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Basics of Vibration Data Acquisition and Processing

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October 23 & 24, 2018

RAM XI Training Summit

Overview

- Test Conception
- Transducer Selection Principles
- Choosing Data Acquisition System Settings
- Checking Data and Common Issues
- Data Processing

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- ***Test Conception***
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Test Conception

- Why is the data being collected?
- What key metrics are being measured?
- What should the test conditions be?
- How will the data be used?
- What constitutes a successful test?

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Transducer Basics

- Transducers convert physical phenomenon into electrical signals
  - Most vibration transducers will output a voltage
  - Some industrial applications use transducers that output a current

- Vibration is most often quantified by measuring motion or force
  - Displacement
  - Velocity
  - Acceleration
  - Force/strain

Considerations for Choosing the Measured Phenomena

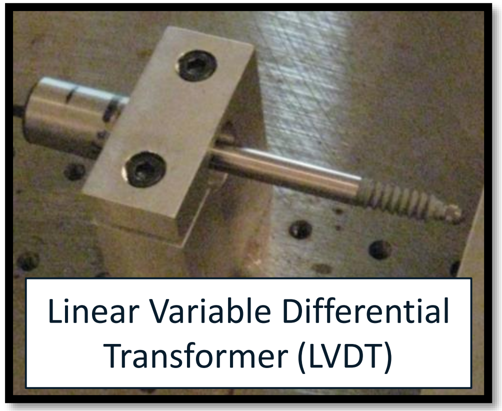
- Signal processing can be used to switch between motion phenomena, but it’s best to measure the actual quantity if possible

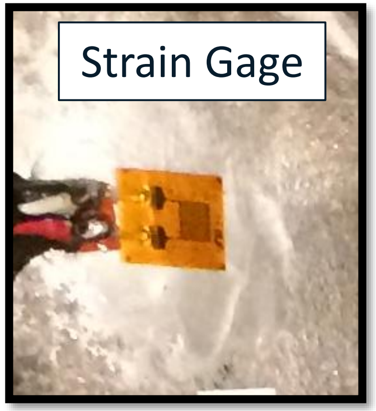
- Displacement and velocity sensors measure the motion between two points and require a reference location

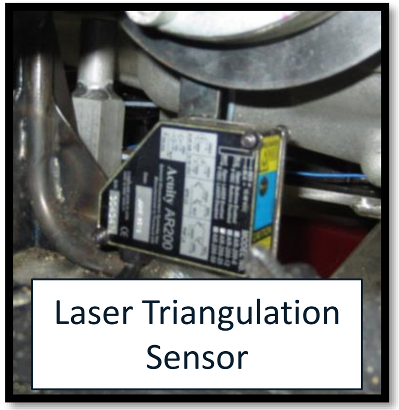
- Load cells must be placed in the load path and can effect how the load source is coupled to the receiver

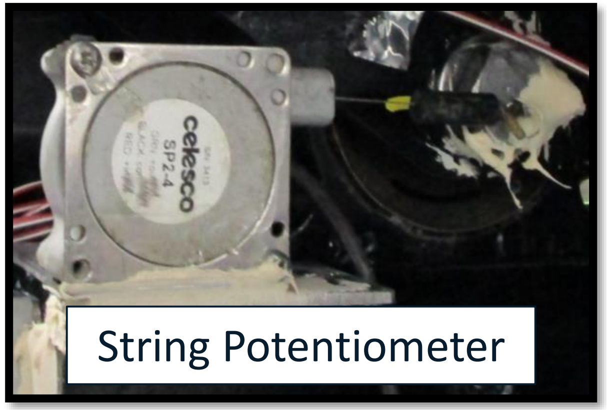
- ***Accelerometers are typically considered the industry standard for vibration measurements***
  - Accelerometers are referenced to inertial forces, reducing the potential sources of measurement error
  - Accelerometers need to be affixed only to the desired measurement location, greatly simplifying the set-up process
  - Accelerometers have significant historical use in vibration measurements, which means that engineers have a good “feel” for what the sensor output means

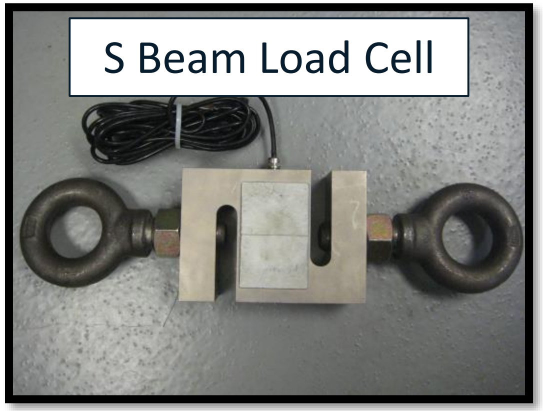
Transducer Types











Many more transducer types exist for a variety of phenomenon and applications

Primary Transducer Specifications

- ***Sensitivity*** is the electrical output per engineering unit of the measured phenomenon (e.g. mV/g)
  - Chosen based on the expected vibration levels and voltage range of the data acquisition system, typically based on experience
  - 10 mV/g for accelerometers are typically used if the vibration levels are unknown

- ***Frequency range/response time*** should be appropriate for the test

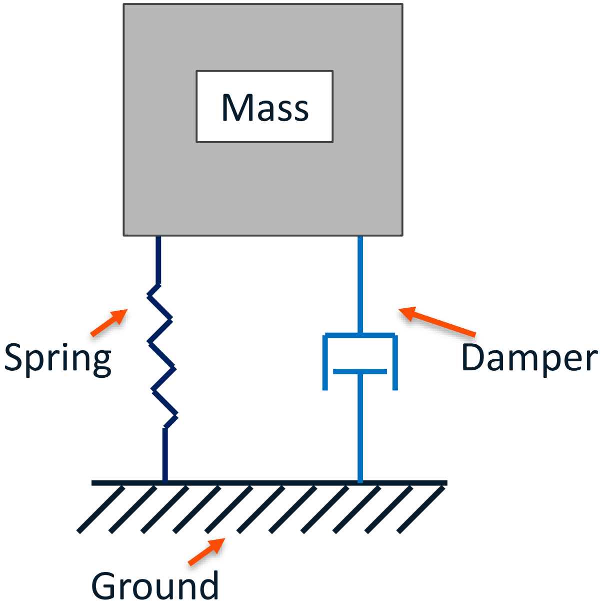
- ***Physical size and weight*** – smaller is generally better but not always necessary

Transducer Mounting Considerations

- Typical mounting methods include adhesives, magnets, and mechanical connections

- ***The transducer attachment to the test article needs to be sufficiently rigid for the desired frequency range***
  - Think of the transducer as a SDOF oscillating system with the attachment as a spring
  - Super glue and epoxy attachment methods are typically stiff enough for accelerometers that weigh ≤20g in a 2-3 kHz frequency range

SDOF Oscillating System



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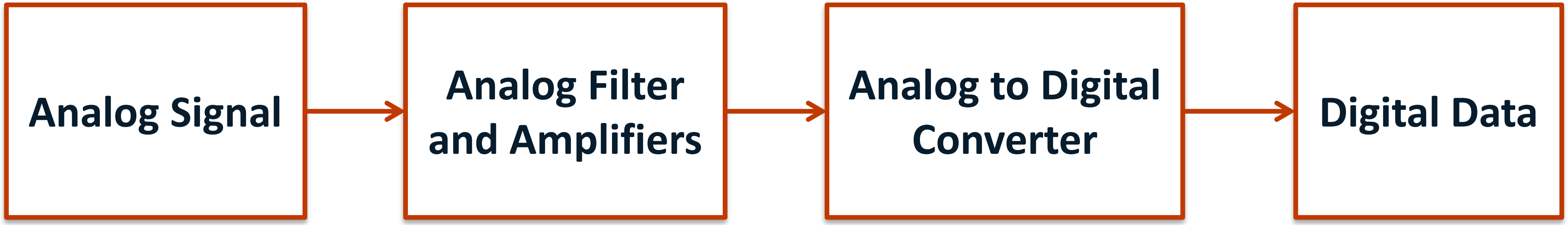
Data Acquisition System Function

- The data acquisition (DAQ) system converts the transducers output (analog electrical signal) into digital data that can be used by a computer

- The signal conversion is performed by an analog to digital converter (ADC) through two operations:
  1. *Sampling* generates the time axis, depending on the sampling frequency
  2. *Quantization* determines the amplitude of the signal at each sampled time, depending on the input range and ADC bit depth

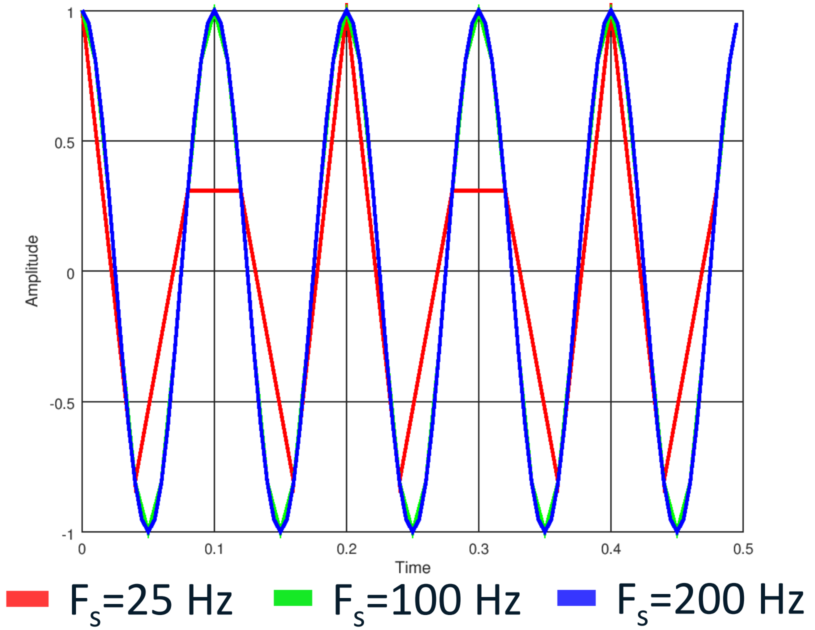


ADC Operations – Sampling Rules of Thumb

- <u>Sampling Frequency:</u>
  - *Data for frequency analysis* – sample at 2.5x the maximum frequency of interest
  - *Data for time domain analysis* – sample at 10-20x the maximum frequency of interest, apply low pass filter according to maximum frequency of interest
  - Main limitation is DAQ buffer size and convenience of working with data

- <u>Sampling Duration:</u>
  - *Transient conditions* – the duration should be sufficient for the test condition and the potential data processing methods
  - Steady state conditions – 30 seconds of data is typically considered sufficient but this is dependent on the data processing methods

10 Hz Sine Wave Sampled at Different Rates

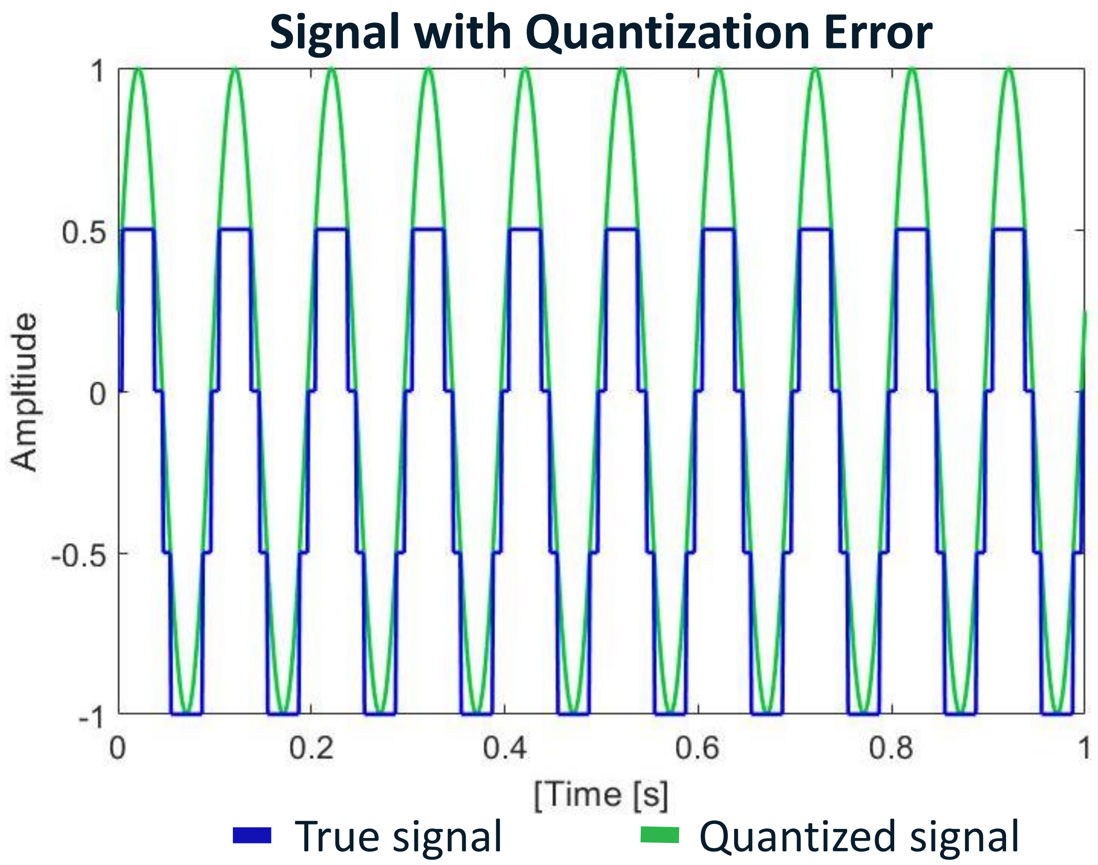


ADC Operations – Quantization

- Number of bins for common ADC bit depths
  - 12 bit ADC – 4,096 bins
  - 16 bit ADC – 65,536 bins
  - 24 bit ADC – 16,777,216 bins

- Poor signal ranging causes quantization error, where the ADC assigns consecutive samples with the same value – *this is almost always unacceptable*

- ***The ADC voltage range should be chosen to be ~2x the maximum signal value***, proper transducer sensitivity should be chosen if the ADC has a fixed range



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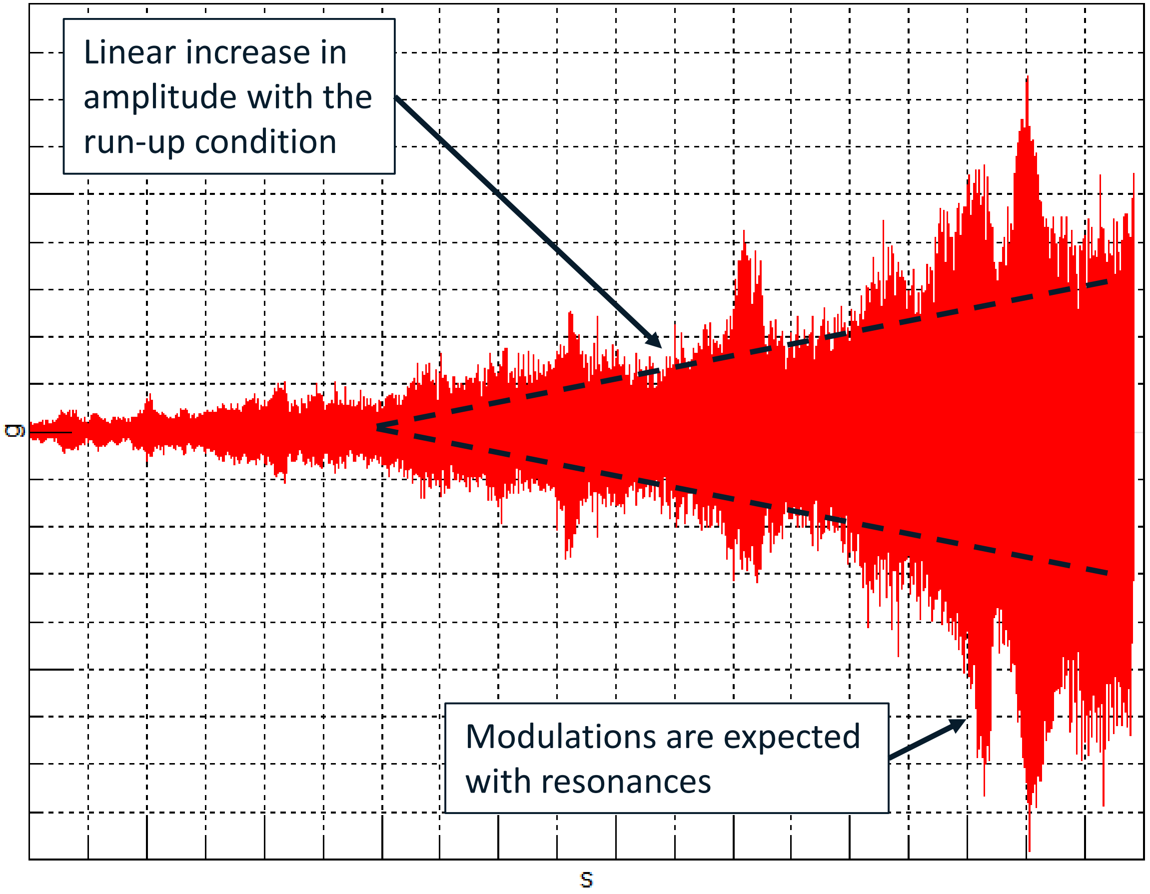
Data Quality Checks

- There are four primary data quality checks that should be performed with all tests:
  1. The data should meet the ***test requestor requirements*** – this may change test-to-test
     - Sample rate
     - Test conditions
     - All measurement locations are included
     - Etc.
  2. The data should have the expected ***general shape and amplitude***, depending on the operating condition
  3. The data should not be contaminated with ***EMI/RFI noise***
  4. The data should not have any ***overloads or quantization error***

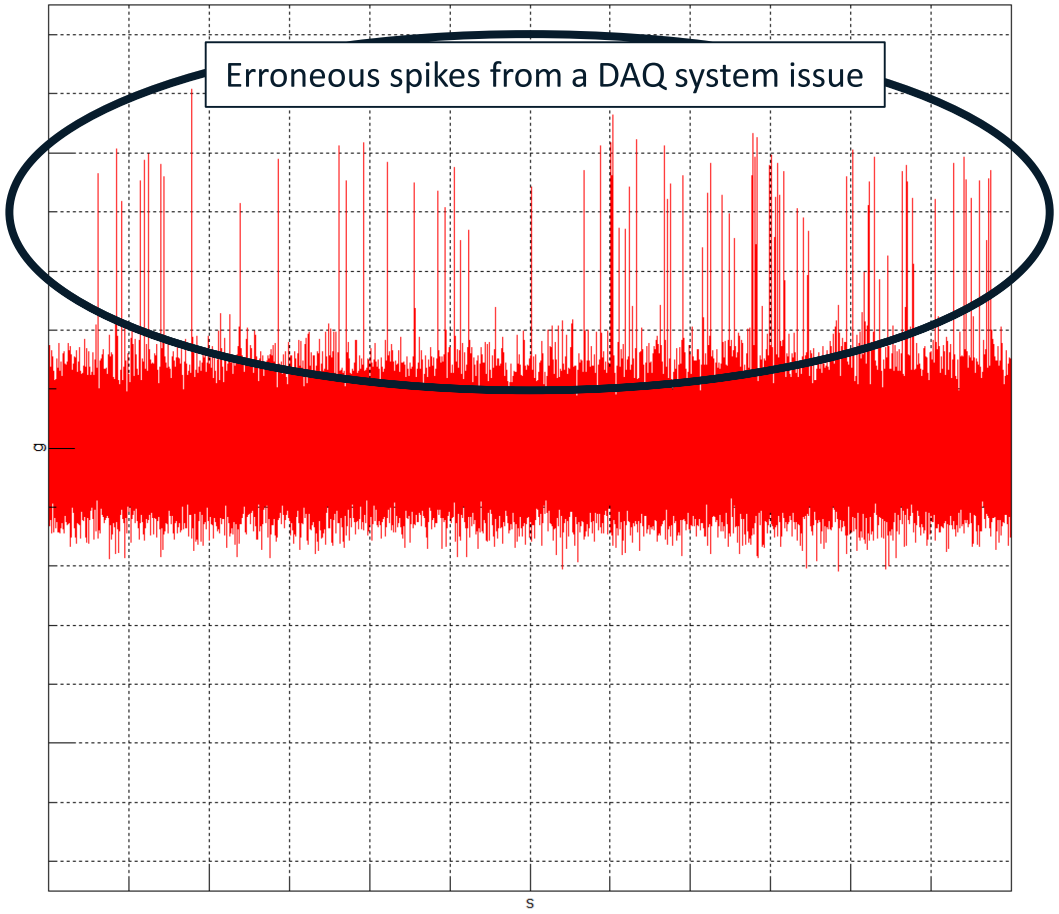
- These data checks should be performed *during* testing so any issues can be resolved and data can be re-collected, if necessary.

Data Quality Checks – General Shape and Amplitude

Sample Data from Run-Up Condition



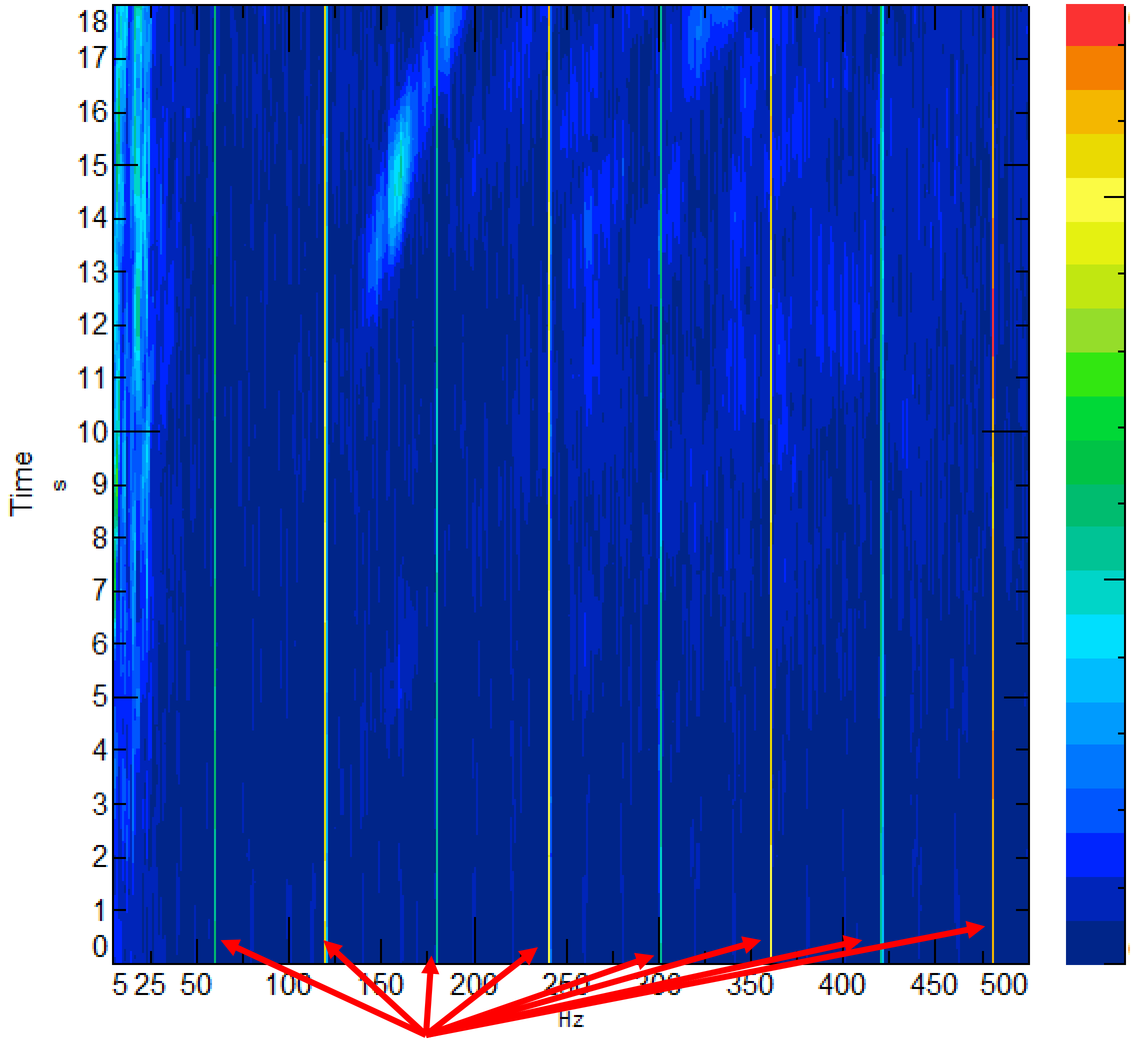
Sample Data from Steady State Condition



Data Quality Checks – EMI/RFI Noise

- EMI/RFI noise can be avoided by:
  - Using an isolated power supply
  - Ensuring that the transducers are electrically isolated from the test article
  - Ensuring that cable shielding isn't compromised
  - Ensuring the transducer, DAQ system, computer, and test article have suitable electrical grounding

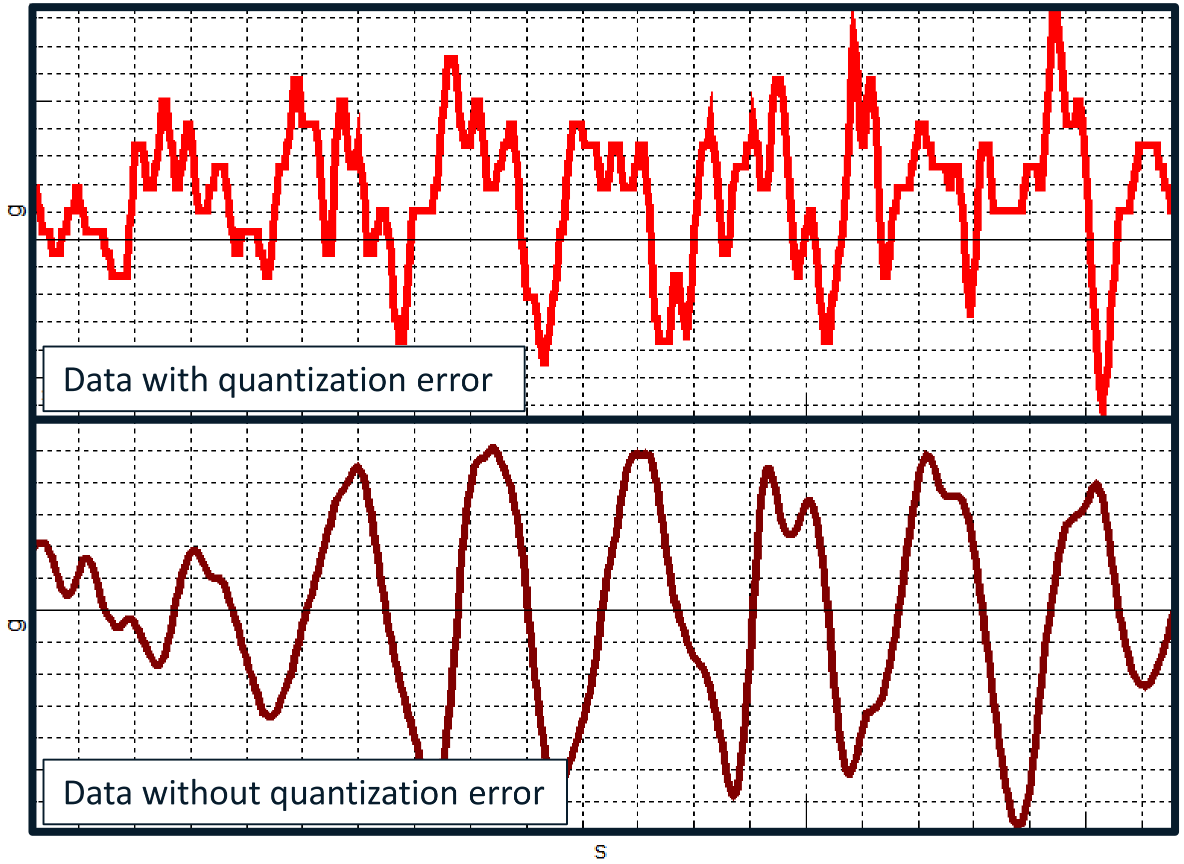
Sample Data Showing Electrical Noise



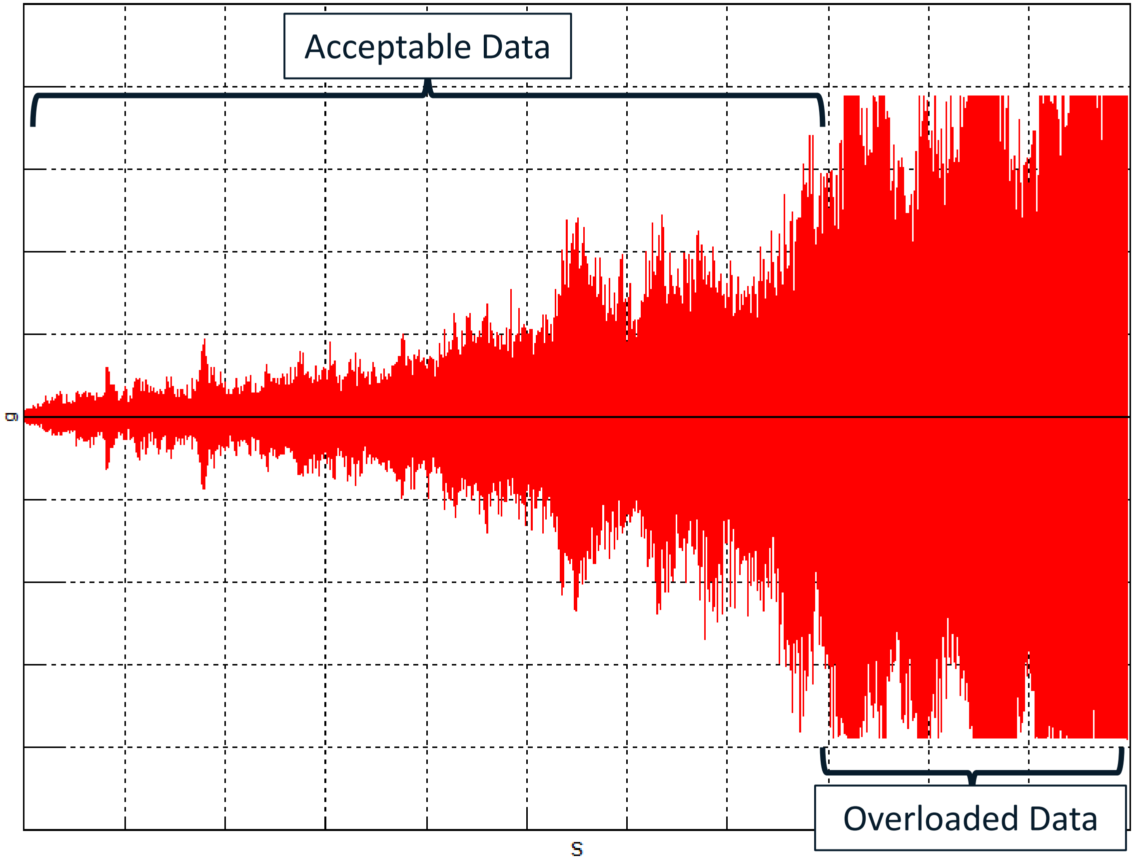
Vertical lines from electrical noise (60 Hz and harmonics)

Data Quality Checks – Overloads and Quantization Error

Sample Data Showing Quantization Error*



Sample Data Showing Overloading



Overloads and quantization errors should be addressed by using appropriate transducer sensitivities and ADC voltage ranges

*Note that the displayed data are not from the same measurement location

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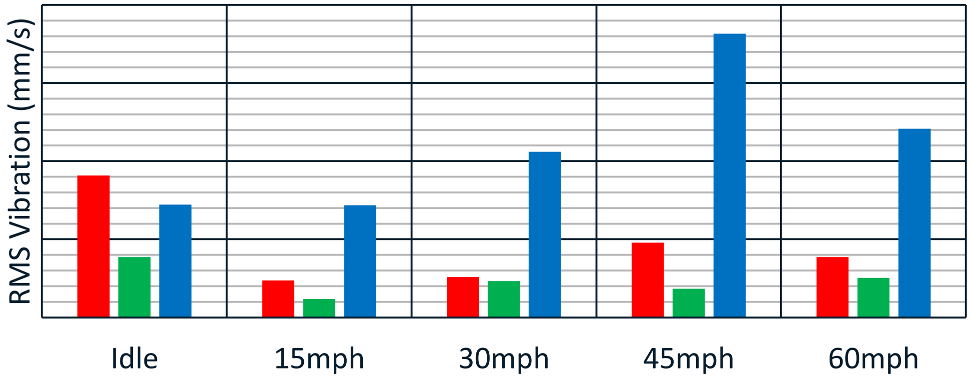
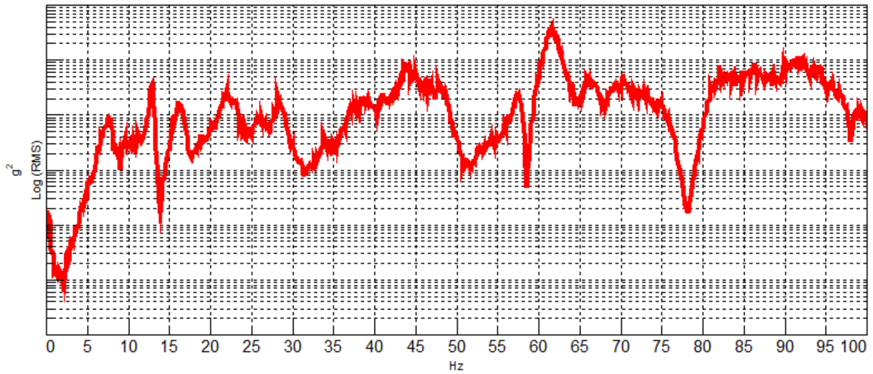
Data Processing

- <u>Time Domain:</u>
  - Statistical analysis
  - Filtering
  - Mathematical processes



- <u>Frequency Domain:</u>
  - Spectrum analysis
  - Order/harmonic analysis



- <u>Additional Processing Methods:</u>
  - Modal analysis
  - Time-frequency analysis
  - Angle domain processing

Spectrum Calculation

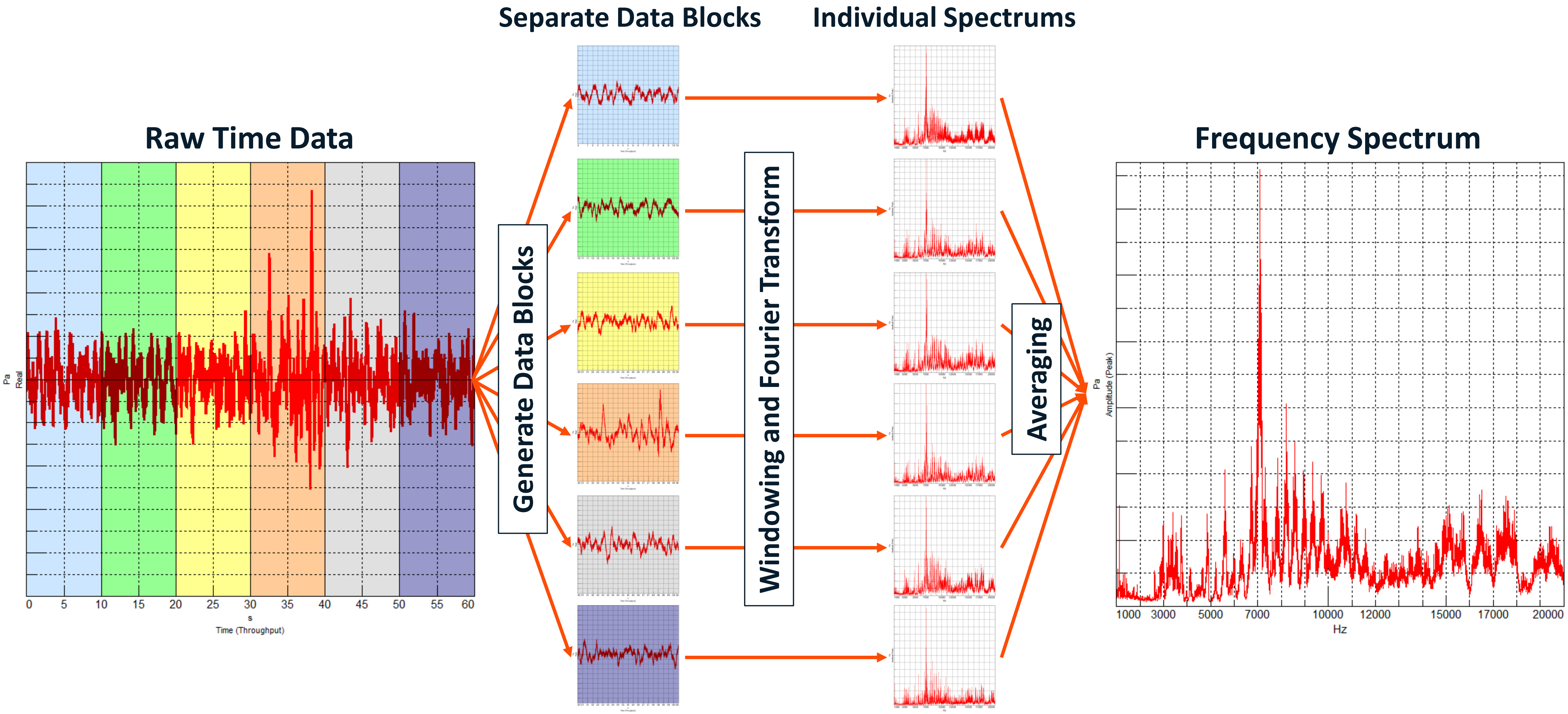
- The Fourier transform is used to convert the data from the time domain to the frequency domain

- The signal should be periodic or a totally observed transient for the transform to work correctly

- The main settings that effect the spectrum calculation are:
  - Sampling frequency
  - Block size/frequency resolution
  - Window
  - Averaging and overlap
  - Function type

Consistency in processing parameters is mandatory for comparisons between data sets

Spectrum Calculation Process



Block Size and Frequency Resolution

- Block size is the number of samples that will be used in the Fourier transform

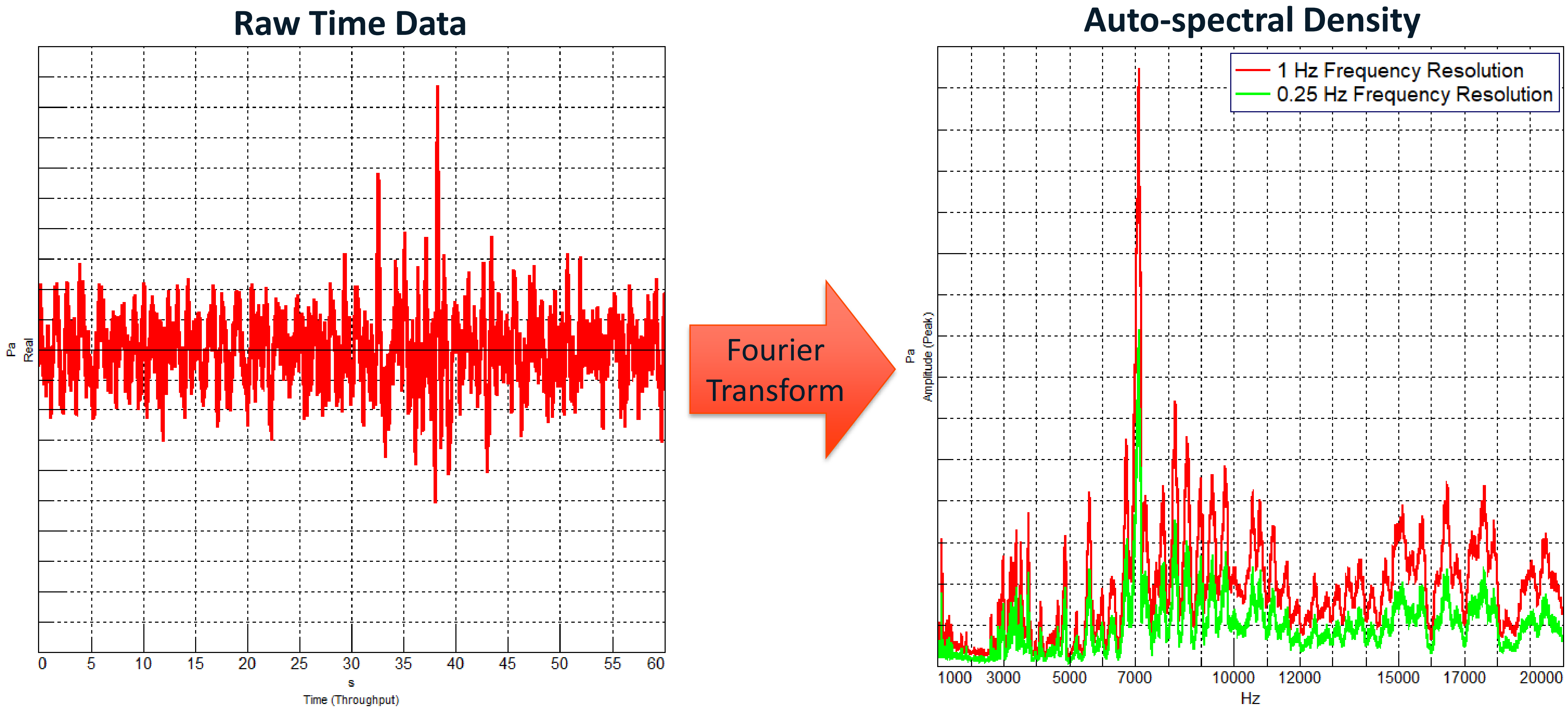
- Frequency resolution is the difference in frequency between the spectral lines in the spectrum. It is directly related to the block size by:

$$\Delta f = \frac{1}{N * F_S}$$

- The frequency resolution affects the amplitude of the spectrum because the Fourier transform is energy preserving – *the sum of the spectral line amplitudes stays the same regardless of frequency resolution*

- The block size can also effect the spectrum because of the data that is included in different blocks for the Fourier transform

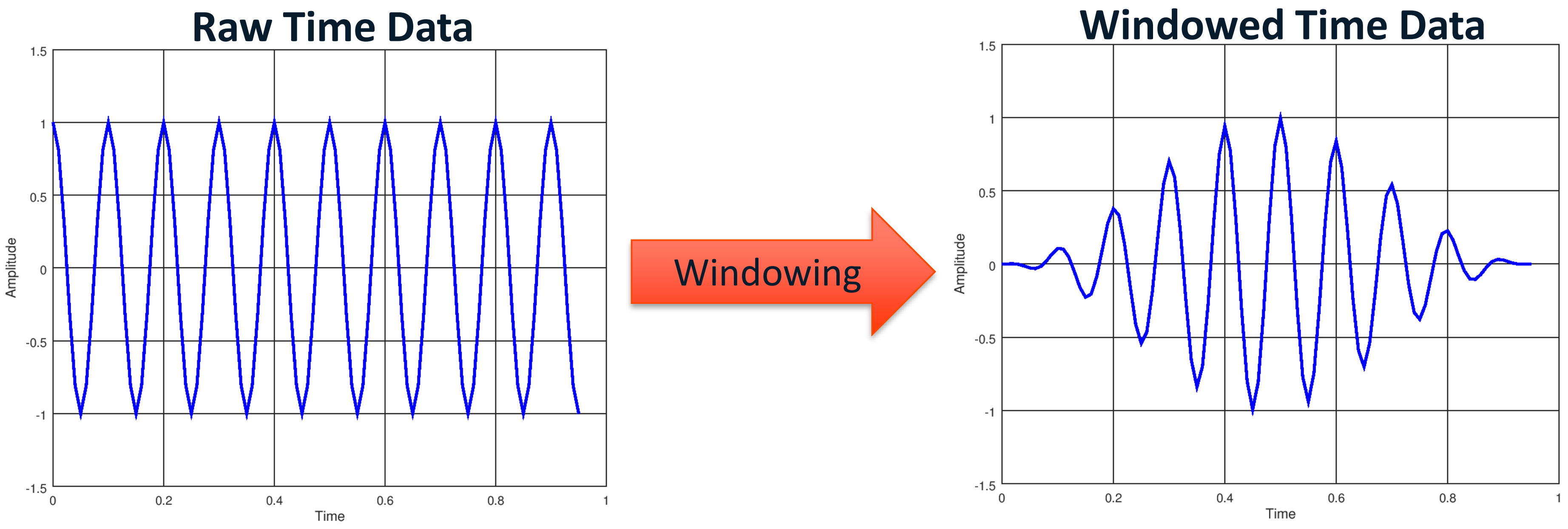
Block Size and Frequency Resolution



The spectrum with 0.25 Hz frequency resolution is half the amplitude of the spectrum with 1 Hz resolution since the Fourier transform preserves the sum of the energy in the frequency band!

Windowing

- The Fourier transform requires periodicity to be error free, which is unlikely to occur in random data
- The error related to non-periodicity is referred to as leakage and can lead to significant amplitude errors and minor frequency resolution errors
- Windows are used to force the signal to be periodic and reduce (but not eliminate) the leakage error – *the “Hanning Window” is the most common window for general vibration data*



Averaging and Overlap

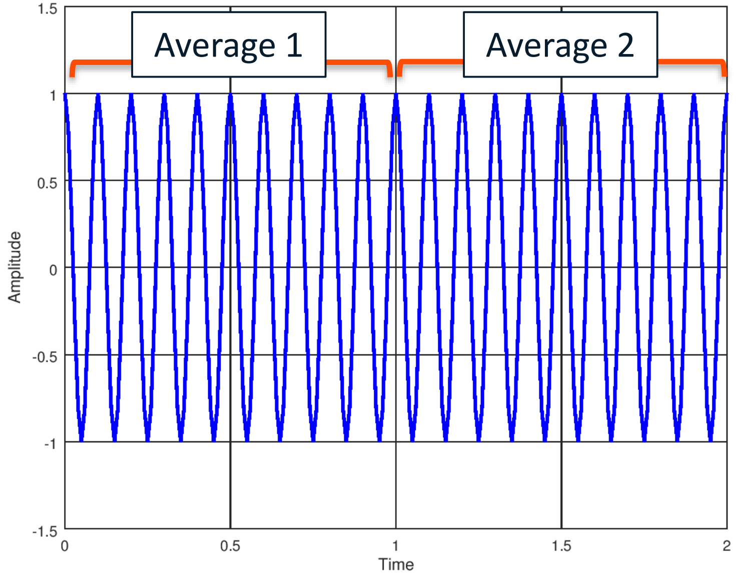
- Averaging is required in most situations to reduce the effects of random noise/error on the calculated spectrum
- Multiple averaging types exist for different data processing requirements – *linear averaging and energy averaging are the most commonly used averaging types for general vibration data*
- Direct averaging in the time domain can cause amplitude errors unless there is a reference to a cyclical time event
- Averaging is typically done in the frequency domain as various spectrum types can avoid needing a cyclical time event
- Overlap is sometimes used to artificially boost the number of averages by “recycling” data

Overlap

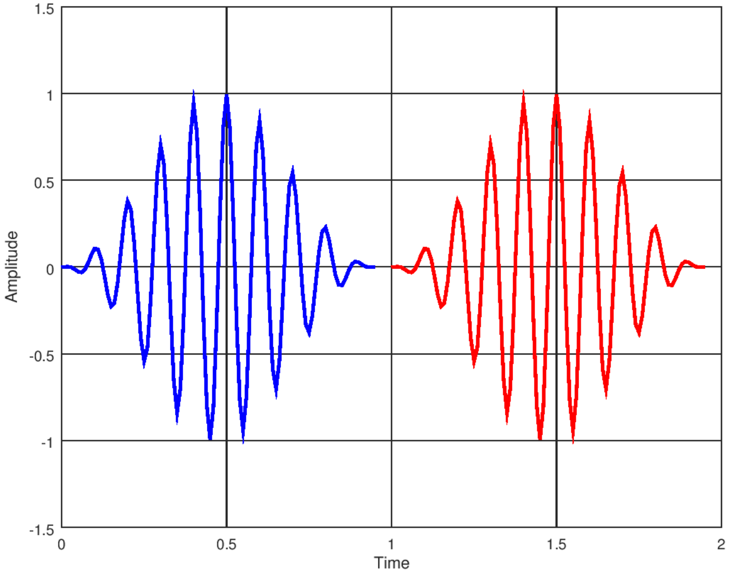
Raw Time Data

Windowed Time Data

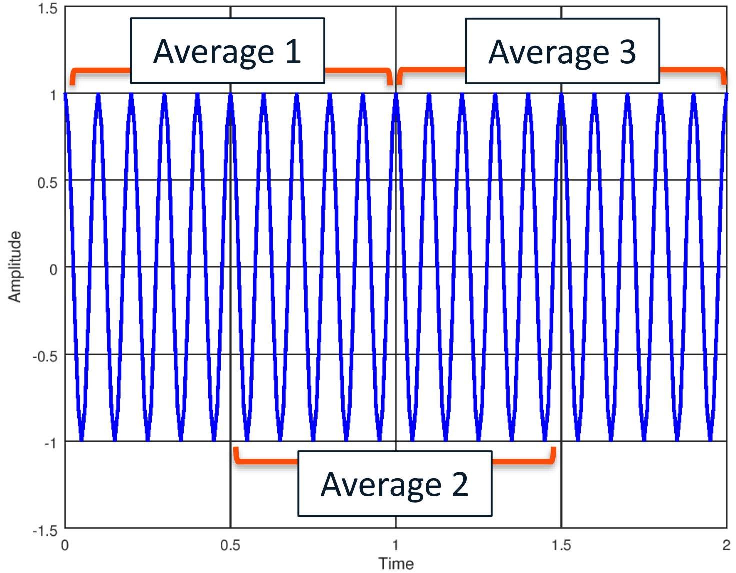
0% Overlap Case



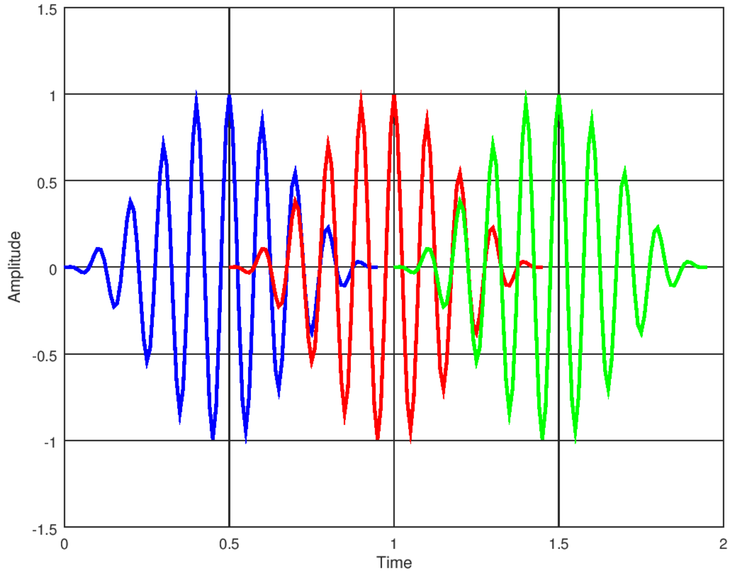
Windowing



50% Overlap Case



Windowing



Function Type

- Frequency spectrums are typically represented as “power spectrums”
  - Auto-spectral density function – *the amplitude is dependent on the frequency resolution*
  - Power spectral density function – *provides consistent spectrum amplitude for different frequency resolutions*
  - Cross-spectral density function – *gives information about how two locations move in reference to each other, the amplitude is dependent on the frequency resolution*

- Many other function types exist for specific uses
  - Fatigue damage spectrum
  - Shock response spectrum
  - Frequency response function
  - Etc.

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Thank You!