FLUKE®
Reliability

Slow Speed Machines & Impact Demodulation

Azima DLI

Best Practices Webinar Series

Meet the Speaker

Steven Hudson

Director, Professional Services

- Remote Vibration Analysis/Reporting
- Reciprocating Compressor Analysis
- Startup / Field Services

Background:

- 35 years in Predictive Maintenance
- ISO Cat IV Vibration Analyst
- Naval Nuclear Power (Submarines)

Joined Symphony Industrial in 2010

Roles:

- Chief Analyst
- Strategic Account Manager / Technical Sales
- Operations

Bearing Fault Detection on Slow Speed Shafts

- Today We Are Discussing Slow Speed Shaft Techniques and impact detection
  - Applications Based on Industrial Piezo-electric Accelerometers.

- Todays Topic will not Apply to:
  - Eddy Current Probes
  - Strain Gauge Based Sensors

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

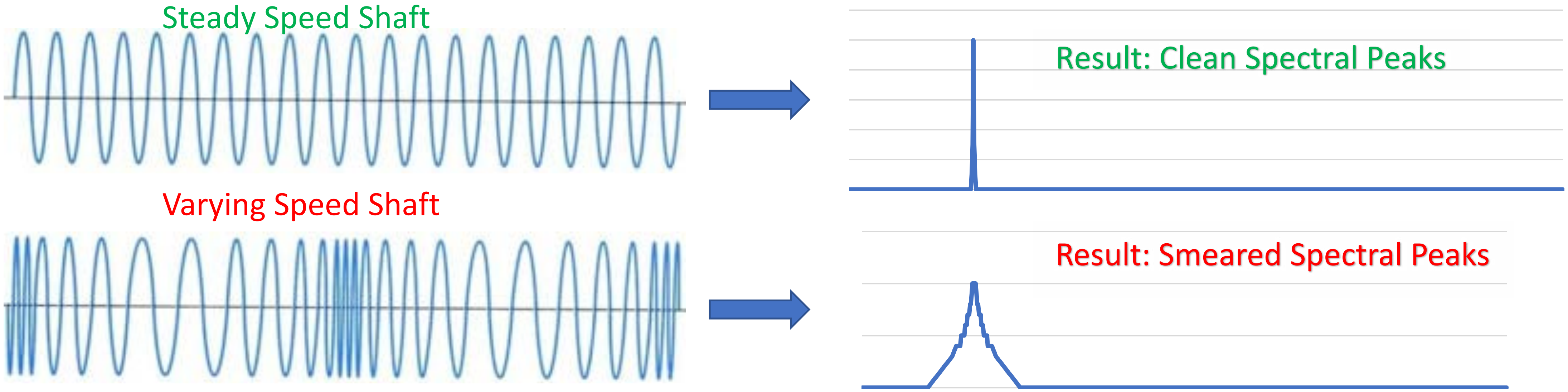
Time

- 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
- At Low Frequencies, Very Little Voltage Change In Terms Of Acceleration

	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

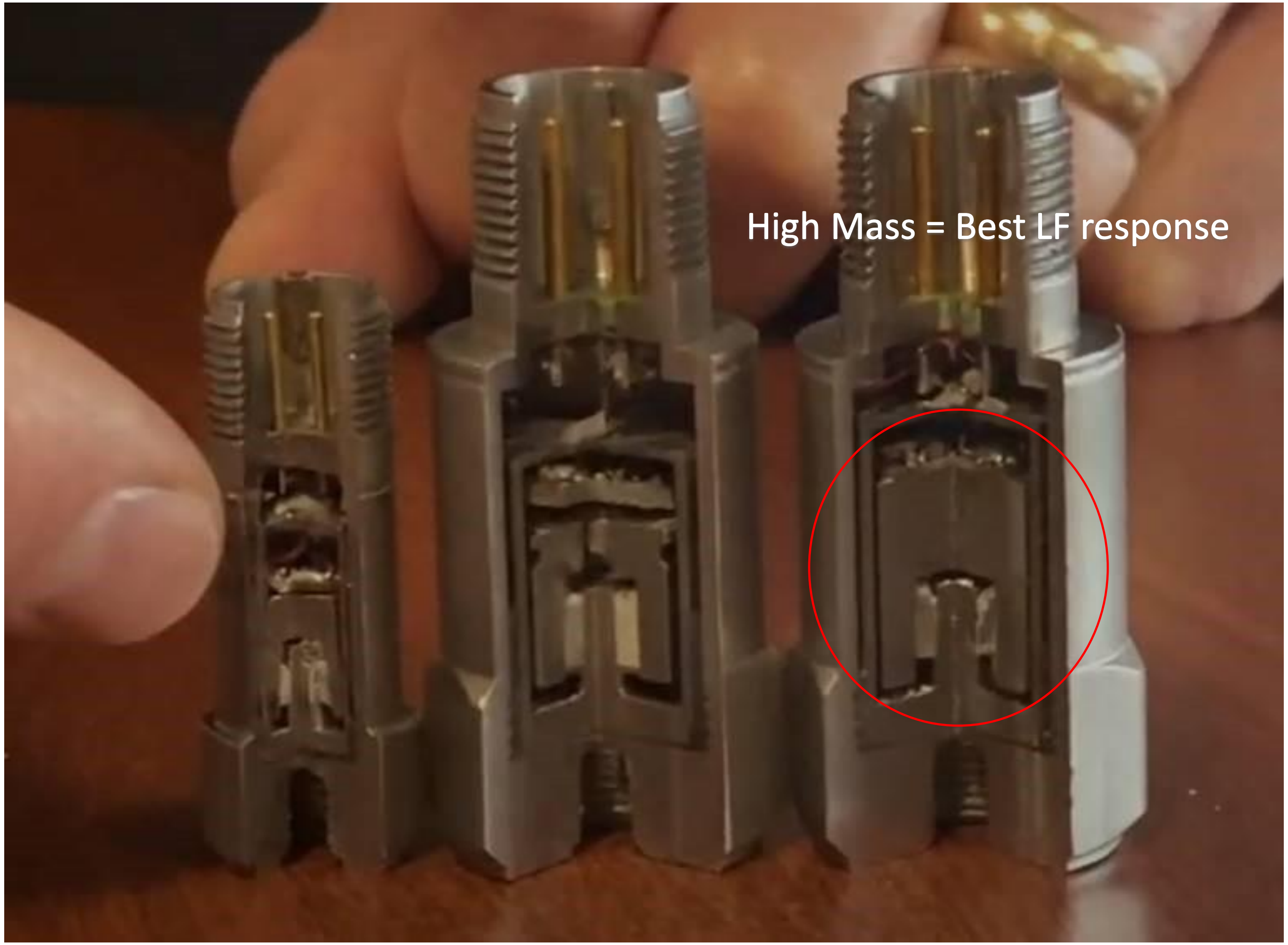
Accelerometer Selection

- 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

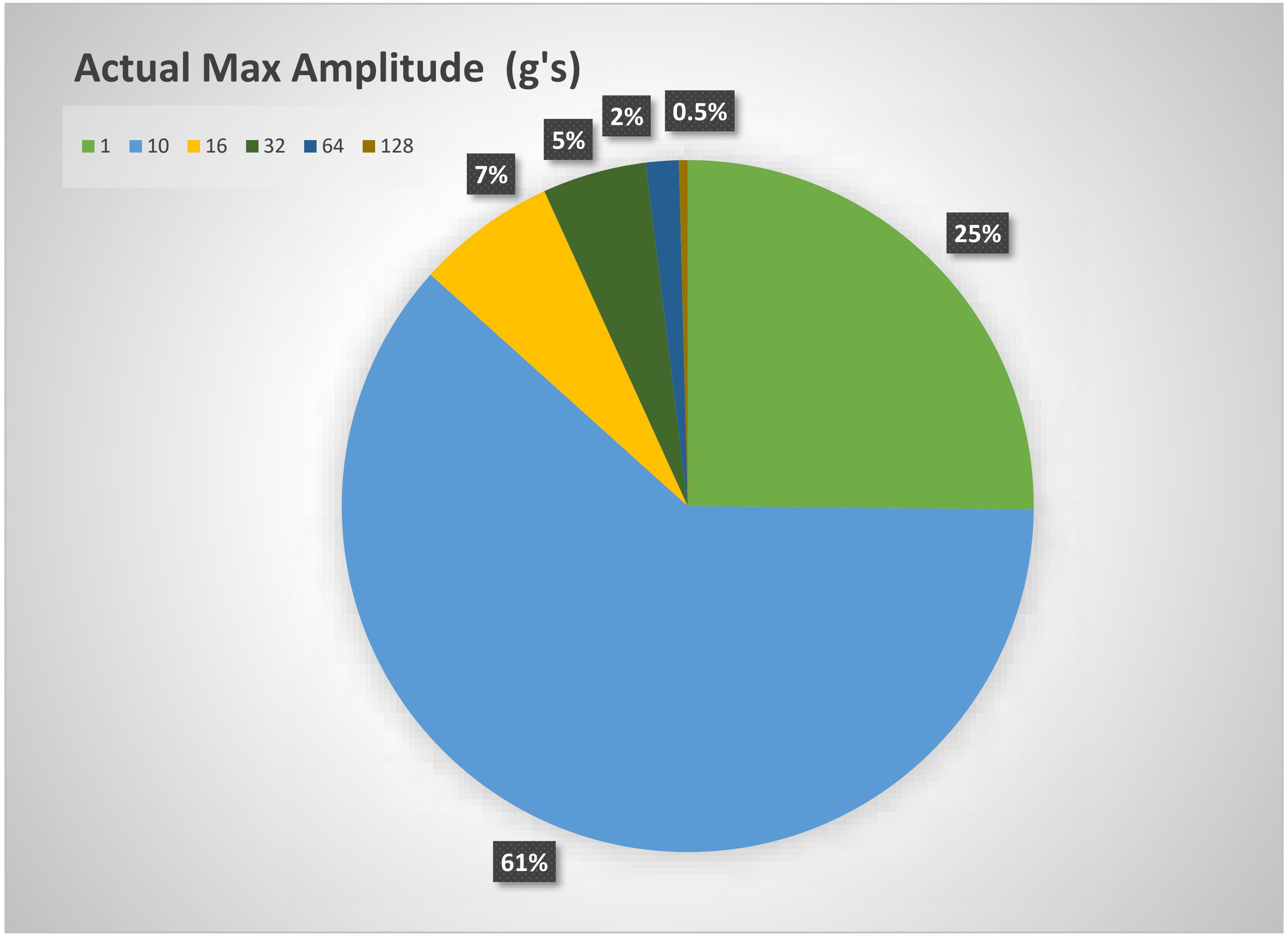
F=MA Principal Applies

Accelerometer Selection



Accelerometer Real World Max Amplitudes

- 4 Months Data
- 50,000 Machine Tests
- 130 Tests exceeded 100g
- 1 Test exceeded 200 g.



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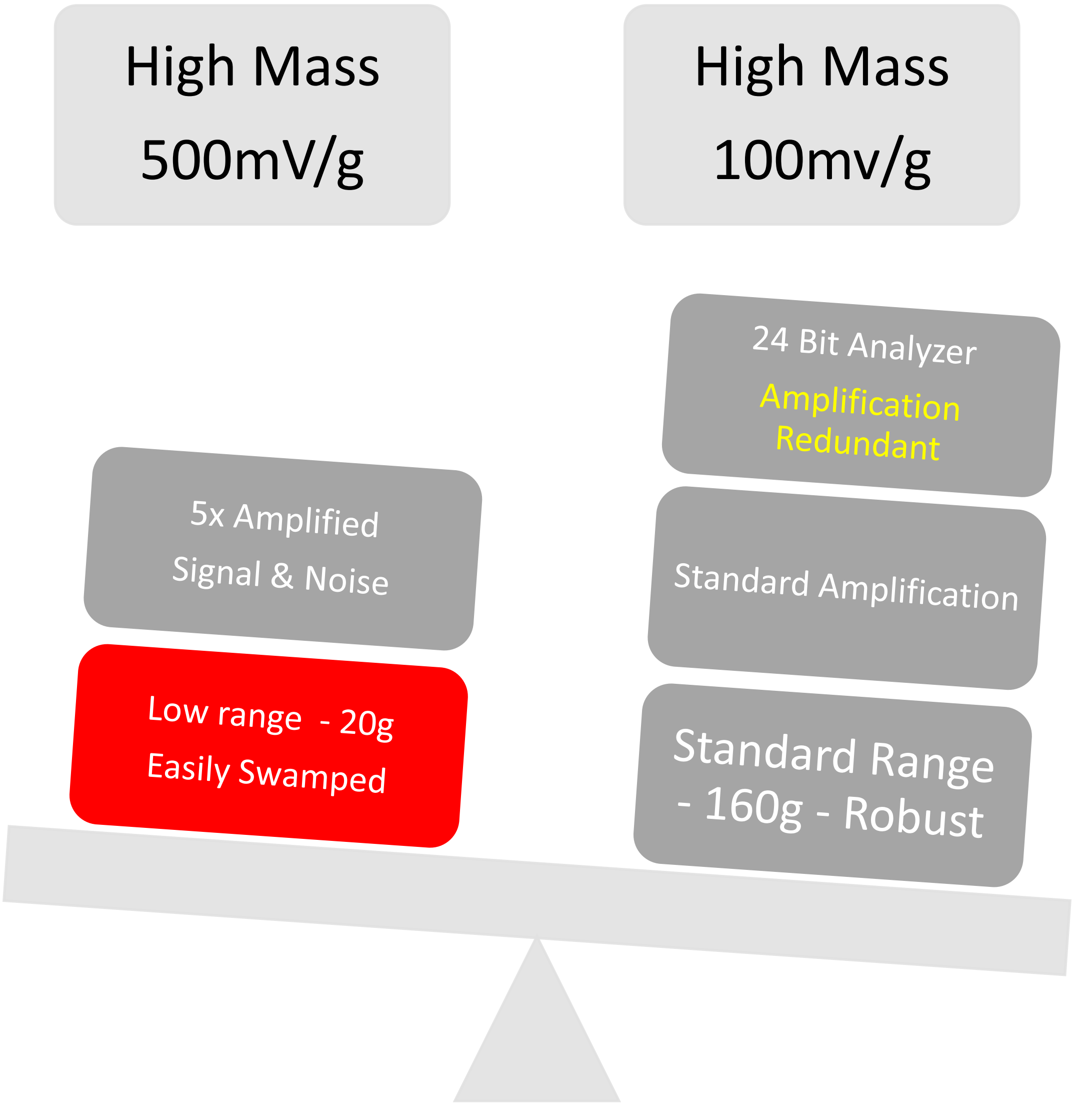
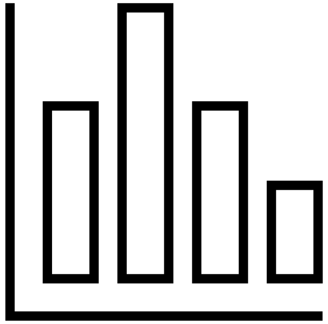
500mV vs 100mV



Poll Question



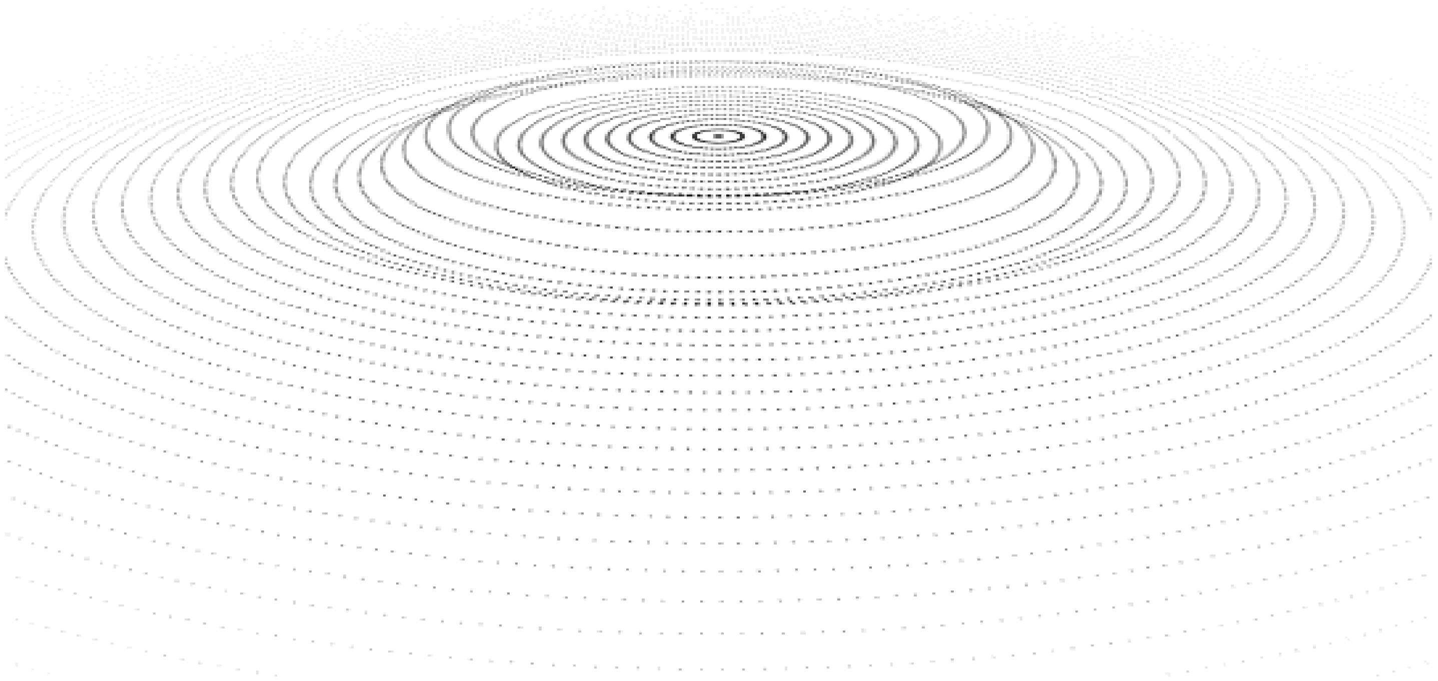
Q: How critical are slow speed (<60 RPM) machines to the Operation of your facility or Business.

Accelerometer Selection

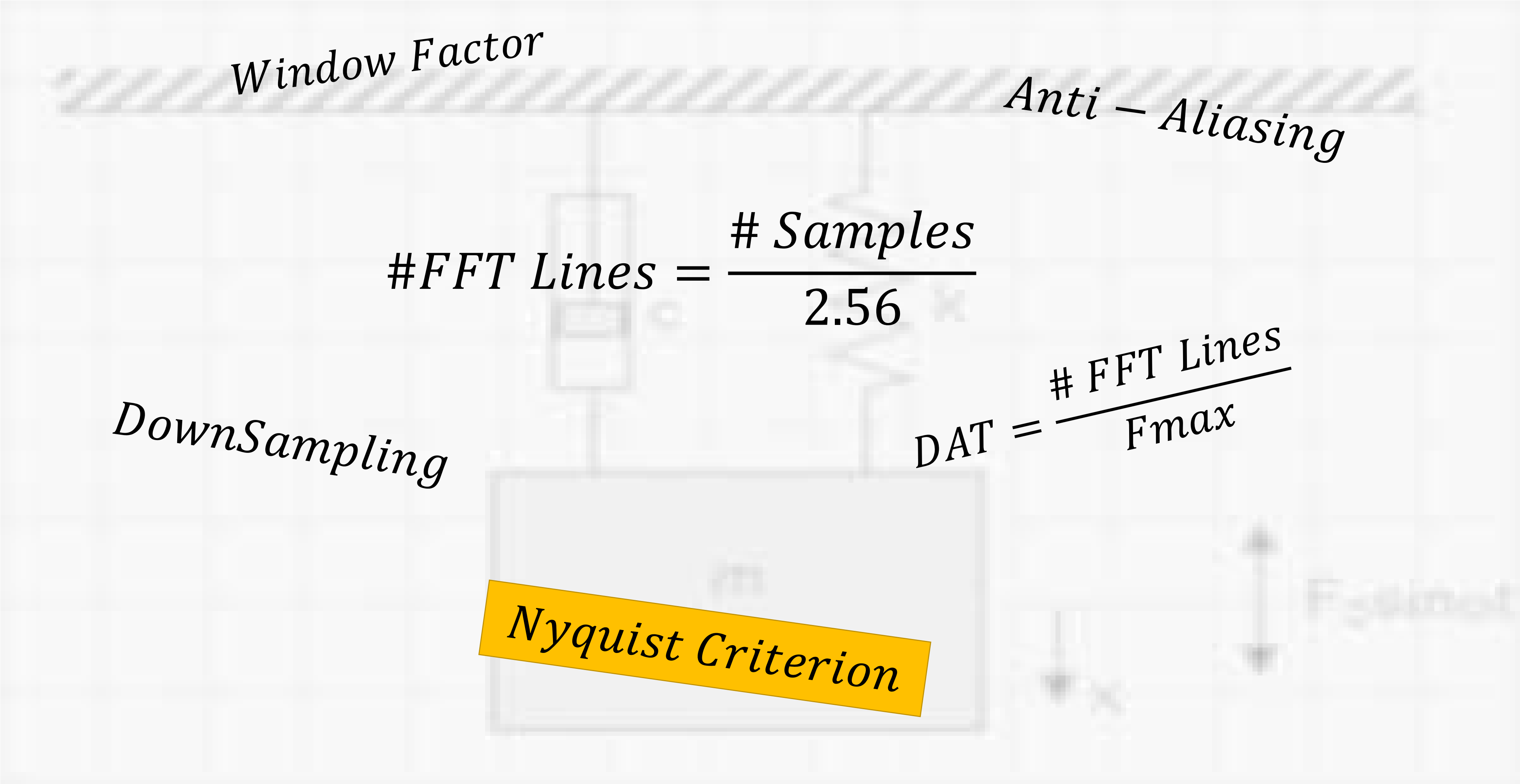
SETTLING TIME

- 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 Detection



Things to Consider



Window Factor

Anti – Aliasing

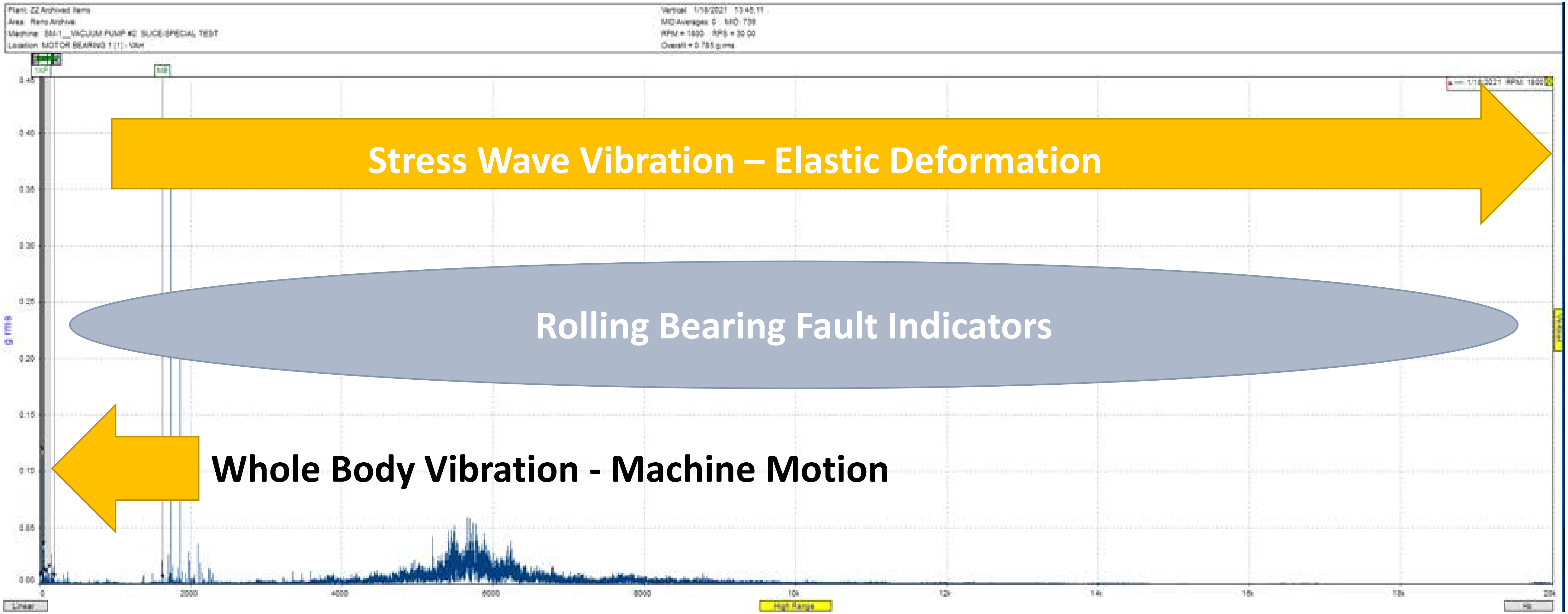
$$\#FFT\ Lines = \frac{\#\ Samples}{2.56}$$

DownSampling

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

Nyquist Criterion

Things to Consider



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**

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ALIASING Visualization

Anti-Aliasing Strategies

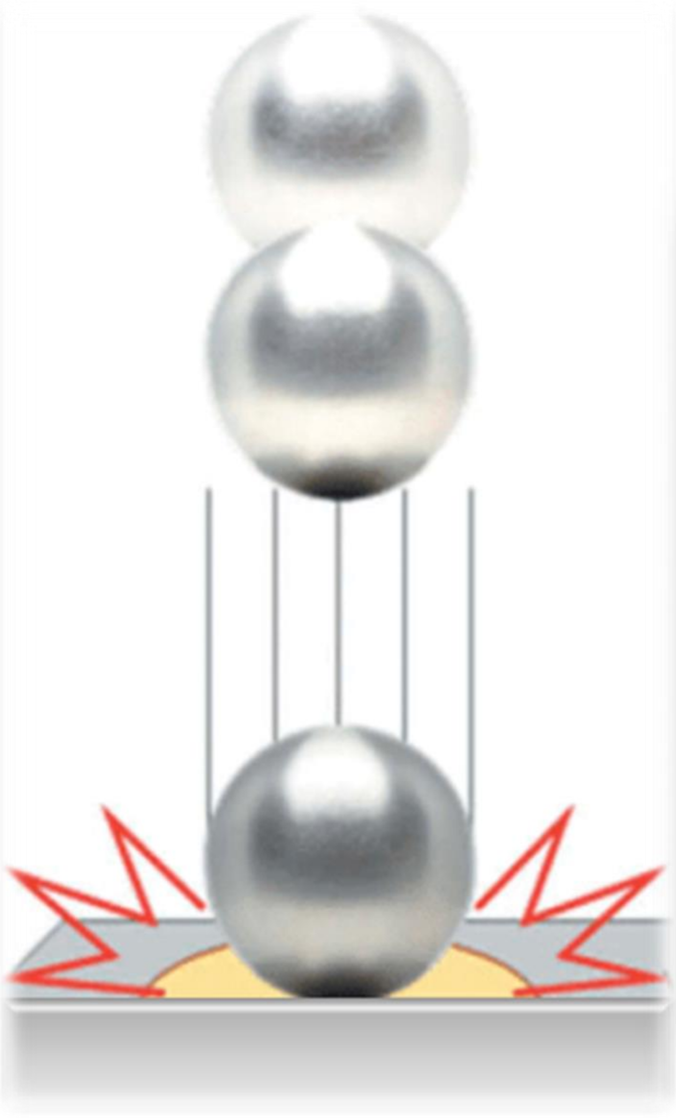
How do Digital Data Collectors comply with Nyquist Criterion

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.

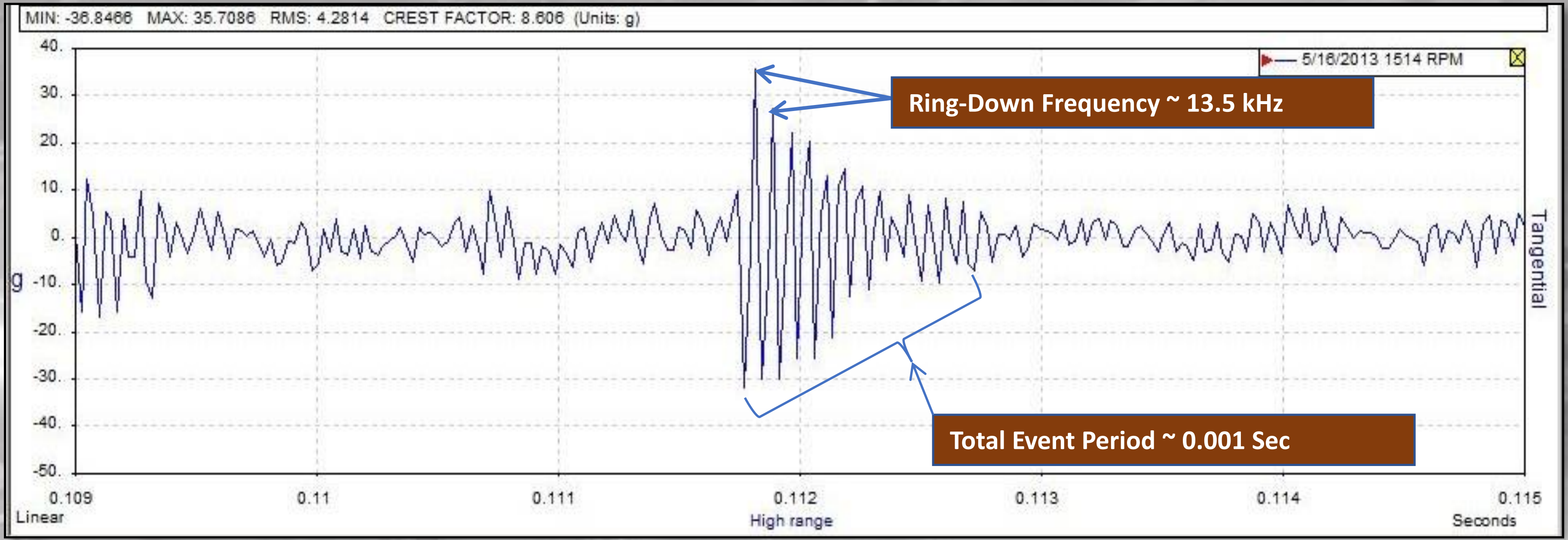
Note: Don’t mistake Sensor Frequency Response as the maximum measurable frequency.

Distinguishing an Impact

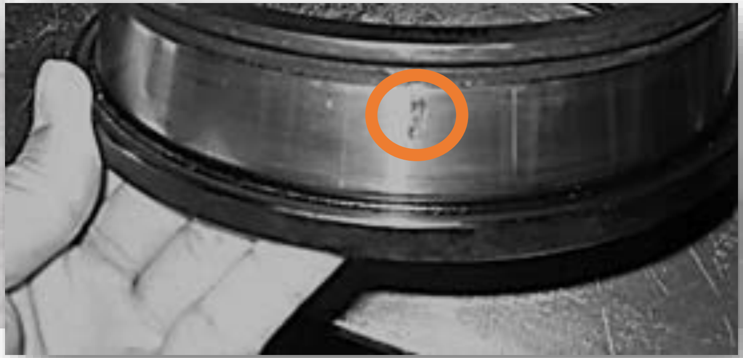


Single Impact in Time Waveform

Actual Single Impact Event Example

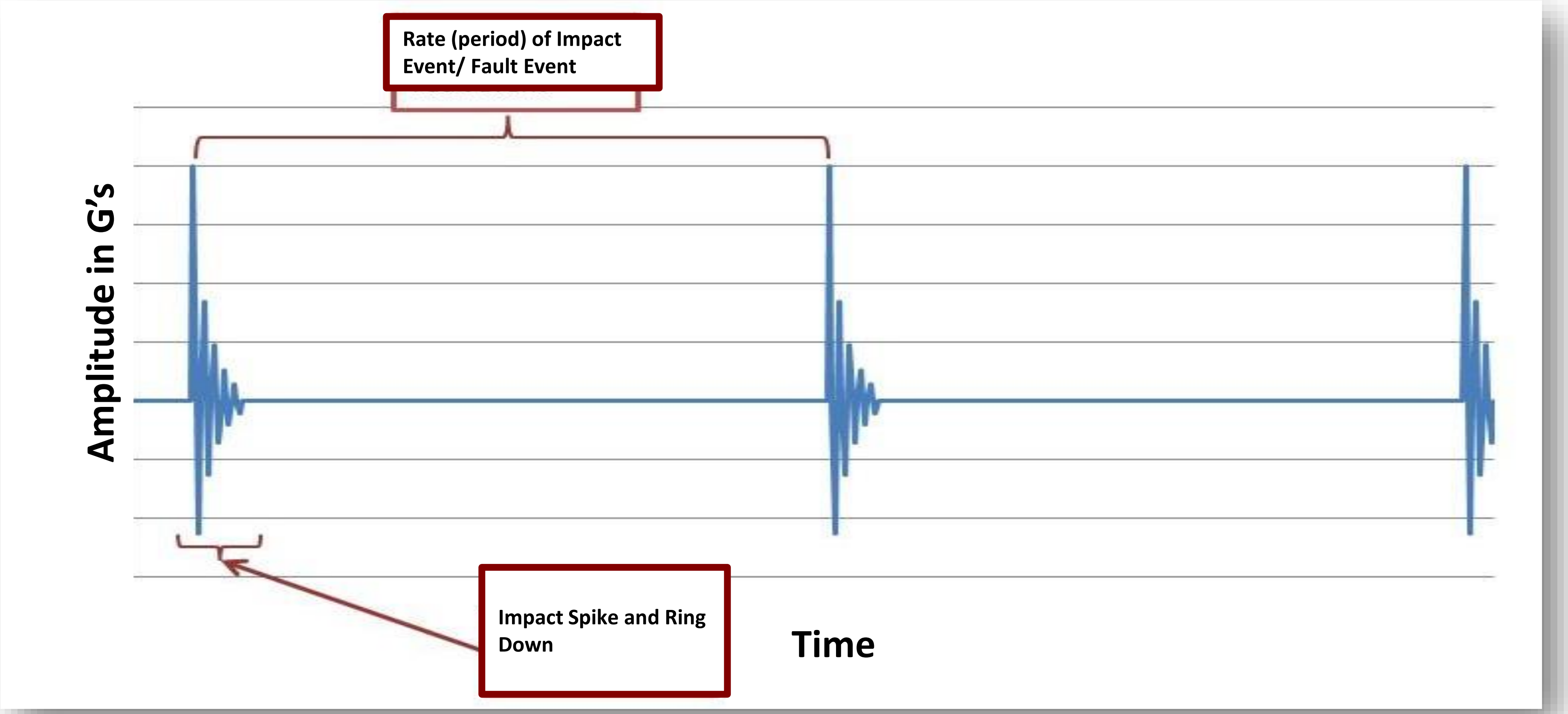


Note: <u>Entire</u> Event Period Must Meet Nyquist Criteria Or It Will Be Eliminated By Anti-Aliasing

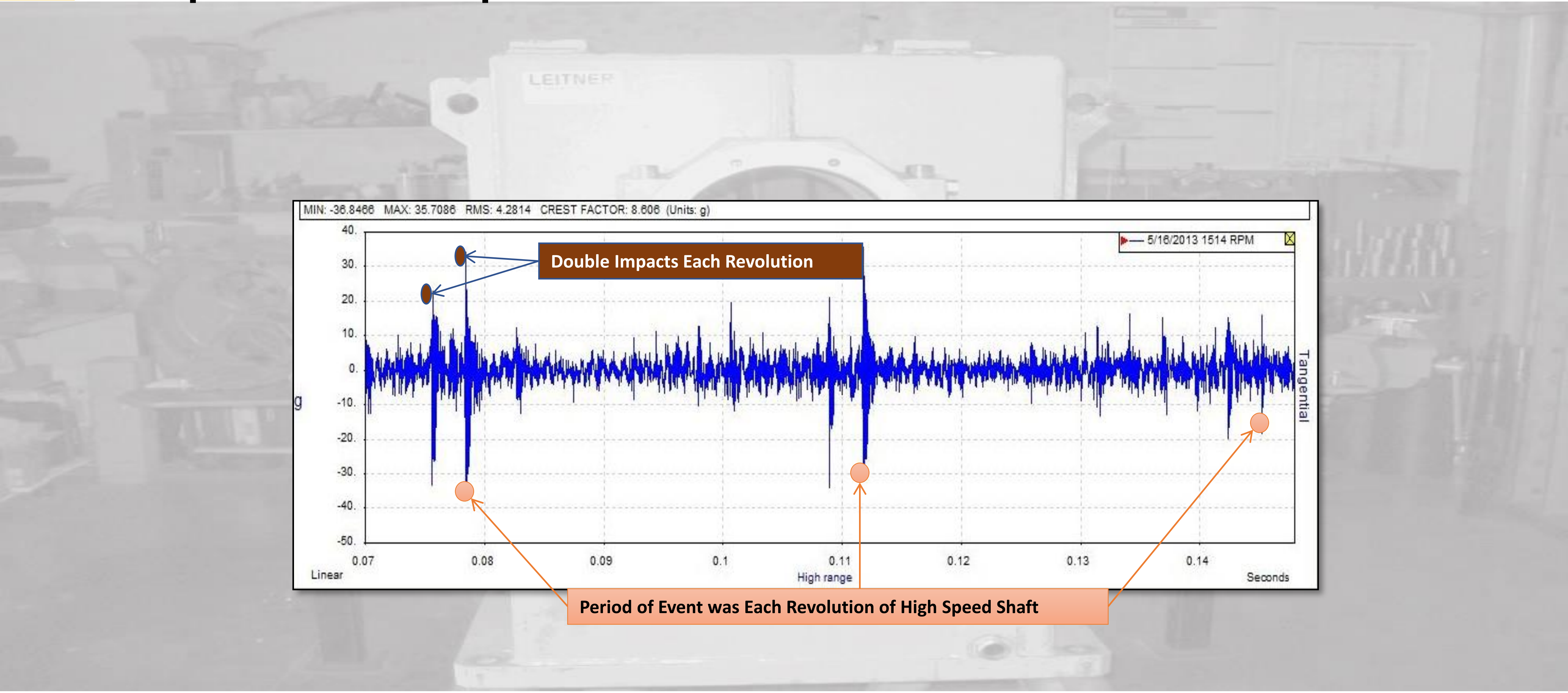


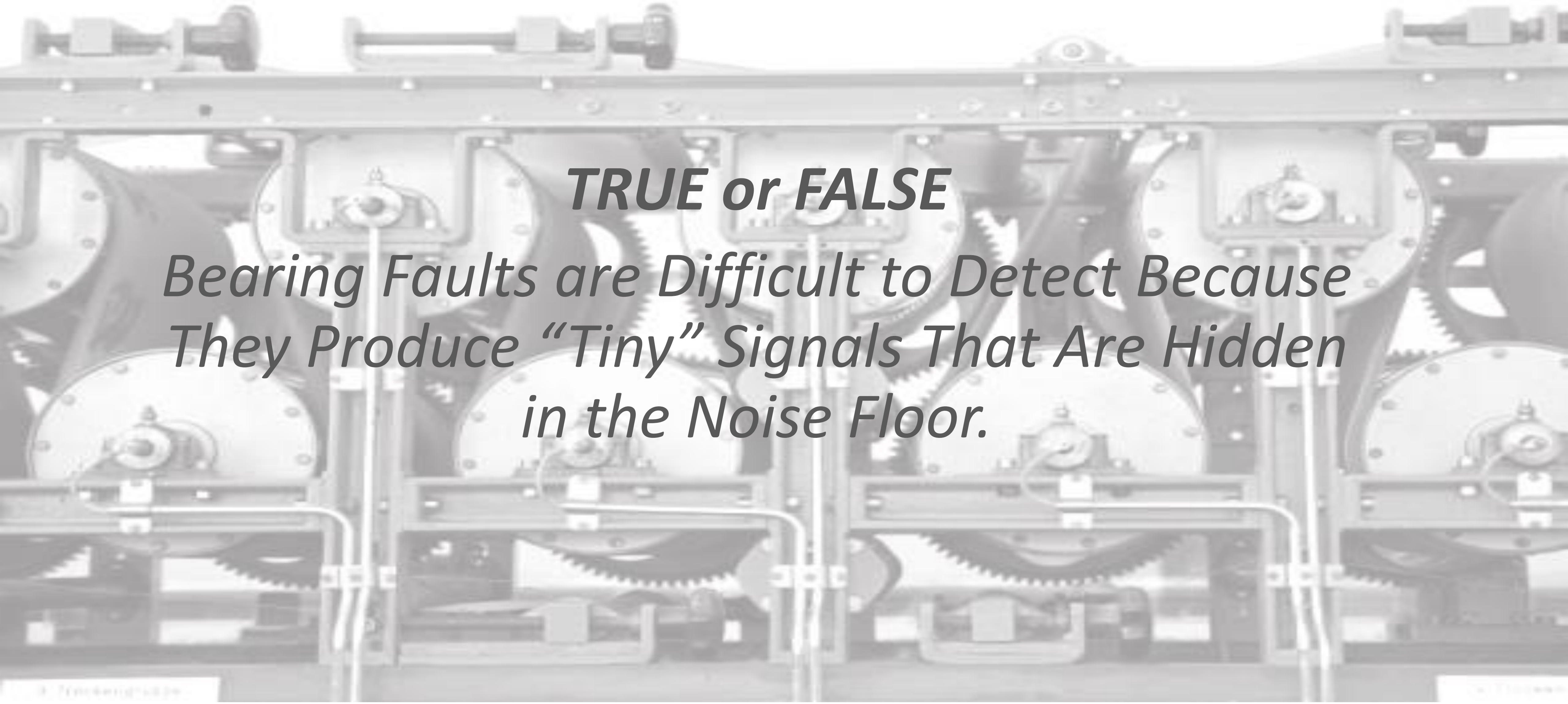
Periodic Impact Spikes

Impact Illustration in Time Waveform



Example: Periodic Impact Events





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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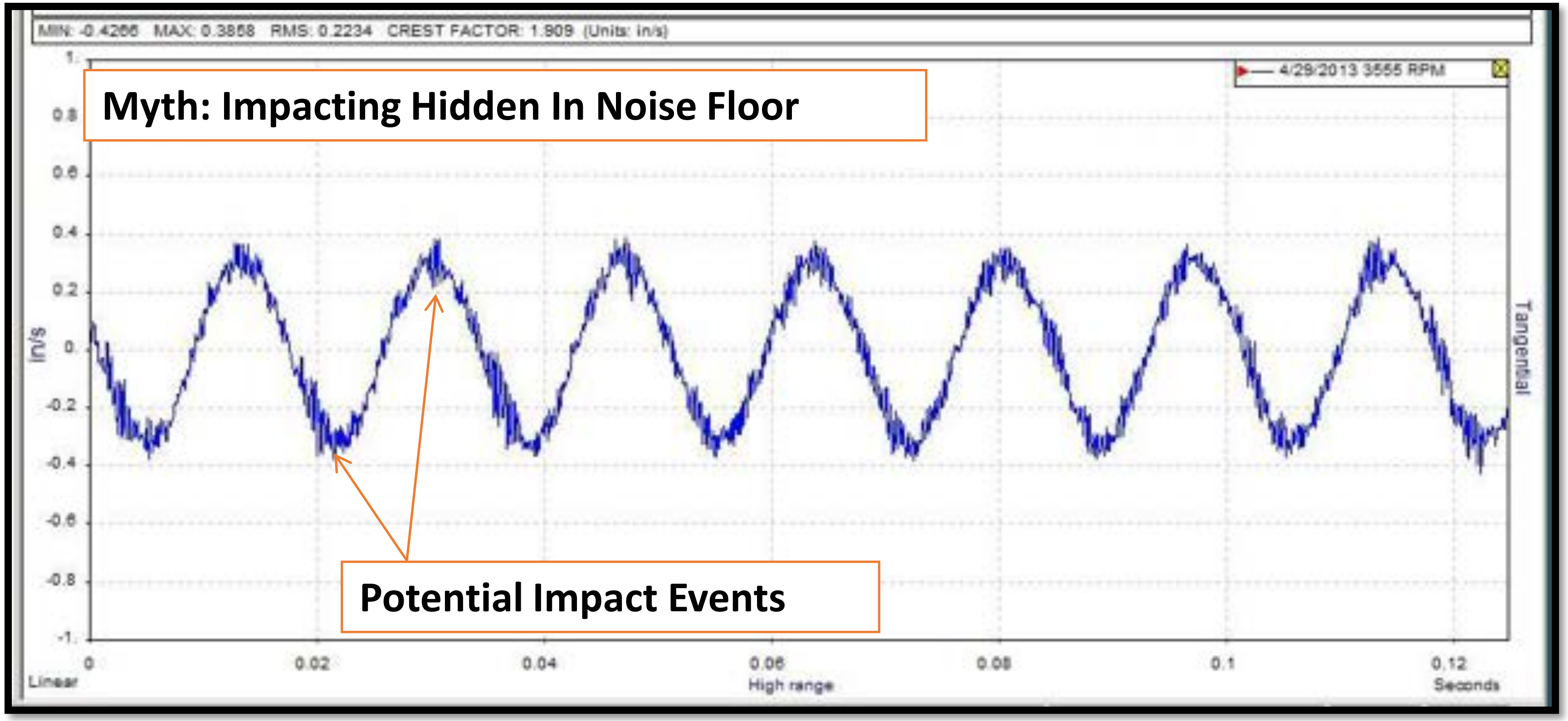
Impact Misconception

Impacting Amplitude Example - Low Impacting

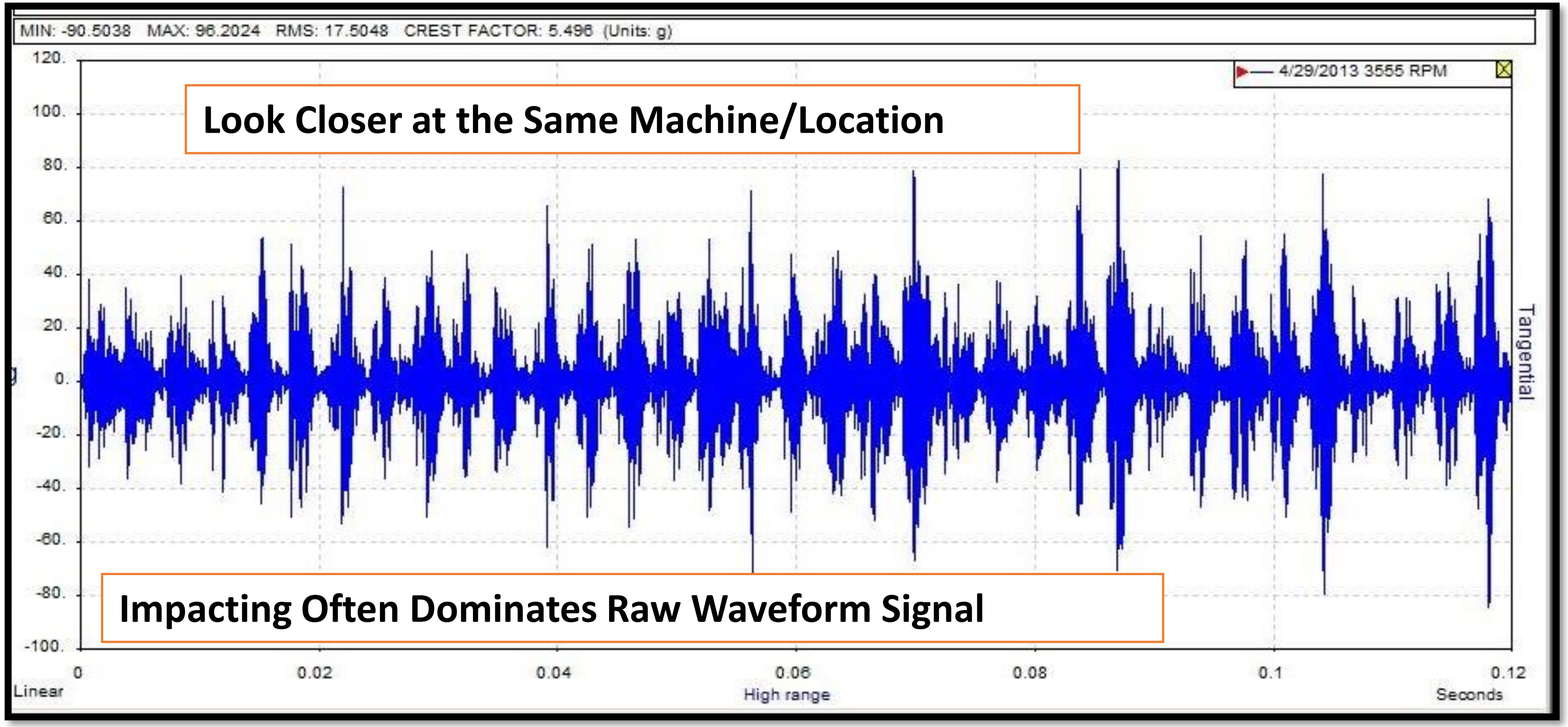
- Fmax at 6000Hz (Integrated)



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

High Sample Rate Equivalent

Typical:

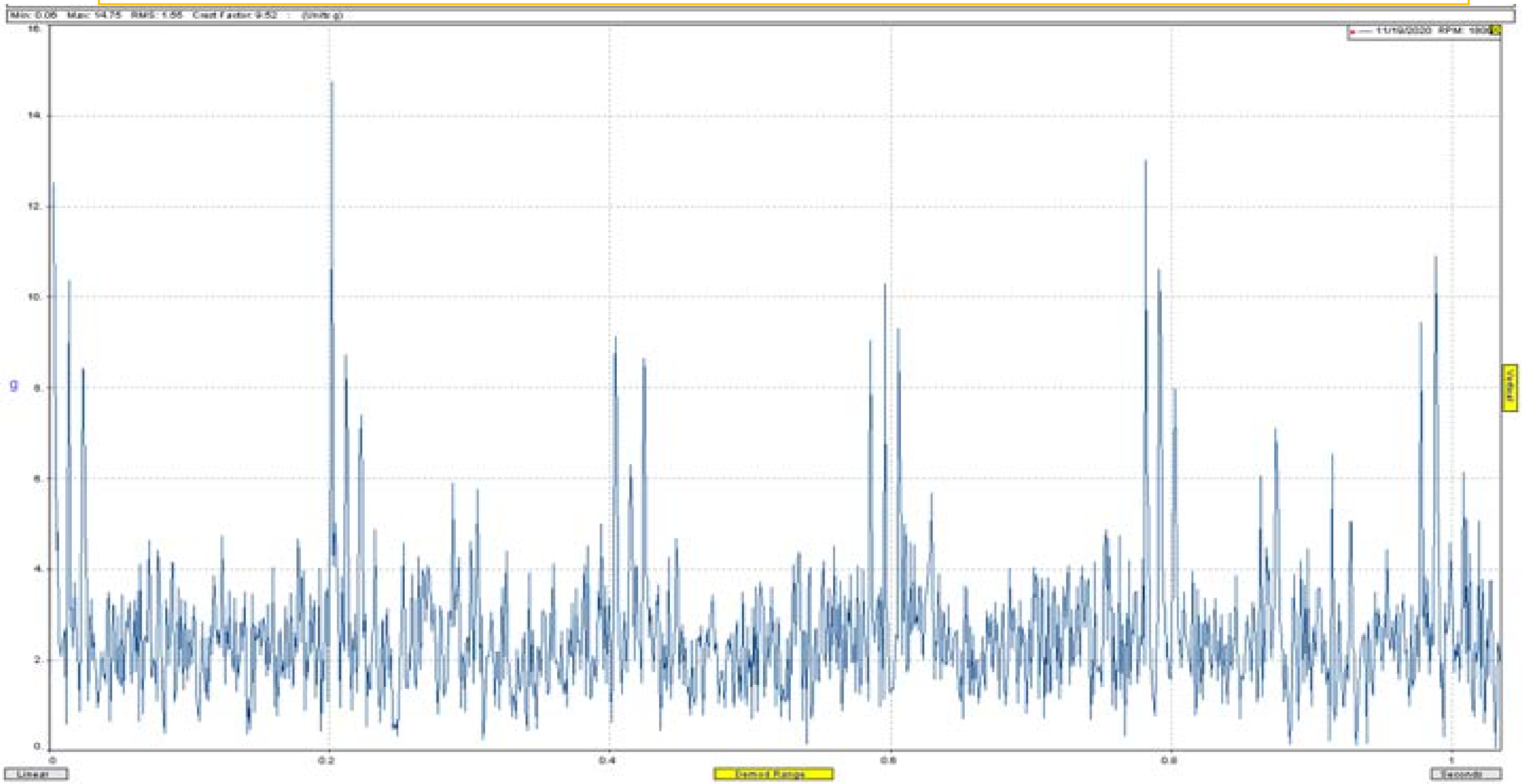
- Fmax:
  - 40,000Hz / 4,250,000 Lines
- Results
  - 10,880,000 Samples
  - 1.7 CPM Separating Frequency

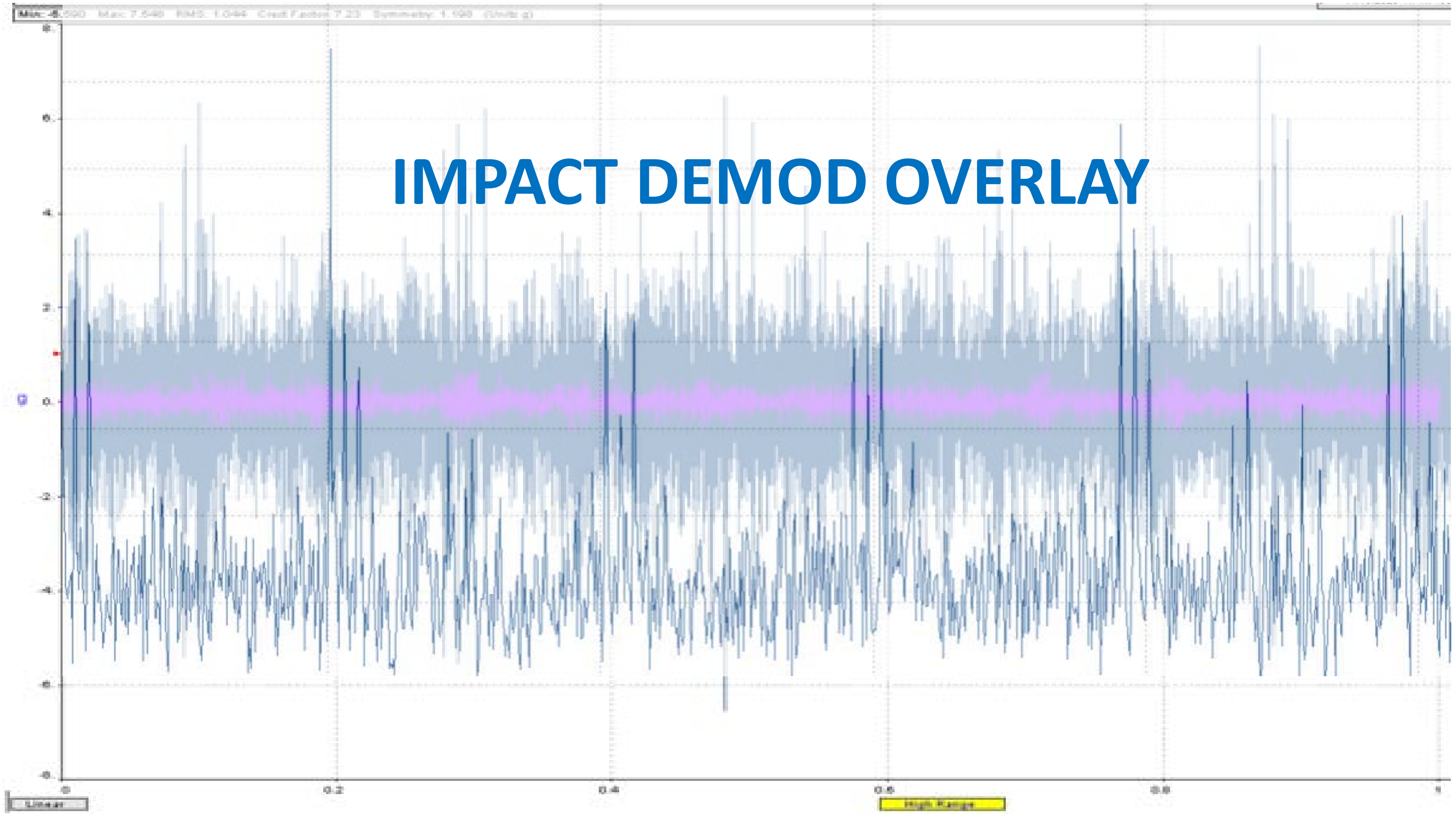
Demodulation ≈ Data Compression

Example

Impact Demod Detected: 14.7g

Compressor Bearing Inner Race Frequency Modulated by Cage Rate

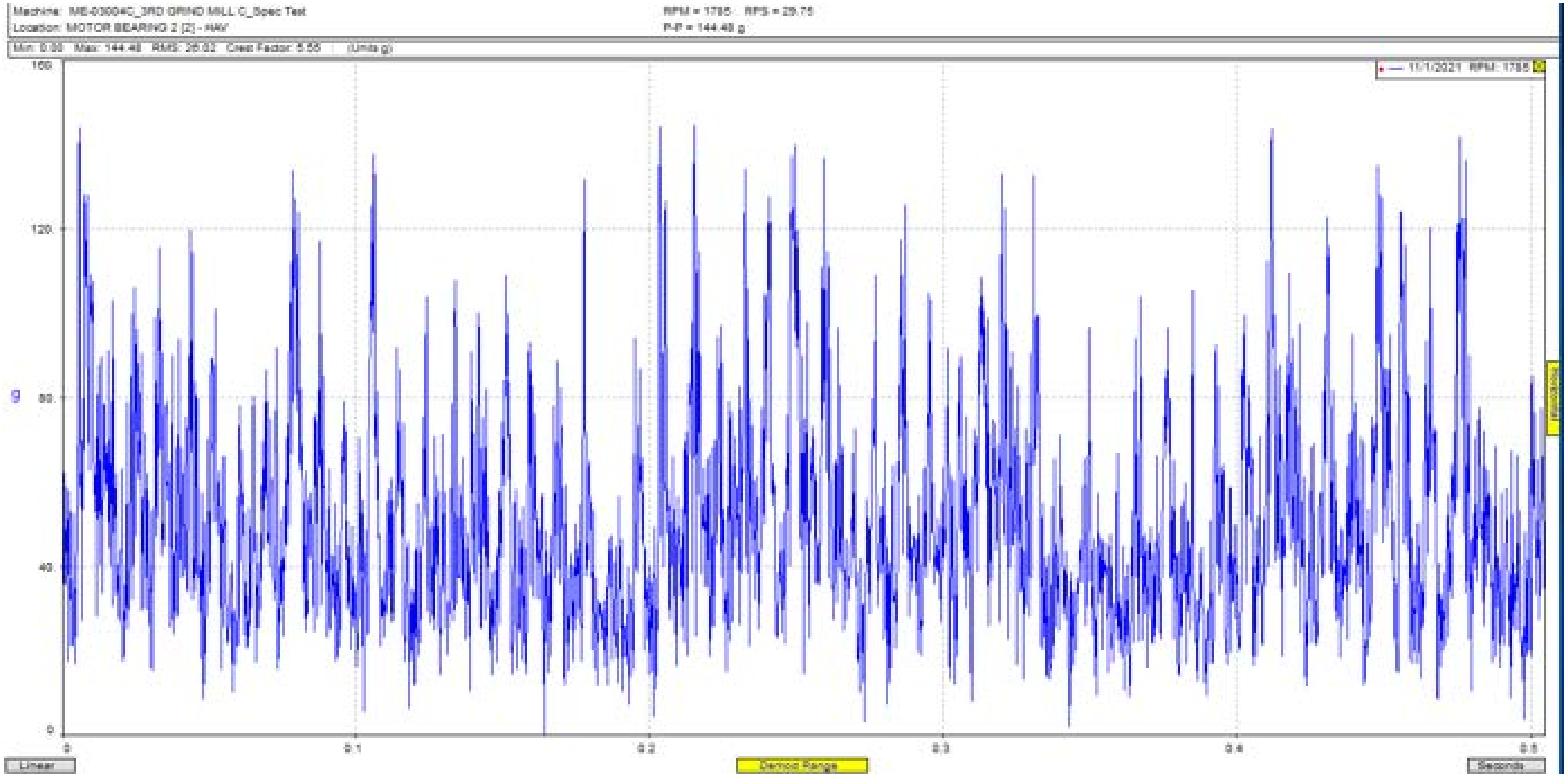




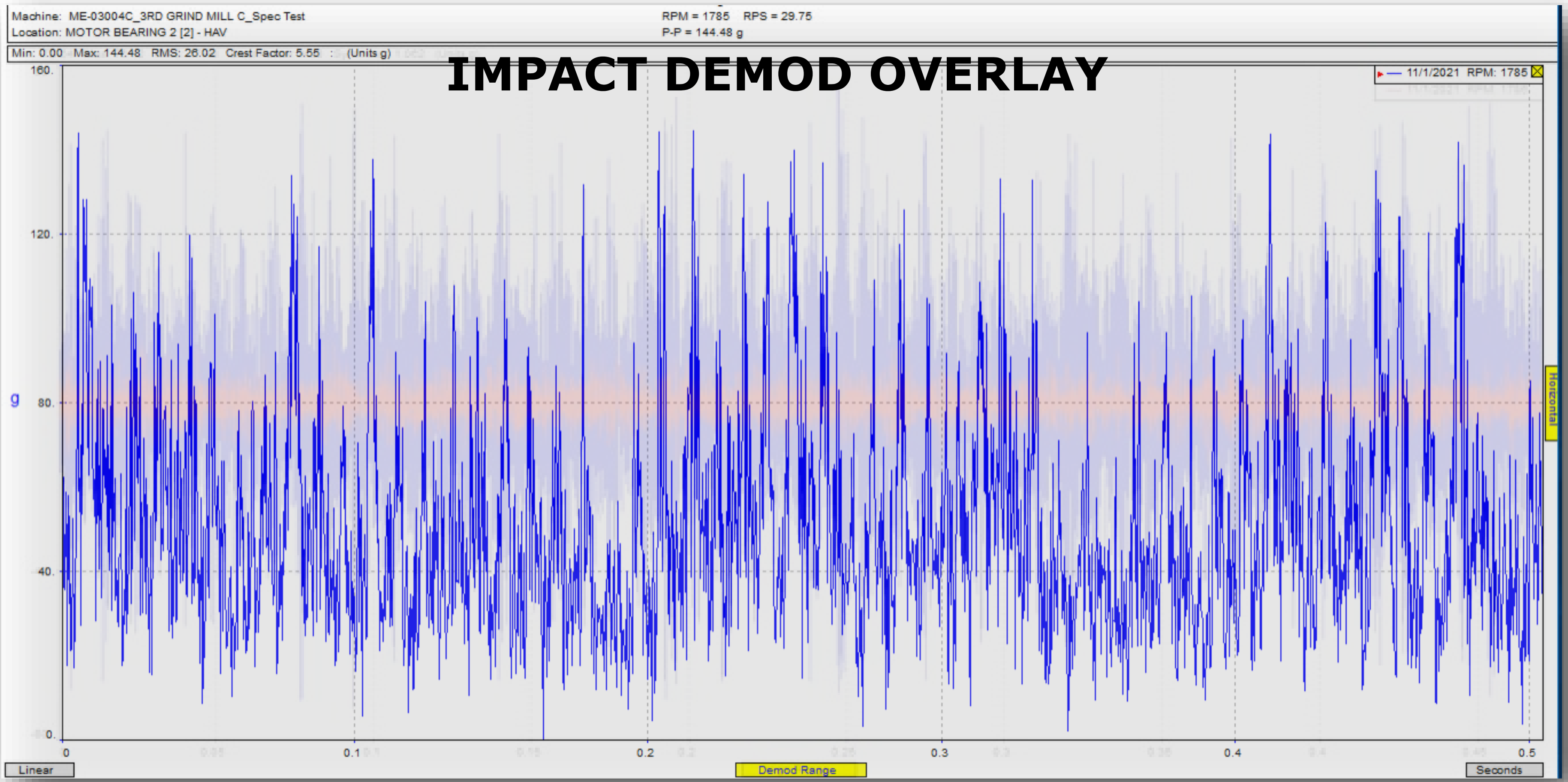
Compare Samples	Standard	High Freq / High Resolution	Impact Demod
Fmax	3000 Hz	25,000 Hz	**40,000 Hz**
Max Amplitude	1.8 g	14.1 g	**14.7 g**
# of Samples	4096	25,600	**4096**

Example (New)

Impact Demod Detected: 144.5g
Motor Bearing Fault



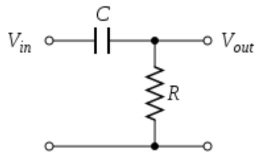
IMPACT DEMOD OVERLAY



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

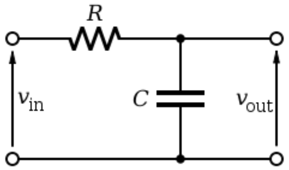
Review of Legacy Demodulation

1. Signal High Pass Filtered



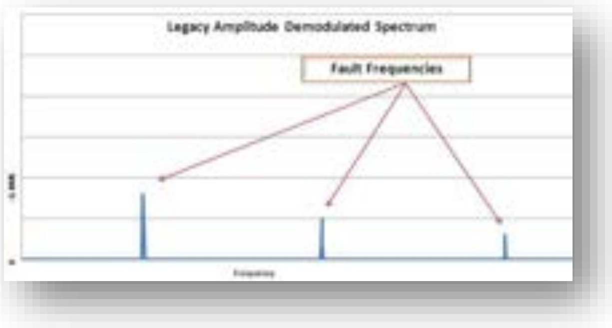
2. Rectify - Force All Peaks to be Positive

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



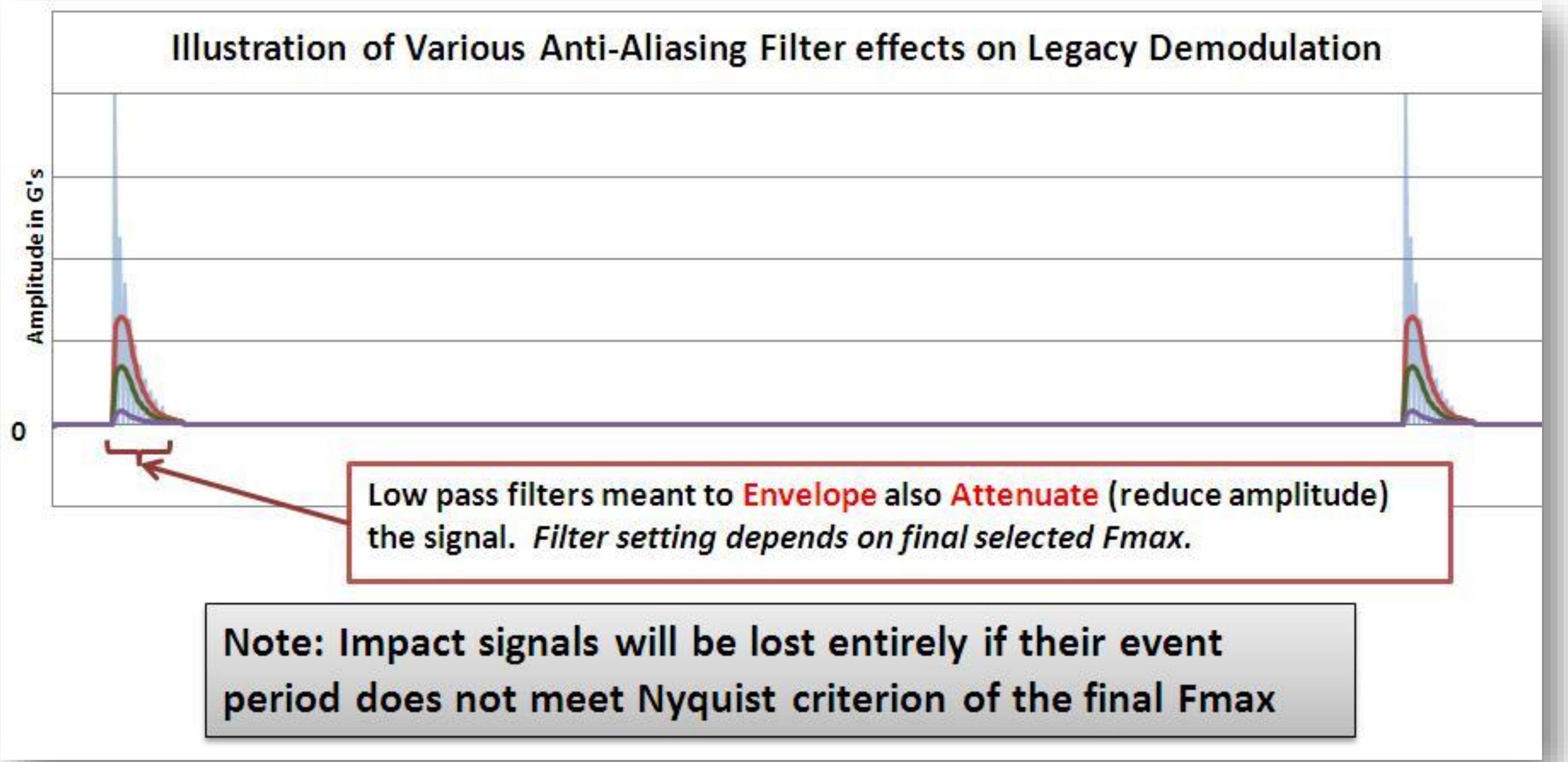
4. Digitize Signal

5. Perform FFT – Generate Spectrum



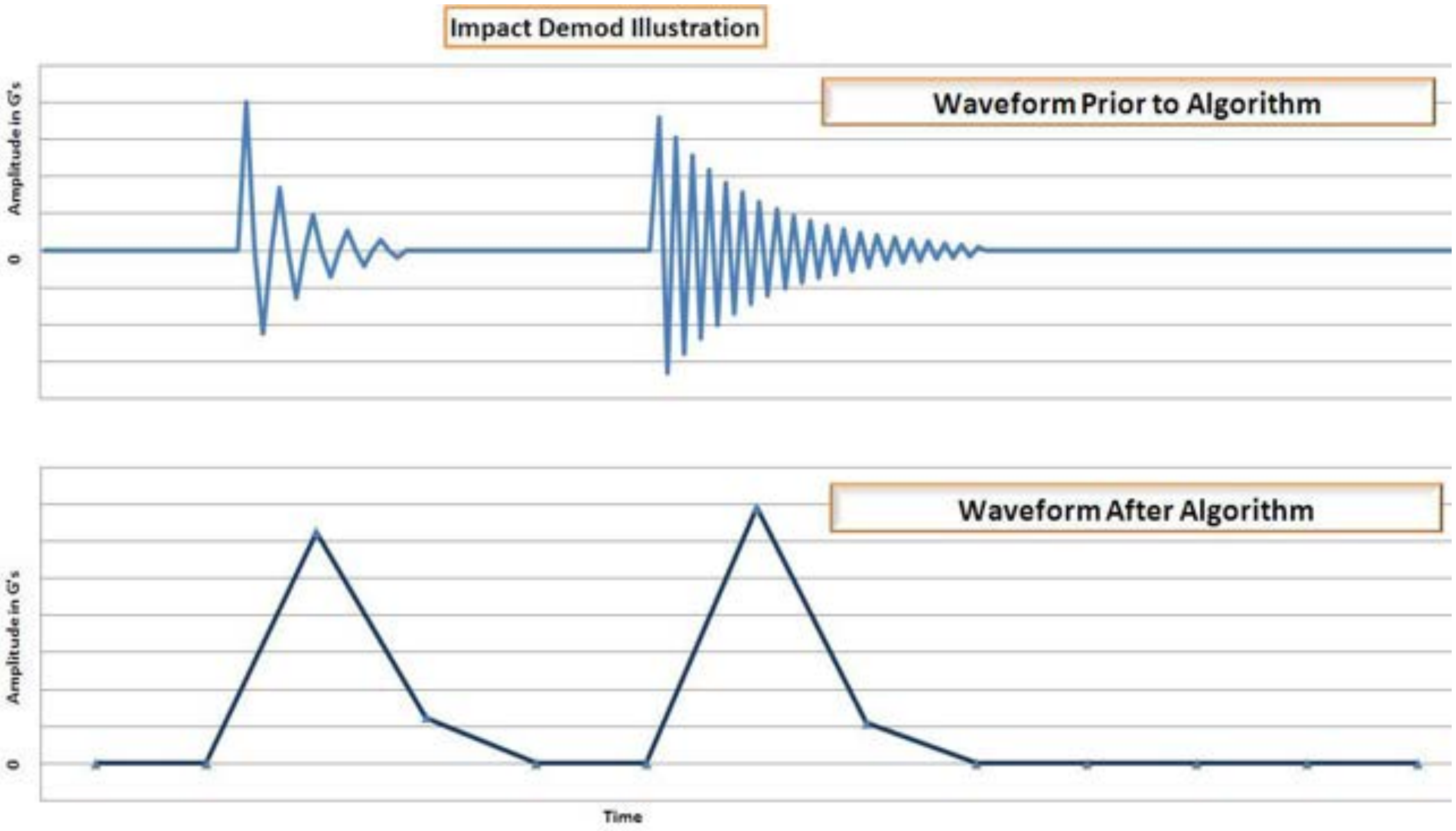
Enveloping Flaw

Required Low Pass Filter must meet Nyquist Criterion

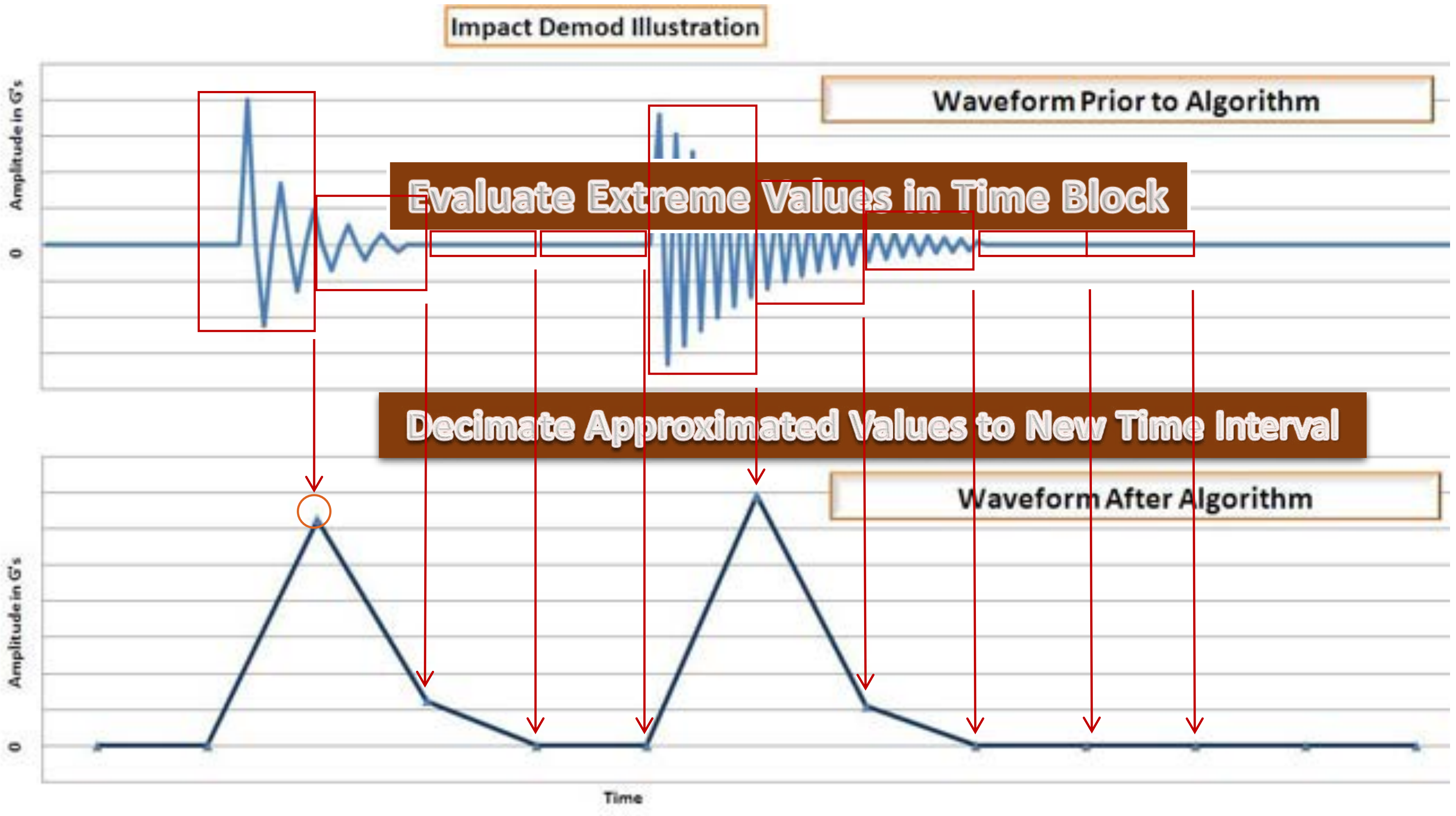


Impact Detection down to 5 RPM

Impact Demod

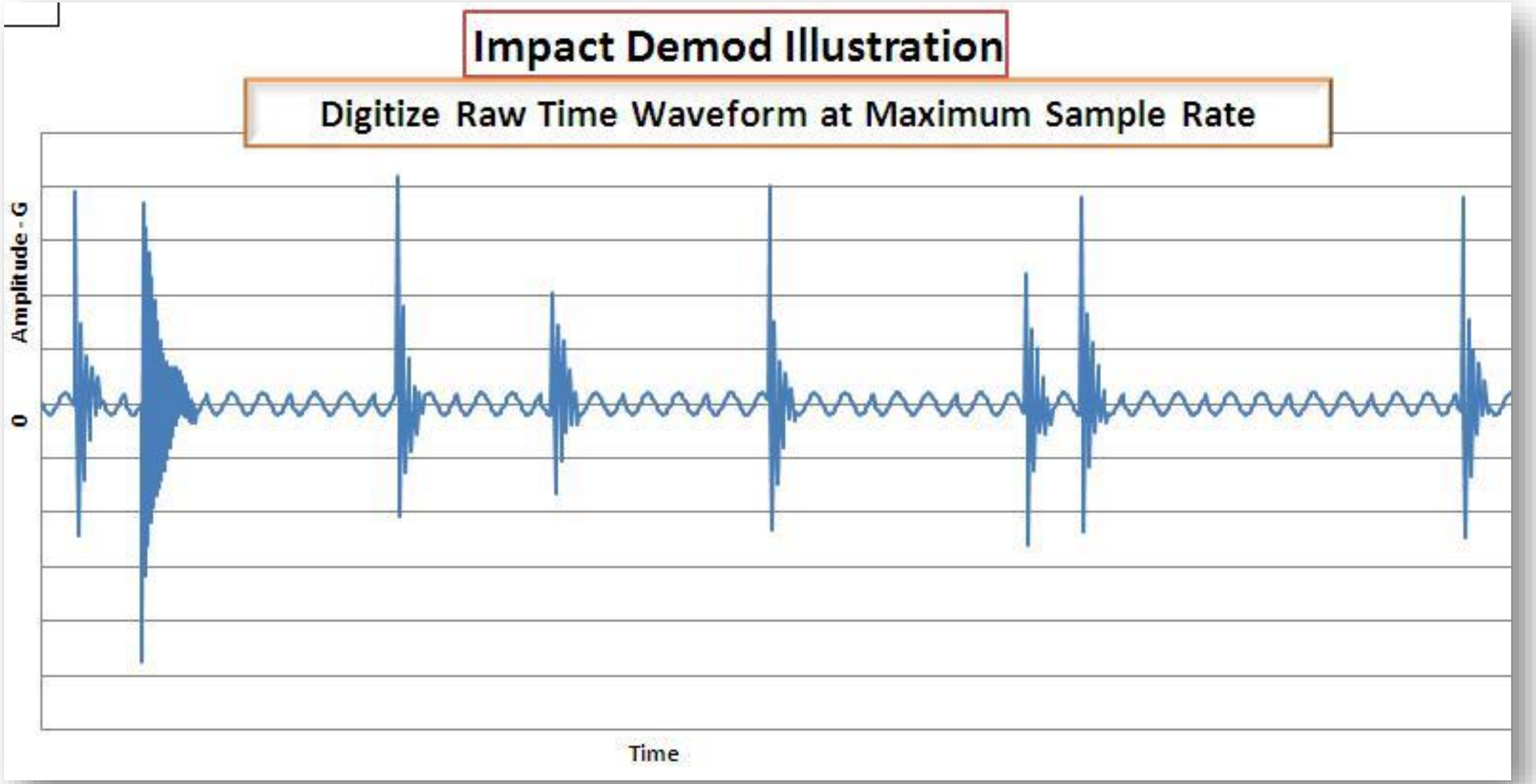


Impact Demod Animation



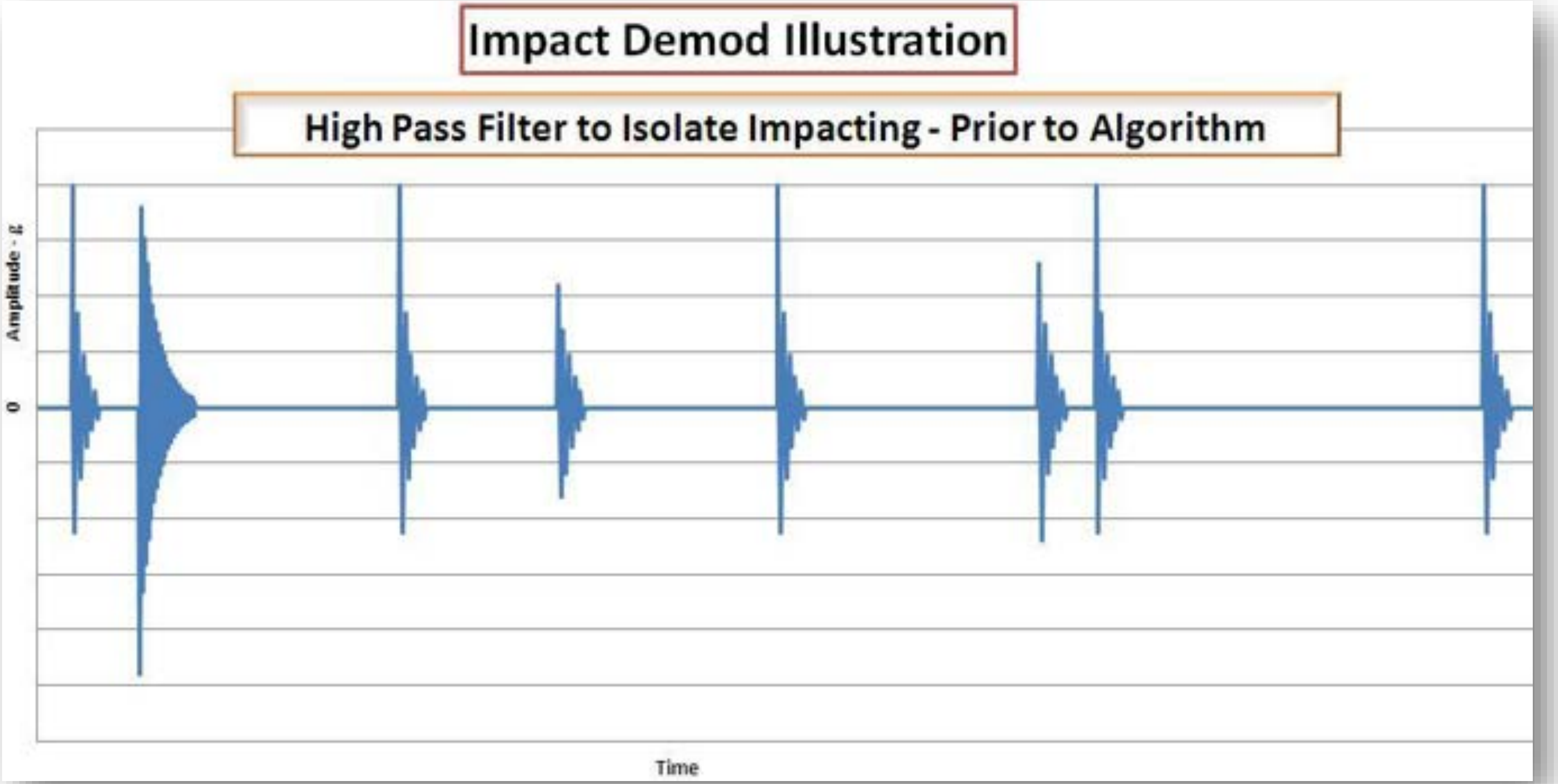
Impact Demod – Step 1

Digitize HF Acceleration Data



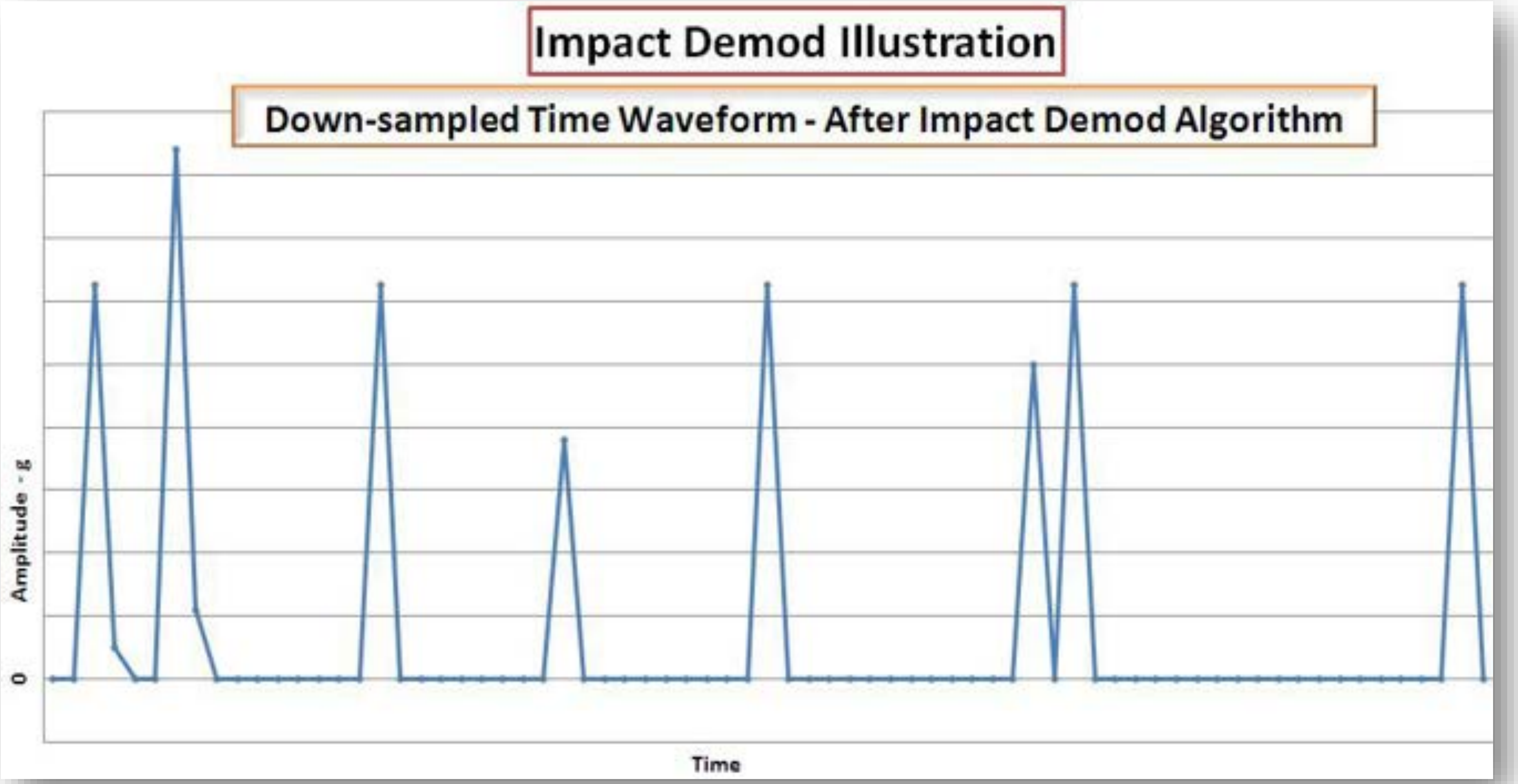
Impact Demod – Step 2

High Pass Filtering



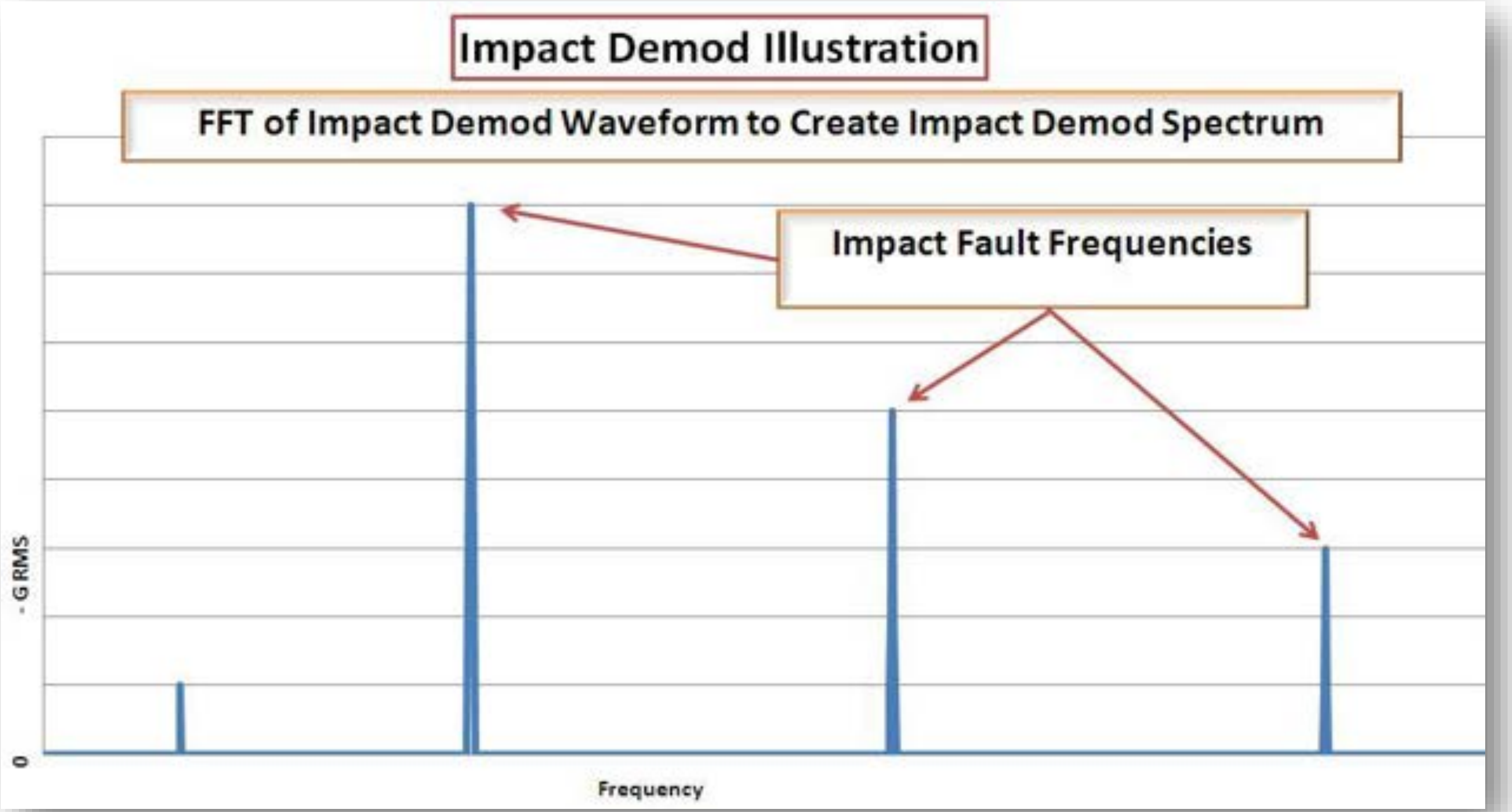
Impact Demod – Step 3

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

Set-up 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)

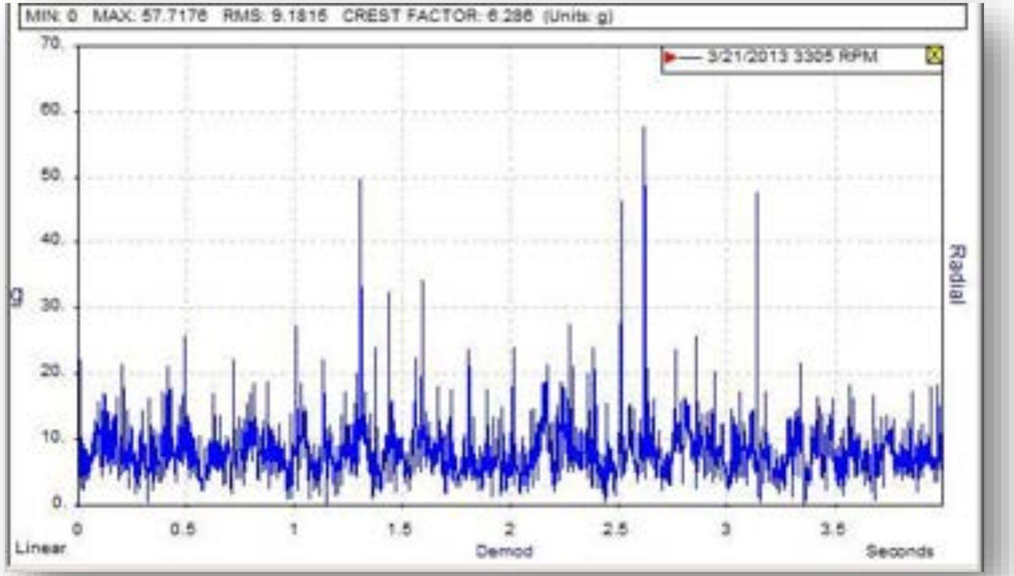
Impact Demod
Analysis Tips

- 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

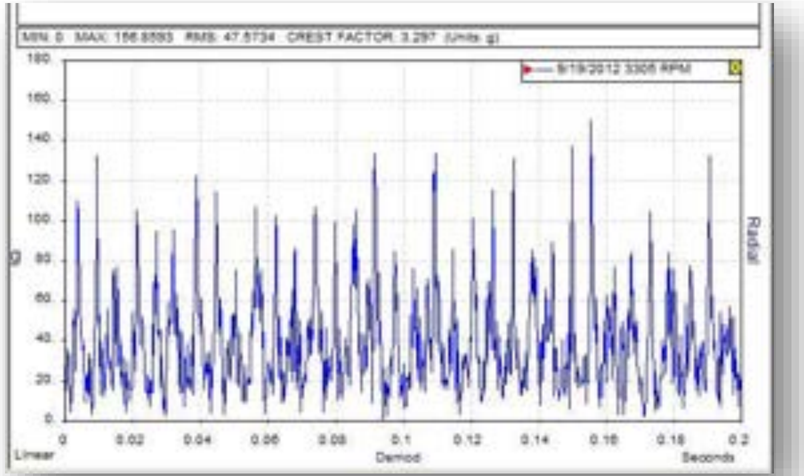
Impact Demod Time Waveform



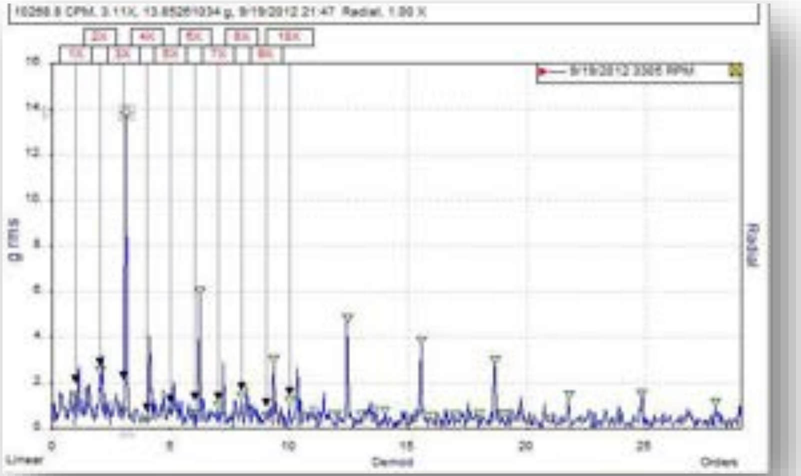
Impact Demod
Analysis Tips (continued)

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

Impact Demod Time Waveform



Impact Demod Spectrum

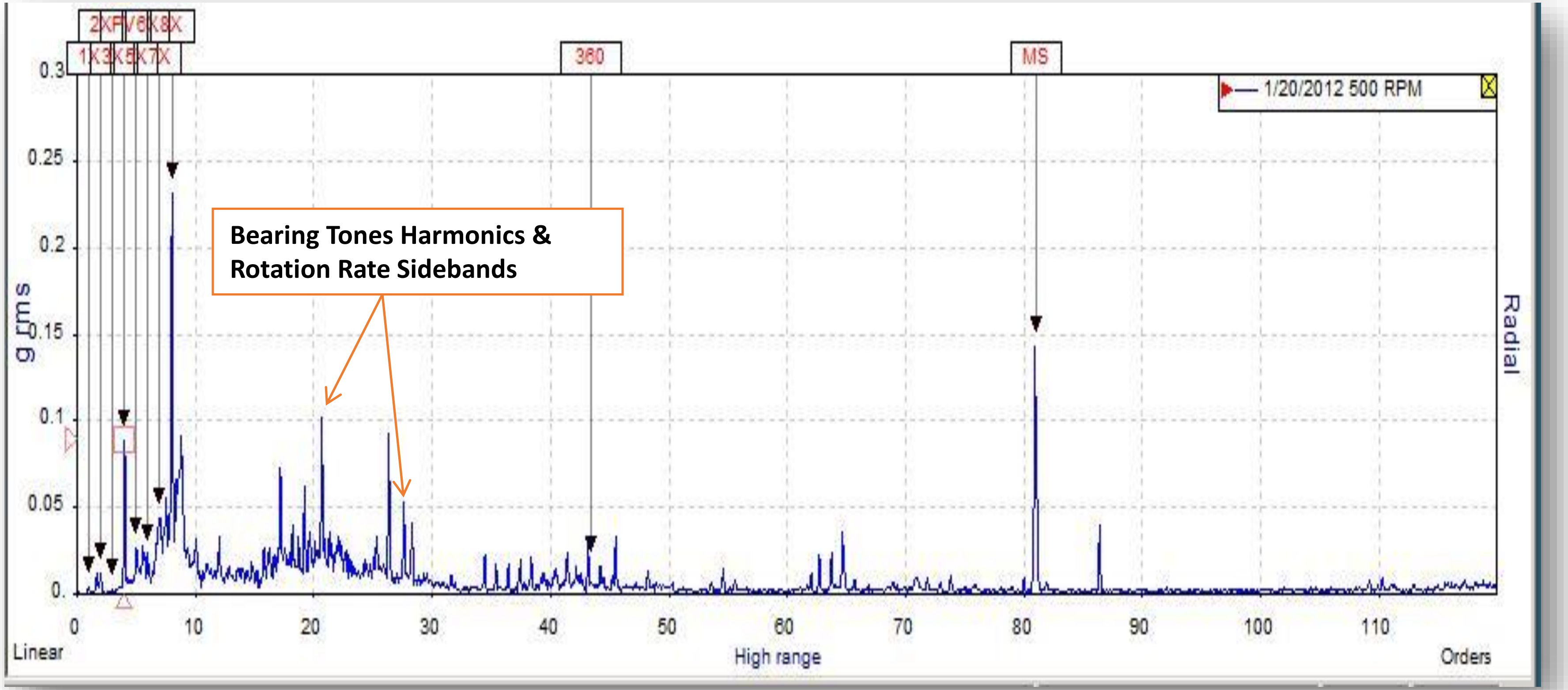


Impact Demod: *Example*

2000 HP Vertical Motor

Slow Speed - Motor Coupled End

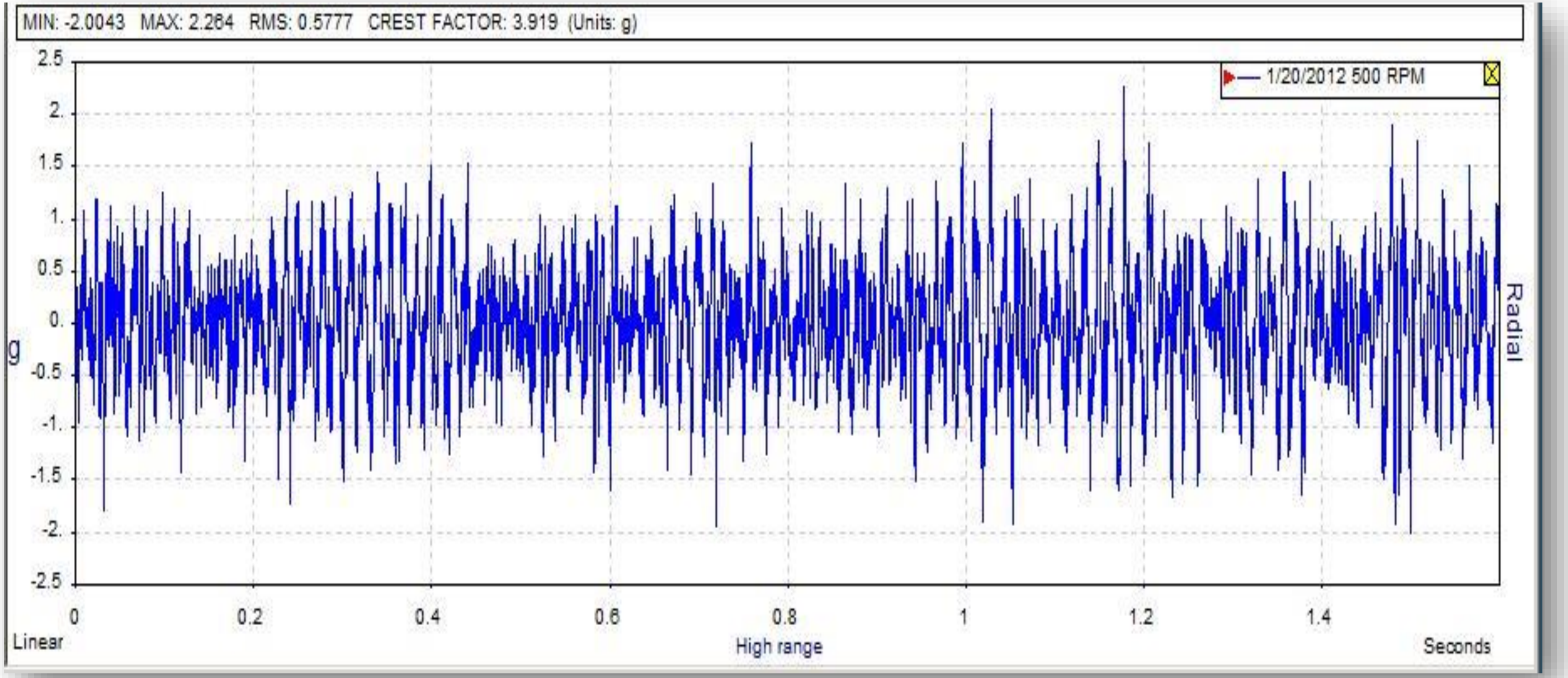
Standard High Range Spectrum



Indication of some HF bearing noise

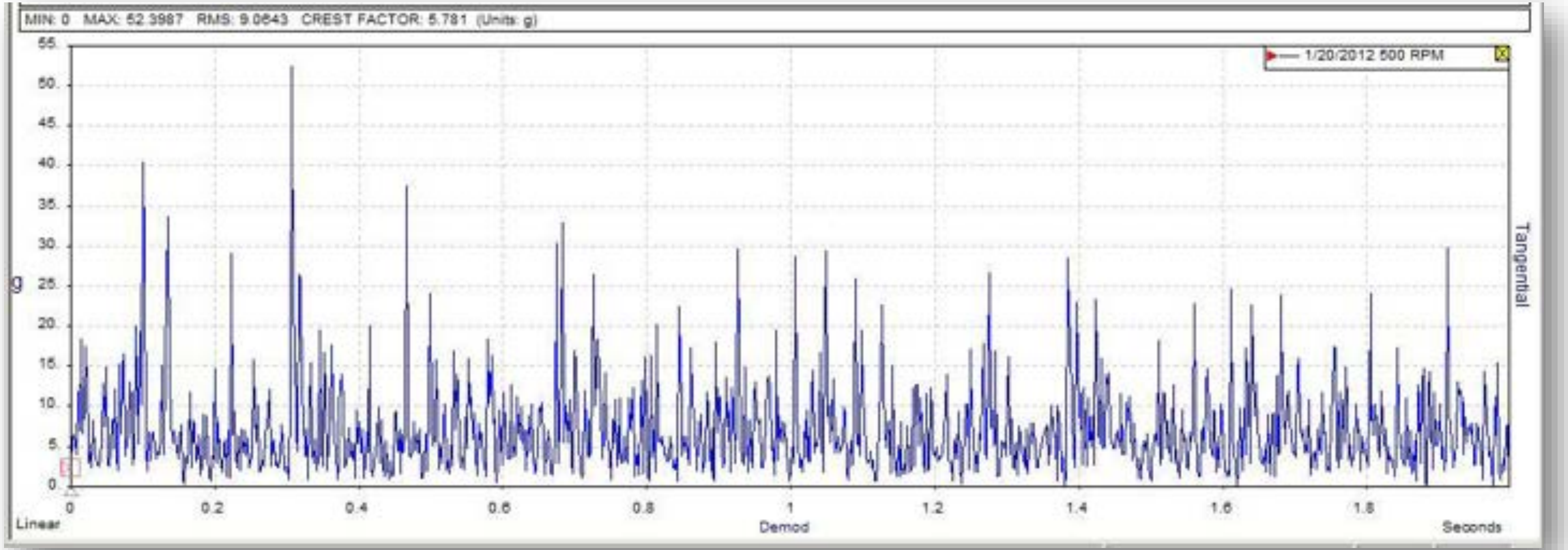
Slow Speed - Motor Coupled End

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



Slow Speed - Motor Coupled End

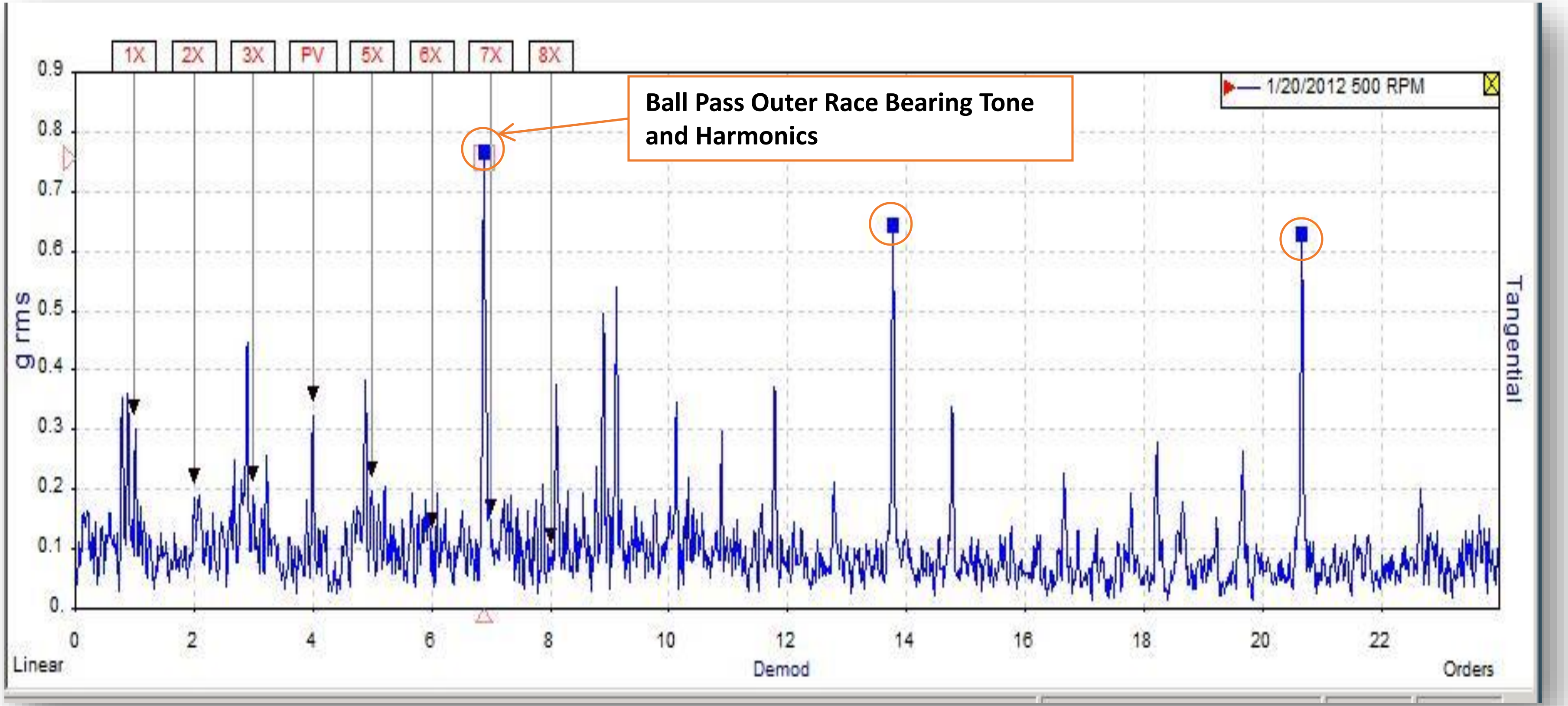
Impact Demod Waveform – 52g peak



Indication of serious impacting

Slow Speed - Motor Coupled End

Impact Demod Spectra



Indication of periodic content at 6.9xM

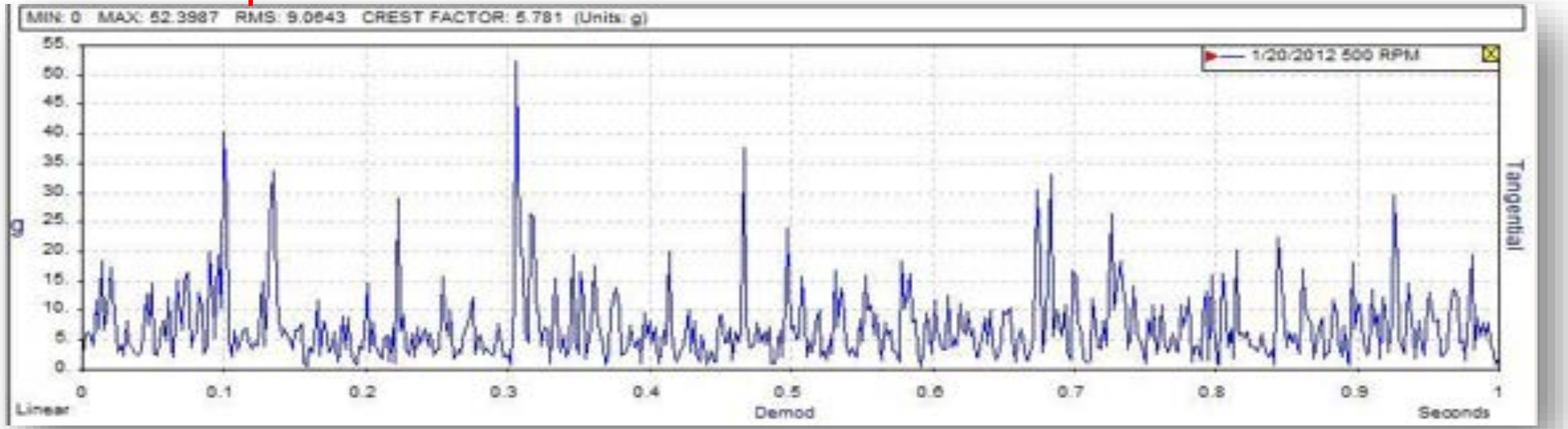
What Was Found

Severe Electrical Fluting

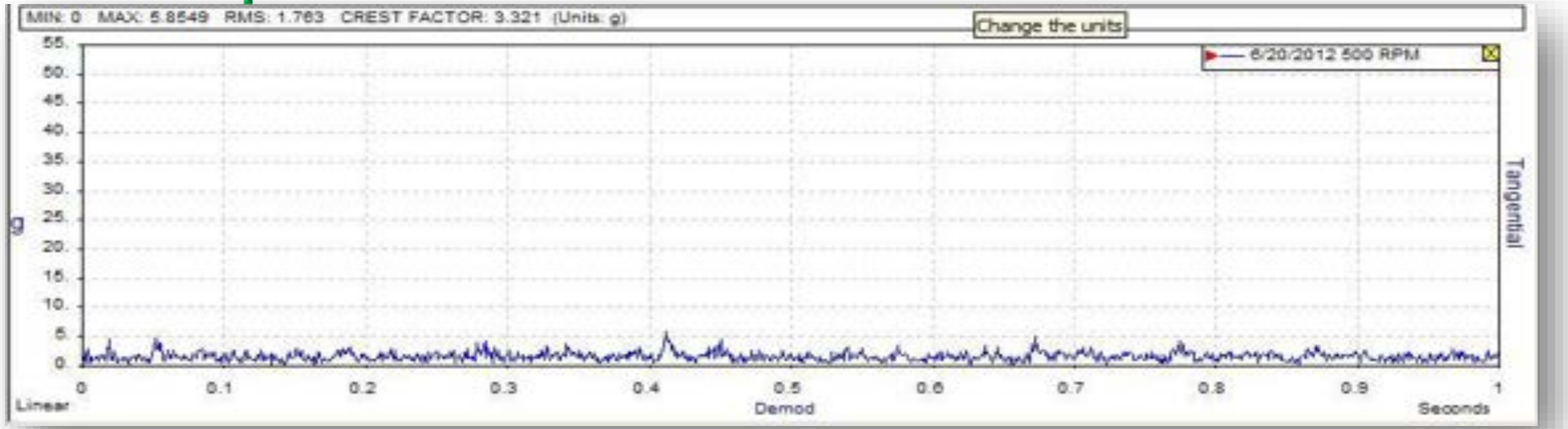
Motor Coupled End

Impact Demod Time Waveform - Comparison

Before Repair



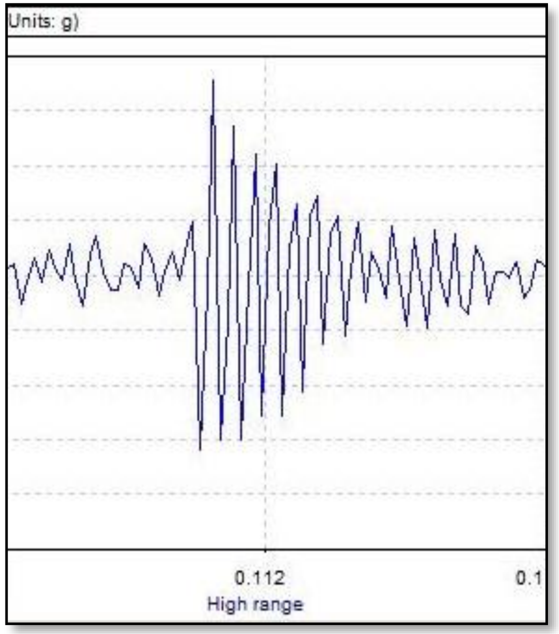
After Repair



Impact Demod: *Gearbox Example*

Gearbox- HS Shaft Free End

Progression of Impact Levels



May – 67g

Jun – 80g

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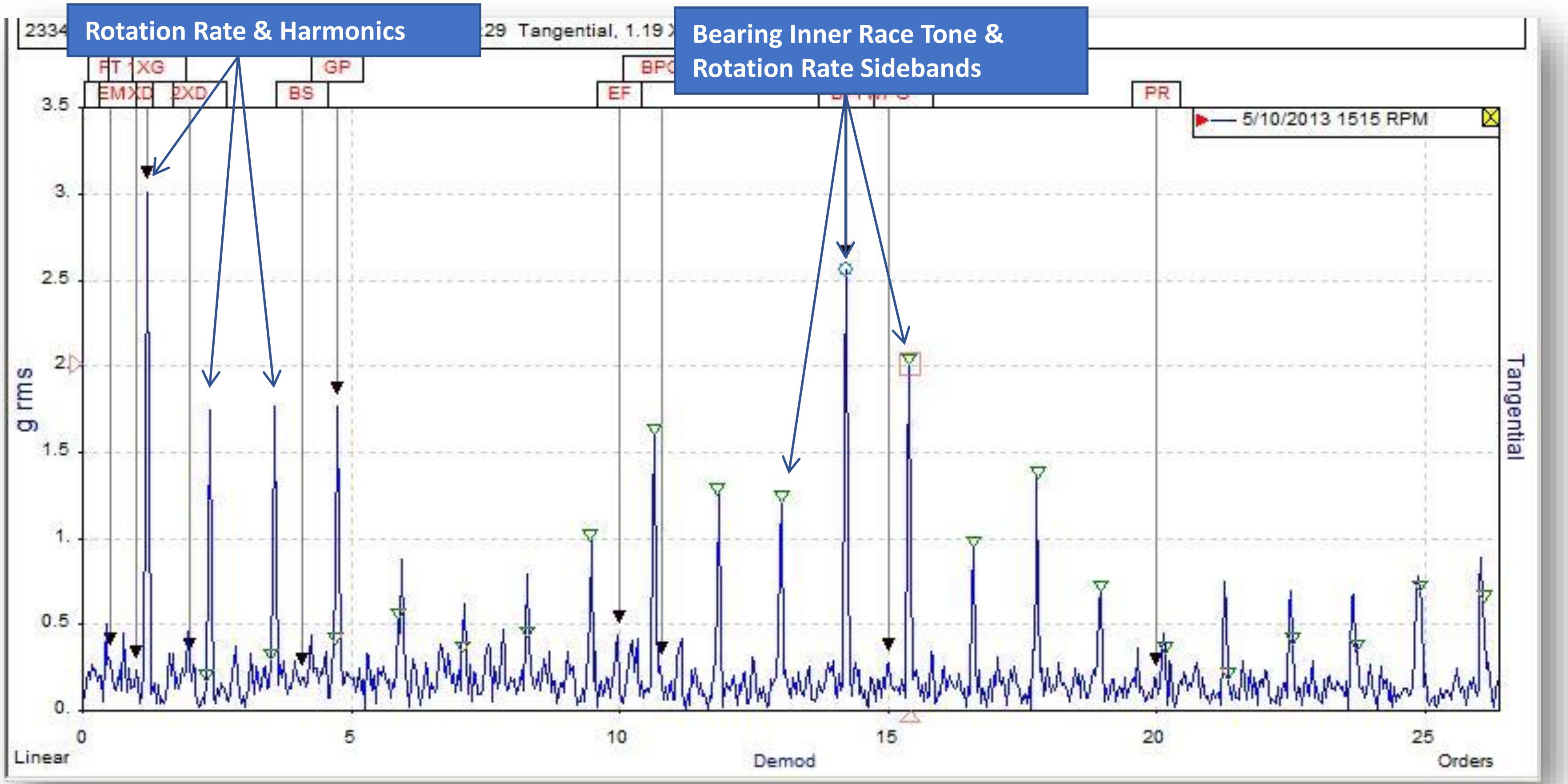
Gearbox- HS Shaft Free End
Impact Demod Spectrum



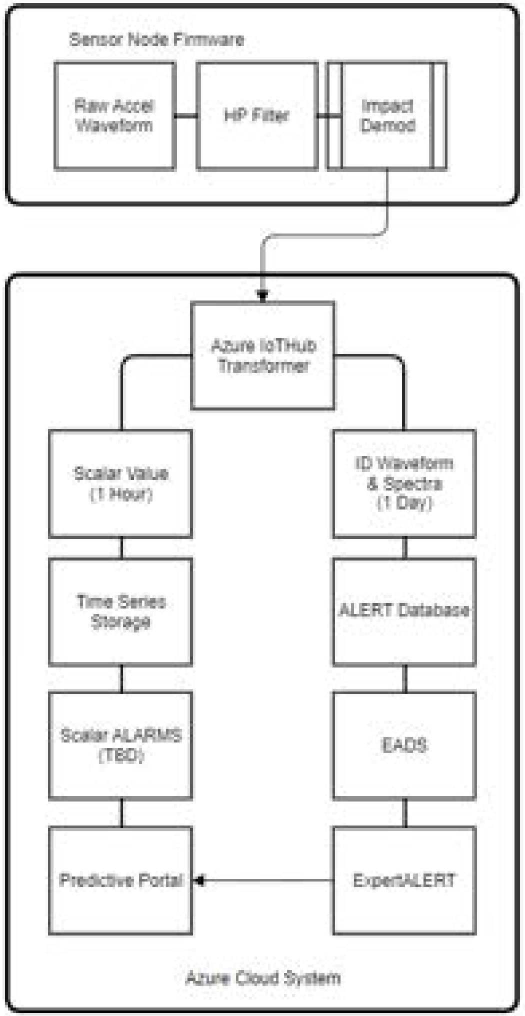
Indication of Inner Race Bearing Fault

Gearbox- HS Shaft Free End

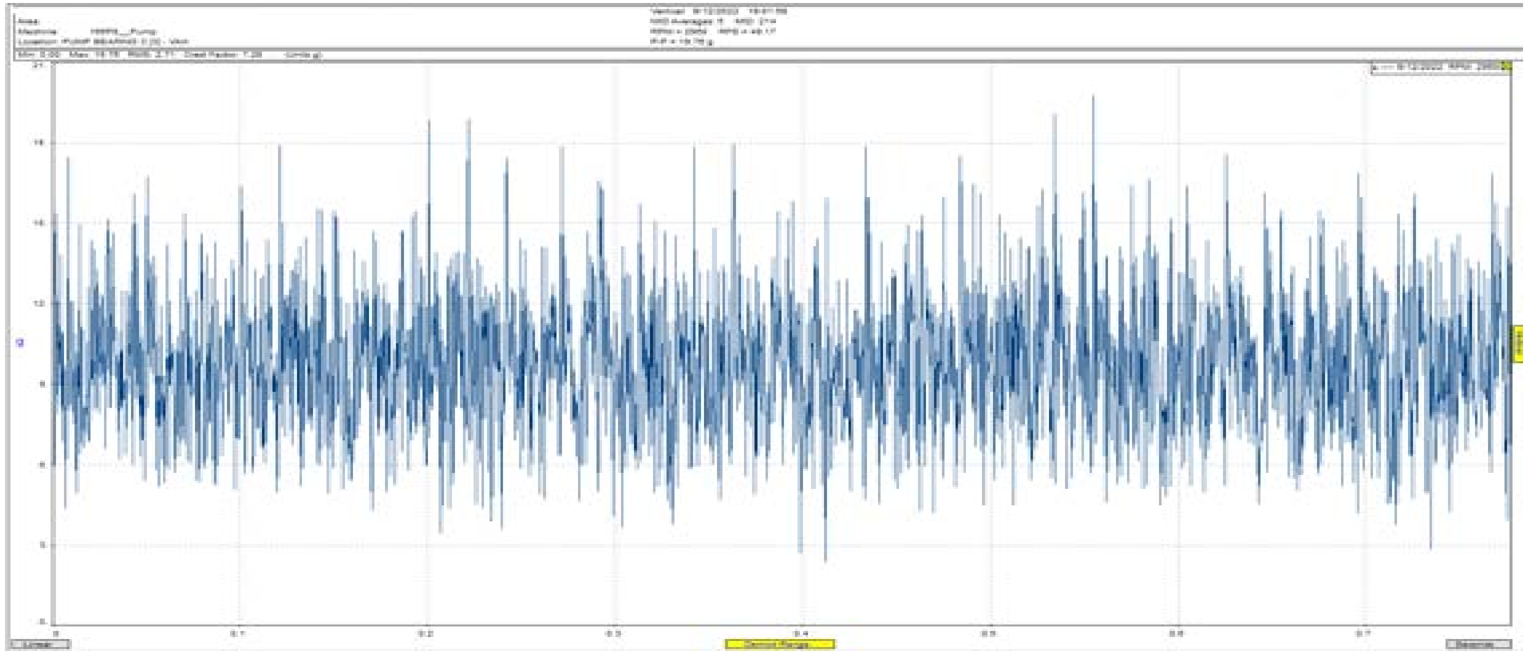
As Found

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 (ODR) ~ 10KHz bandwidth (-3 dB @ 6.6 KHz)
  - 20,480 raw acceleration samples
- Passed through ID algorithm which reduces data samples:
  - 2,000 Hz High pass filter
  - ID sample window = 10 samples/sample: 2,048 Reduced Samples
  - Duration of ID waveform: 0.77 seconds, Fmax: 1,042 Hz
- Scalar data is captured hourly regardless of machine running condition
  - Scalar ID is 'peak' amplitude from ID waveform: one 16bit integer transmitted over-the-air
- ID waveform is captured daily if machine is running
  - 2,049 16bit integers transmitted over-the-air
  - This data is stored in ALERT and is what is processed by EADS.



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

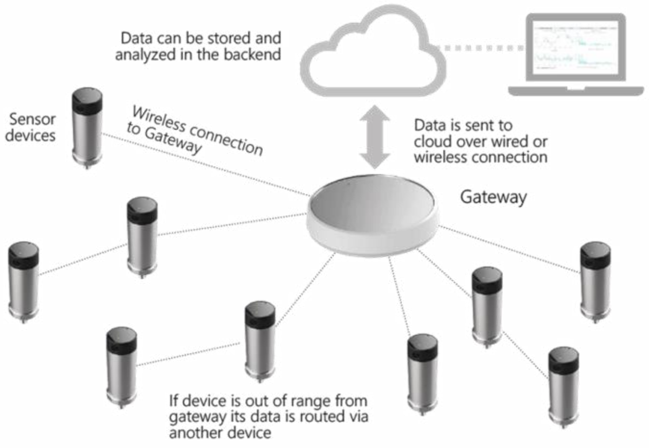
<3> Moderate — Pump Bearing Synchronous Impacting
PUMP BEARING 3 Vertical, Waveform Peak = 13 g

<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 13.44 g

Data Acquisition Hardware



Portable, Manual Acquisition

TRIO – DP-2

- 4 simultaneous channels

Largest asset coverage

- All accessible, industrial, rotating assets

Tech Specs:

- 40kHz Fmax
- 102.4kHz sample rate
- 100g (w/ 100mV/g sensor)
- 25,600 lines of resolution

Permanent, Auto Acquisition

Online i800

- 8 dynamic + 8 process

Most versatile online system

- Inaccessible, critical assets
- Compressors, gearboxes

Tech Specs:

- 40kHz Fmax
- 102.4kHz sample rate
- 100g (w/ 100mV/g sensor)
- 25,600 lines of resolution
- Wireless or wired
- Battery or line-powered

Permanent, Auto Acquisition

Online i110 / i120

- 16 multiplexed or 8+8 simultaneous channels

Monitoring down to 5 RPM

- Paper & metals machinery
- Slow speed gearboxes

Tech Specs:

- 40kHz Fmax
- 102.4kHz sample rate
- 100g (w/ 100mV/g sensor)
- 51,200 lines of resolution
- >14M sample buffer
- Wireless or wired

Permanent, Fully Wireless

Wireless Accel™ 310

- Hi-res, triaxial + temp

Most connected program

- Most common, industrial rotating assets
- Continuous running assets

Tech Specs:

- 6.3kHz - 10kHz Fmax
- 26.7kHz sample rate
- +/-16g input range
- 1,600 lines of resolution
- 3-year battery, fixed
- Mesh + gateway


AZIMA|DLI
CE

Watchman AIR™ - Wireless Vibration Diagnostics

Why ours:

- Actionable Results, not just Alarms or Hand-raiser
  - Daily diagnostic fault analysis with prioritized, actionable results
- Automated Learning Mode
  - Avoid hassle of setting thresholds for all hourly data values
- Is-running Triggers
  - Collects data when machine is in a running state
- Impact Demod
  - Proprietary feature for early bearing fault detection
- Volume Management
  - Persistence Logic, Analyst Workflows
- Low-cost Analysis Services
  - Very cost-effective full solution
- 3-year Battery Guarantee
  - Sealed battery improves performance

FLUKE Reliability

Watchman Online – i110 Data Acquisition Hardware

NEW

- Higher Channel Utilization than i120
  - 16 multi-plexed channels vs 8 simultaneous vibr. + 8 process channels
- Targets:
  - Compressors
  - Slow-speed machines
  - Critical assets

What?

- Multi-channel advanced vibration acquisition device for critical & slow-speed assets

Why?

- Provides permanent application where wireless is insufficient

FLUKE Reliability

Analyst Services

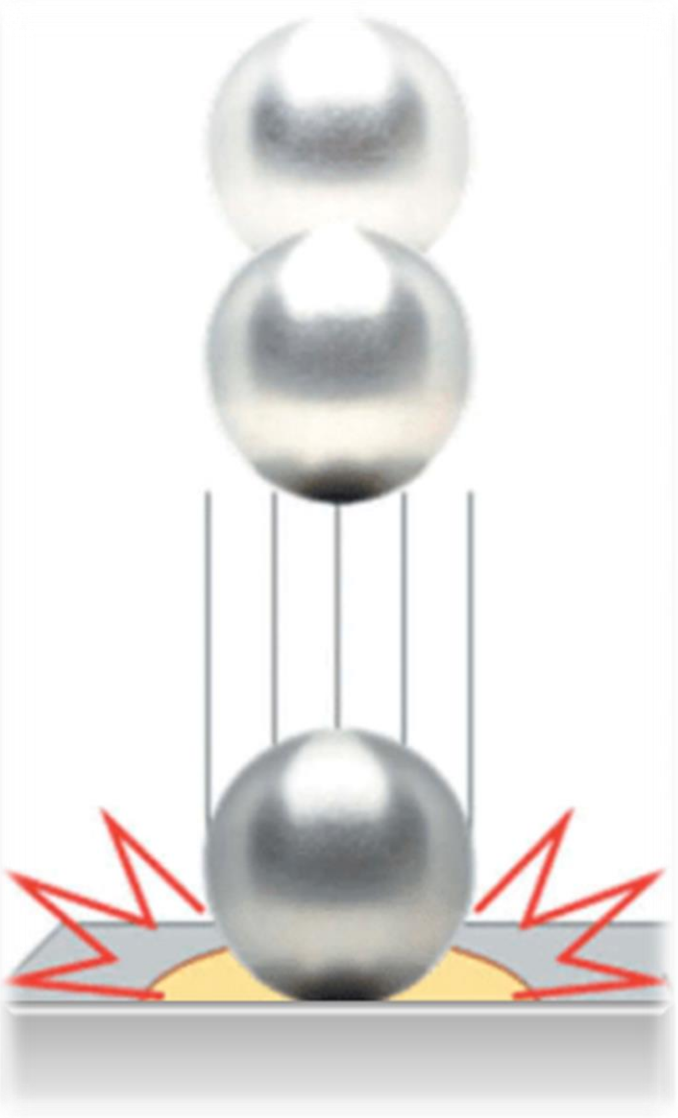
- 30 Analysts / Managers
- ~ 500+ years Vibration Analysis Experience
- Certifications
  - ISO Level I to Level IV Analysts
- ~ 330,000 Delivered Machine Results Per Year
  - (Avg 100,000 Lines/Machine Test)
  - Actionable Results

MOBIUS INSTITUTE

Vibration Institute

FLUKE Reliability

Early Bearing Fault Detection



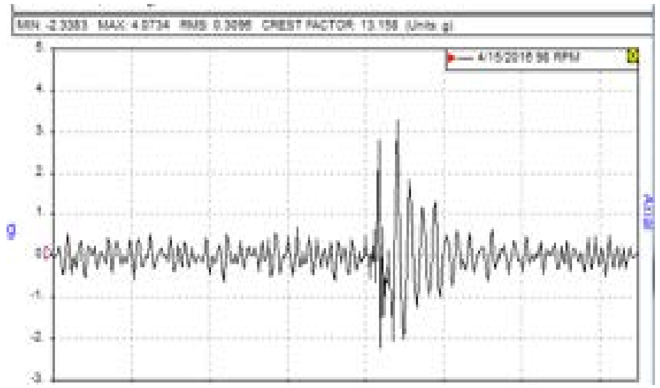
What is Impact Demod

- Captures & display impacts - events caused by stress waves
- Characterized by short duration (microseconds) events
- Not visible in standard (low resolution) time series data

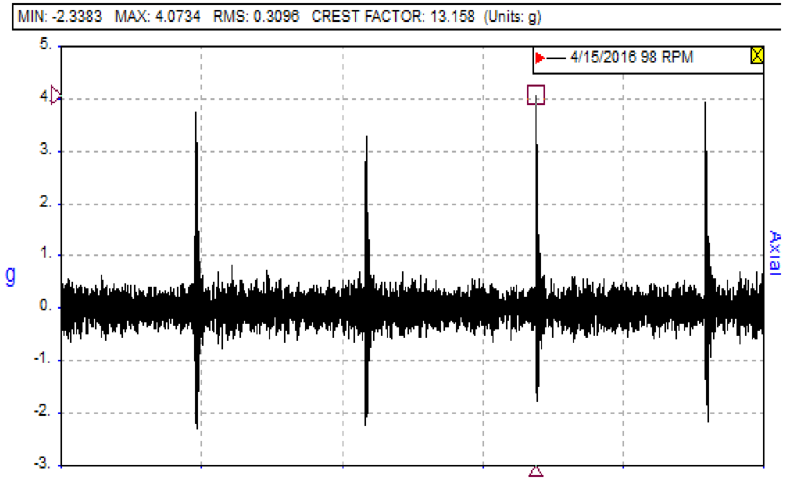
Impact Detection Method

- Use fast sample rate (>25kHz)
- Compress sample while maintaining max time values
- Particularly effective for Slow Speed Bearing Fault Detection

↓ ZOOM ON SINGLE PEAK ↓

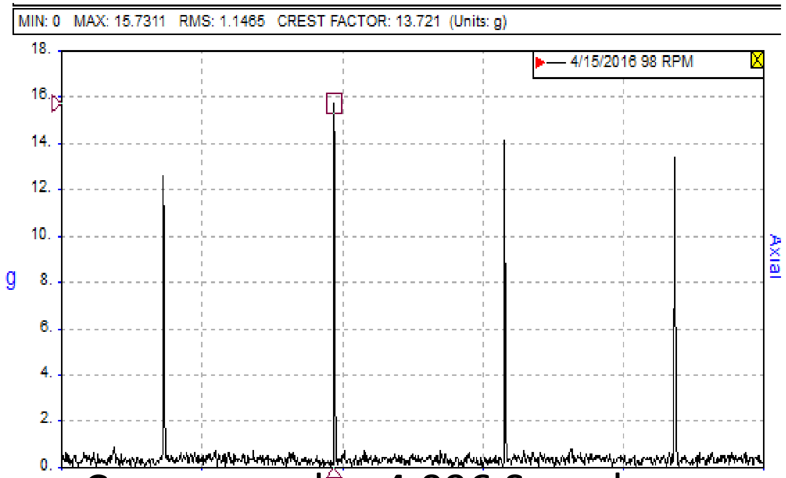


↑WAVEFORM USING MAX SAMPLE RATE ↑



Very Large: ~ 500,000 Samples

↑ IMPACT DEMOD WAVEFORM ↑



Compressed: ~ 4,096 Samples

QUESTIONS ?

THANK YOU!