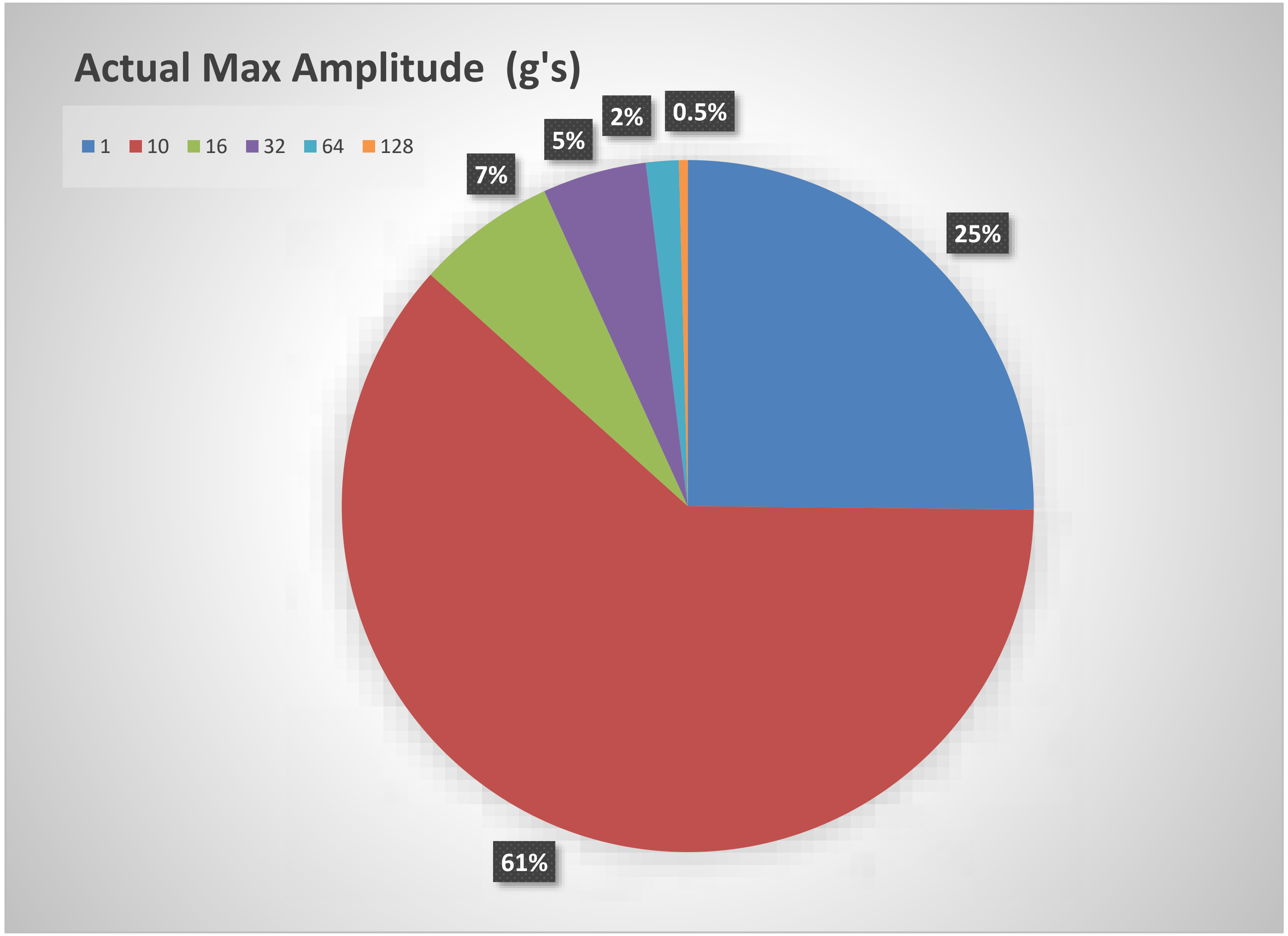
Accelerometer Real World Amplitude Distribution

- **4 Months Data**
- **50,000 Machine Tests**
- **High Sample Rate**
- **~ 10% exceed Range of 500mv/g**
- **130 Tests exceeded 100g**
- **1 Test exceeded 200 g.**



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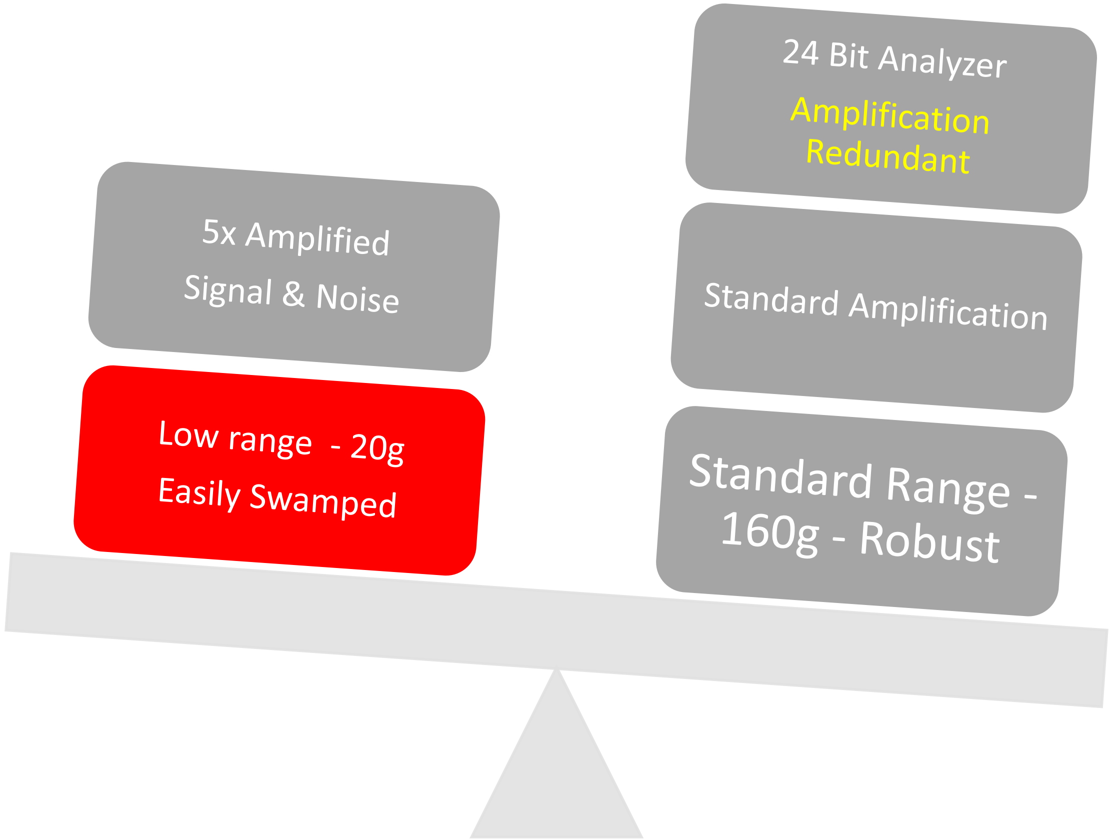
500mV vs 100mV

High Mass 500mV/g	High Mass 100mv/g



Accelerometer Selection

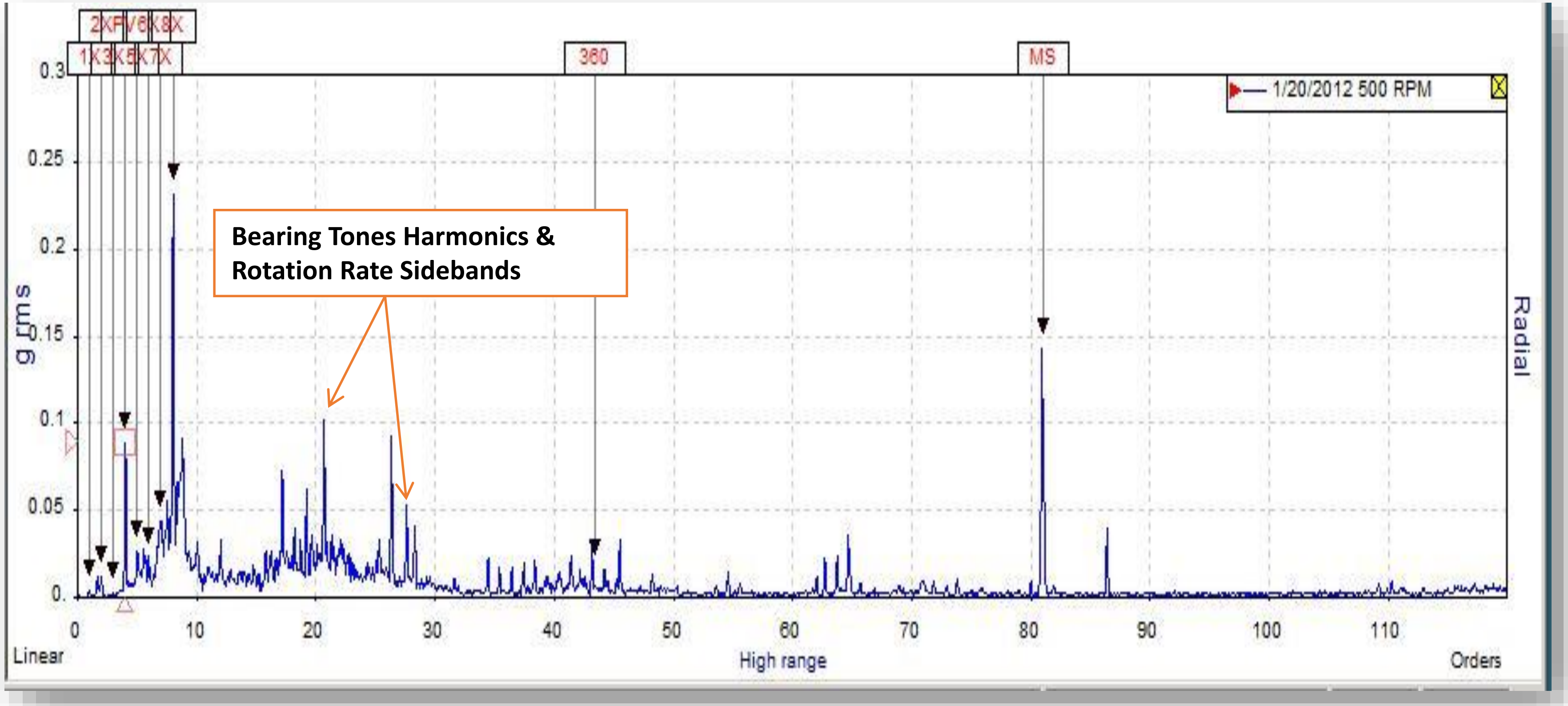
SETTLING TIME

- **R/C Time Constant (TC) Governs Response Time At Low Frequency**
- **High TC = Better Low Frequency Response**
  - **Tradeoff: High TC = Higher Settling Time**
- **Compromise Between Low Frequency Response And Settling Time**

Impact Demod: *Example*

2000 HP Vertical Motor

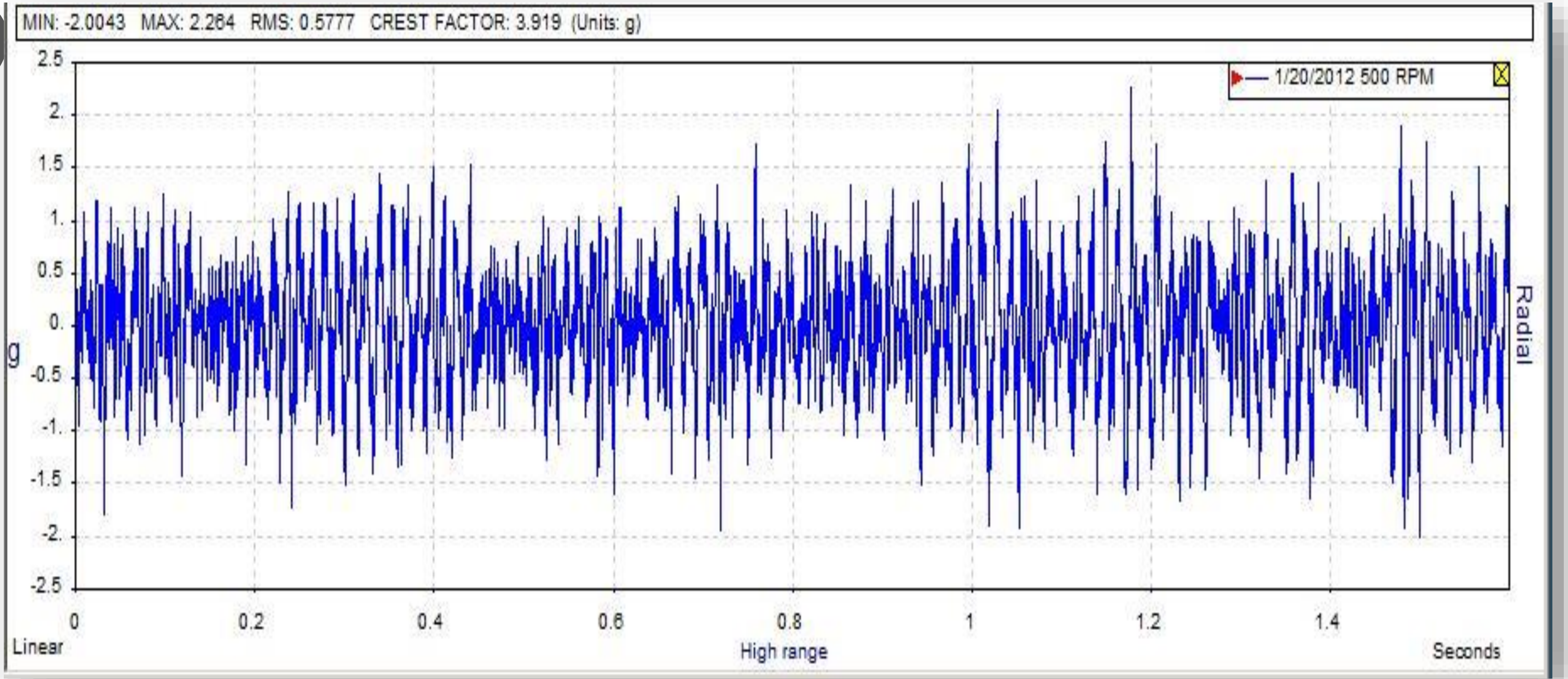
Slow Speed - Motor Coupled End
Standard High Range Spectrum



Indication of some HF bearing noise

Slow Speed - Motor Coupled End

Standard HR Time Waveform - Only 4.3g's P-P)



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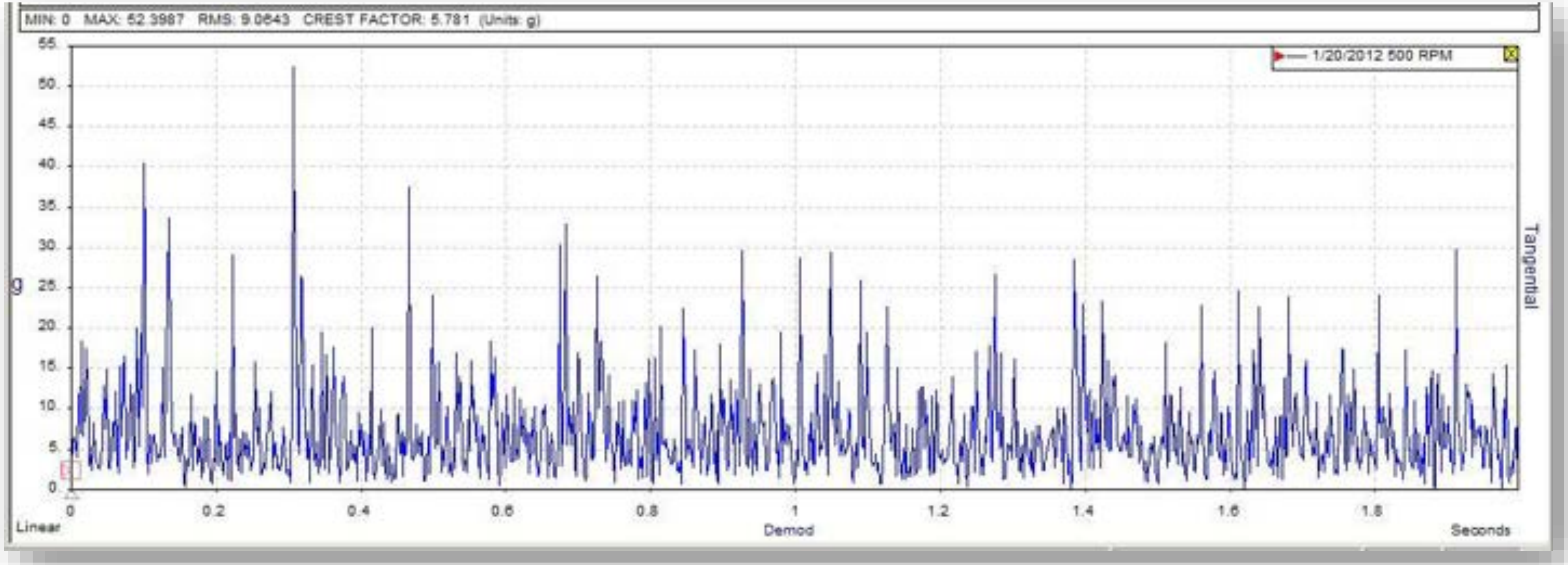
Slow Speed - Motor Coupled End

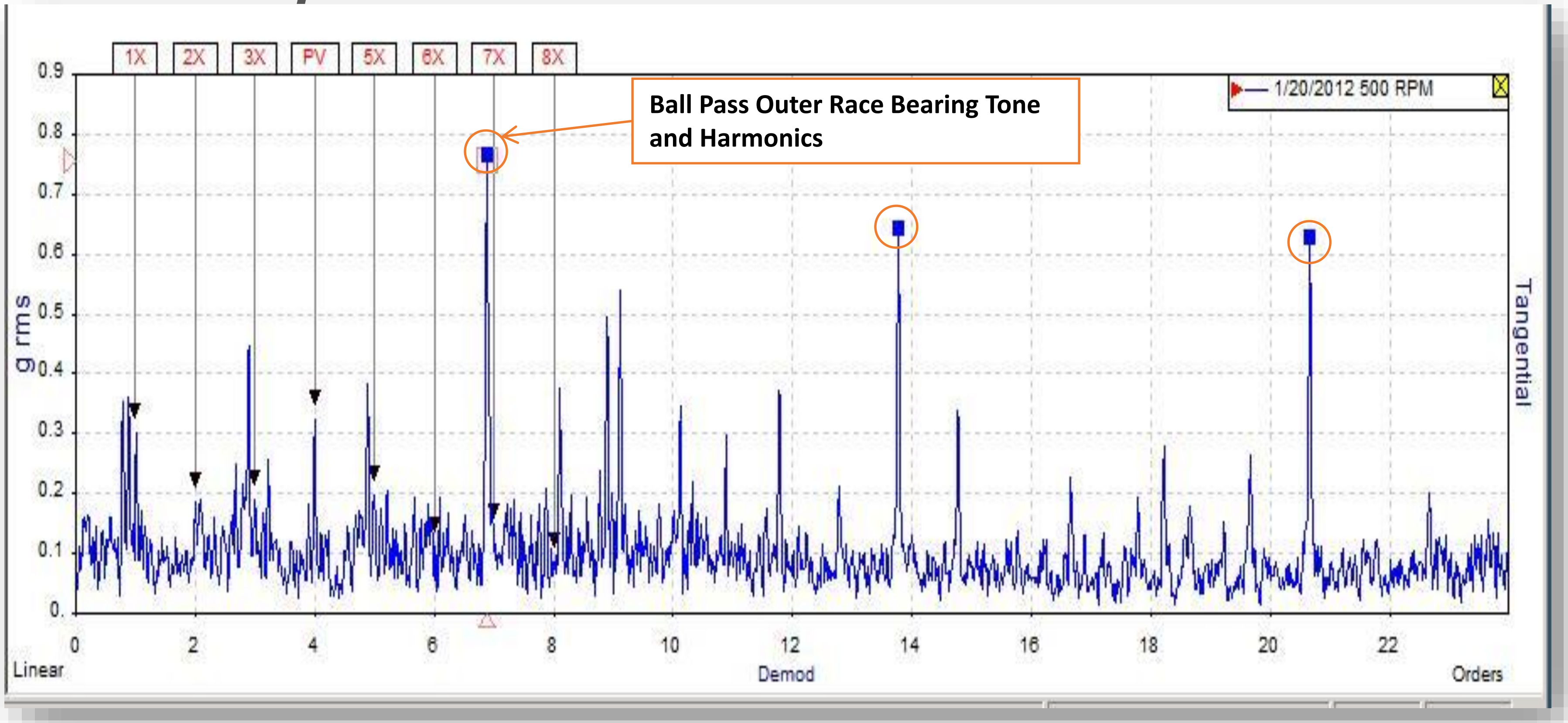
Impact Demod Waveform – 52g peak



Indication of serious impacting

Slow Speed - Motor Coupled End

Impact Demod Spectra



Indication of periodic content at 6.9xM

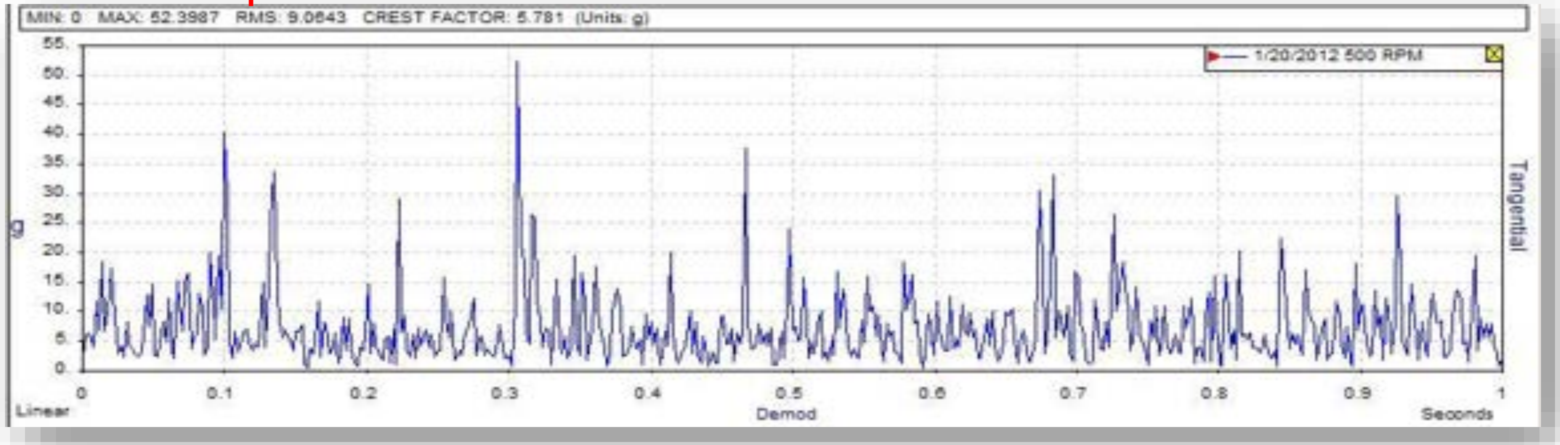
What Was Found

Severe Electrical Fluting

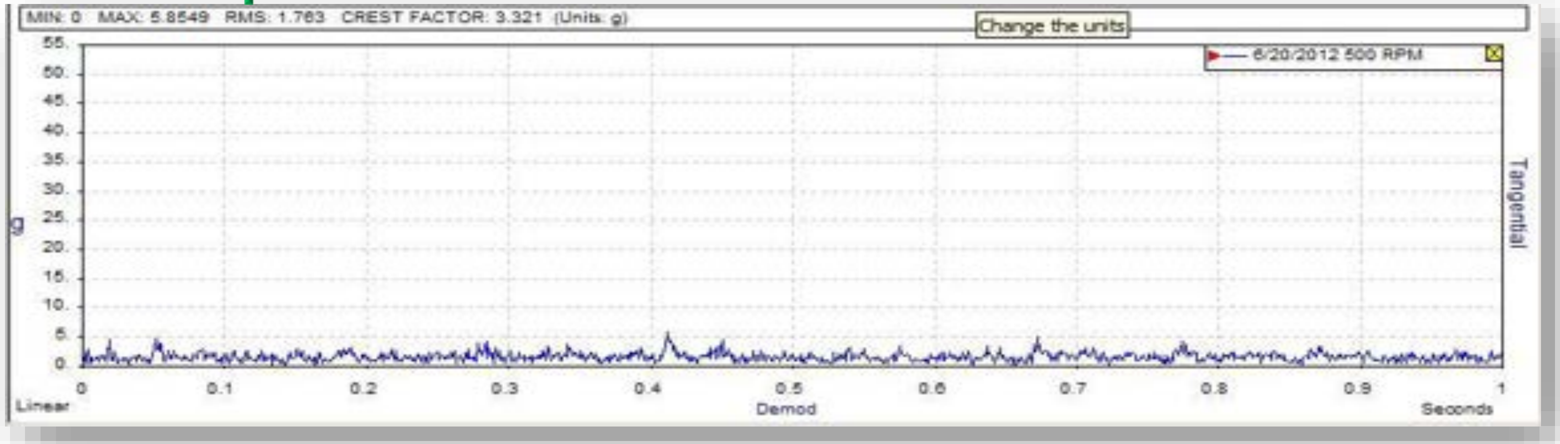
Motor Coupled End

Impact Demod Time Waveform – Comparison

Before Repair

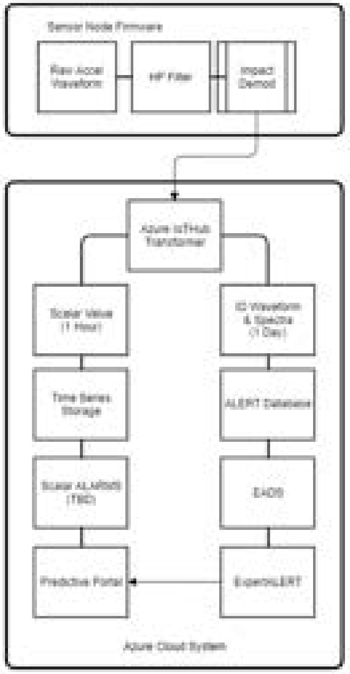


After Repair



Wireless Sensor (MEMS) - Methodology for Impact Demod

- Impact Demod algorithm is embedded in sensor firmware
- Raw acceleration waveform captured in memory:
  - 26,666.7 Hz Sample Rate
  - 20,480 samples –Store/Process
  - Duration of ID waveform: 0.77 seconds
- Passed through ID algorithm (Compression):
  - 2,000 Hz High pass filter
  - Decimated to 2,048 Samples
- Data capture – sent to ALERT & processed by EADS.
  - Hourly - Scalar ID is ‘peak’ amplitude from ID waveform
  - Daily - ID waveform is captured (if machine is running)



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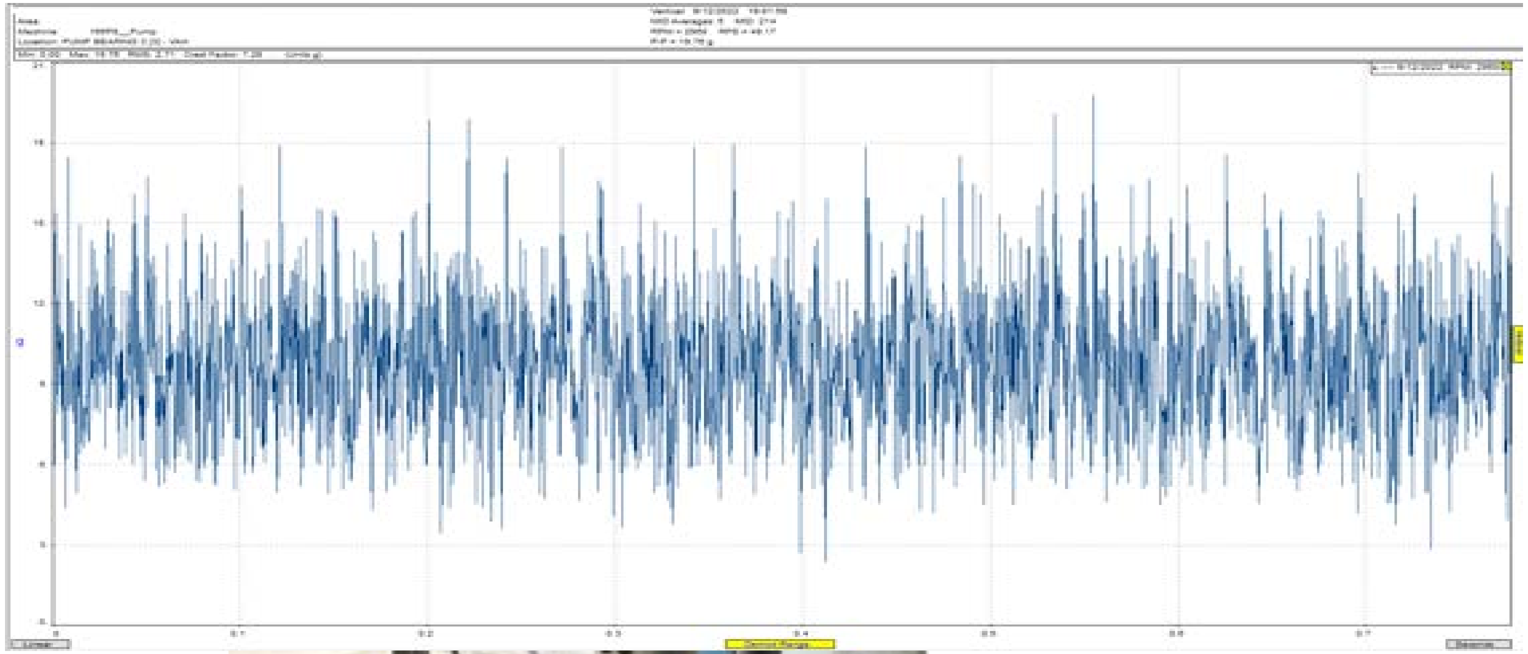
Example ID data & analysis – ID in ALERT



Expert System Results

166P8__Pump

MID:	214
Averages:	5
Report Generated:	9/26/2022 12:52:24 PM (UTC-08:00)
Date Acquired:	9/25/2022 7:02:02 PM (UTC-08:00)
Machine Speed:	2964 RPM
Rulebase:	20220719
	MID Completion = 80%: Needs: Motor Bars, More Averages.
Figure of merit:	234
Maximum level:	0.24 (+675%) in/s at 0.23x on PUMP BEARING 3 Axial

RECOMMENDATIONS:

<3> Desirable:	Verify Proper Lubrication of Pump Bearings and Retest

DIAGNOSTICS:

<3> Moderate	Pump Bearing Non-Synchronous Impacting PUMP BEARING 3 Vertical, Waveform Peak = 13 g
<3> Moderate	Pump Bearing Synchronous Impacting PUMP BEARING 3 Vertical, Waveform Peak = 13 g
<4> Slight	Pump Roller Bearing Wear 0.044 (+ 390%) in/s at 62.9xP on PUMP BEARING 3 Vertical 0.039 (+ 655%) in/s at 35.4xP on PUMP BEARING 3 Horizontal 0.037 (+1002%) in/s at 35.4xP on PUMP BEARING 3 Axial 0.030 (+ 293%) in/s at 58.0xP on PUMP BEARING 3 Horizontal 0.029 (+ 498%) in/s at 43.2xP on PUMP BEARING 3 Axial 0.017 (+ 393%) in/s at 38.3xP on PUMP BEARING 3 Vertical

PROCESS READINGS

OK:	CODE=IMPACT DEMOD PEAK, Position=3, Axis=R,A=12.6 13.46 g

FLUKE
Reliability

QUESTIONS ?

THANK YOU!

Vibration Analysis: Slow-Speed Machine Applications and Impact Detection

In this webinar, we will explore techniques for impact detection methods as well as analyzing slow-speed shafts, and the correlation between the two.