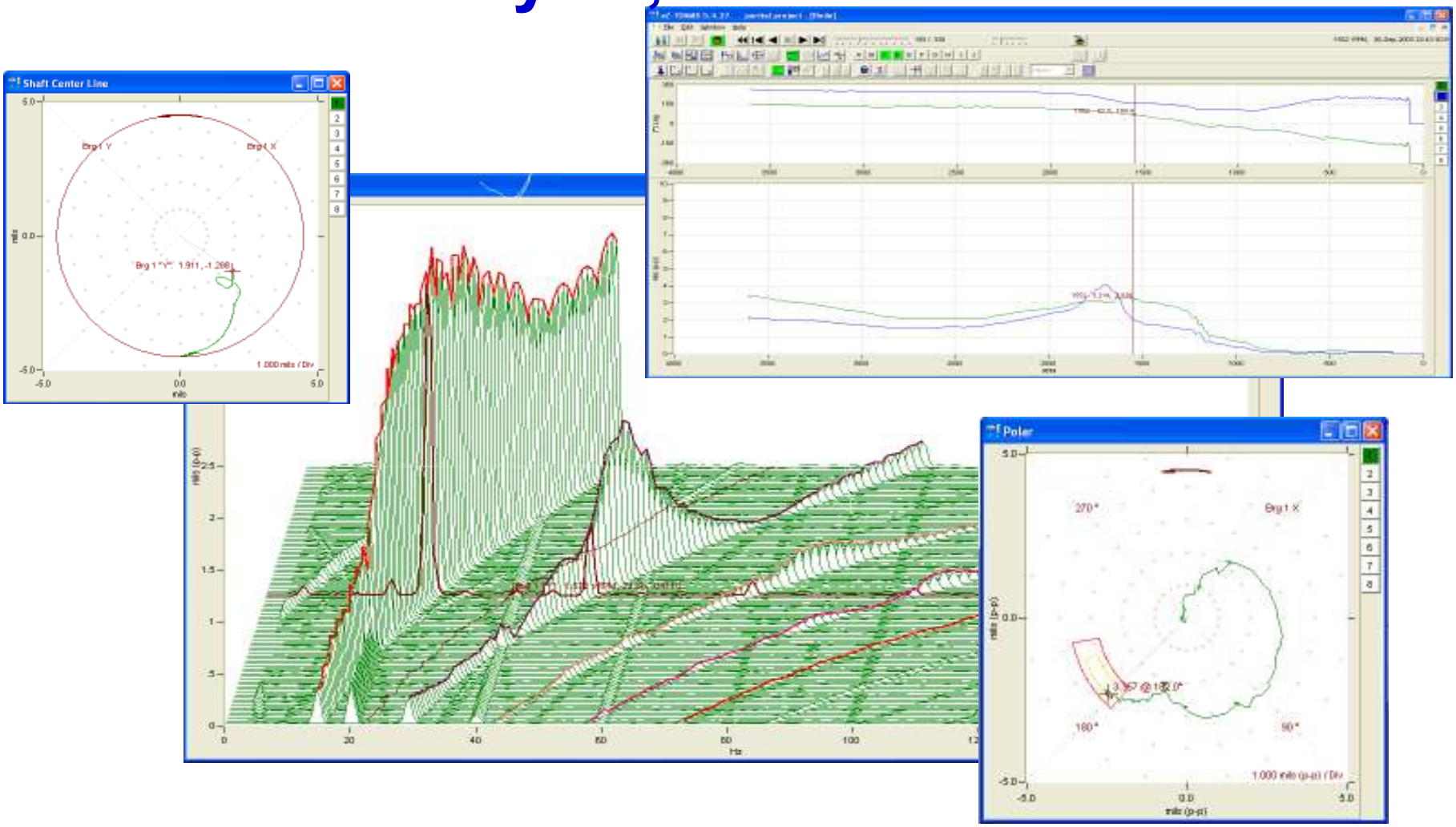
Vibration Seminar, Melville

January 22, 2008



Vibration Seminar, Melville
January 22, 2008

- Presenter :
  - Jack Field, Regional Sales Manager, IOtech Inc.
  - Certified Vibration Analyst, Category III
  - Don Link – Contech Marketing
  - Anthony Yackovich – Contech Marketing

Session Goals

HAVE SOME FUN!!

Learning (and teaching) is far too important to be taken <u>too</u> seriously

If we are all miserable, none of us (your instructor included) will learn a flippin' thing!

Vibration Seminar, Melville
January 22, 2008

Machinery Vibration Basics

Sensor Considerations

Data Acquisition Requirements

Data Recording

Signal Analysis

IOtech Hardware & Software Solutions

What is Vibration?

- The OSCILLATION of an object about an EQUILIBRIUM position

- The RESPONSE of a structure to FORCE

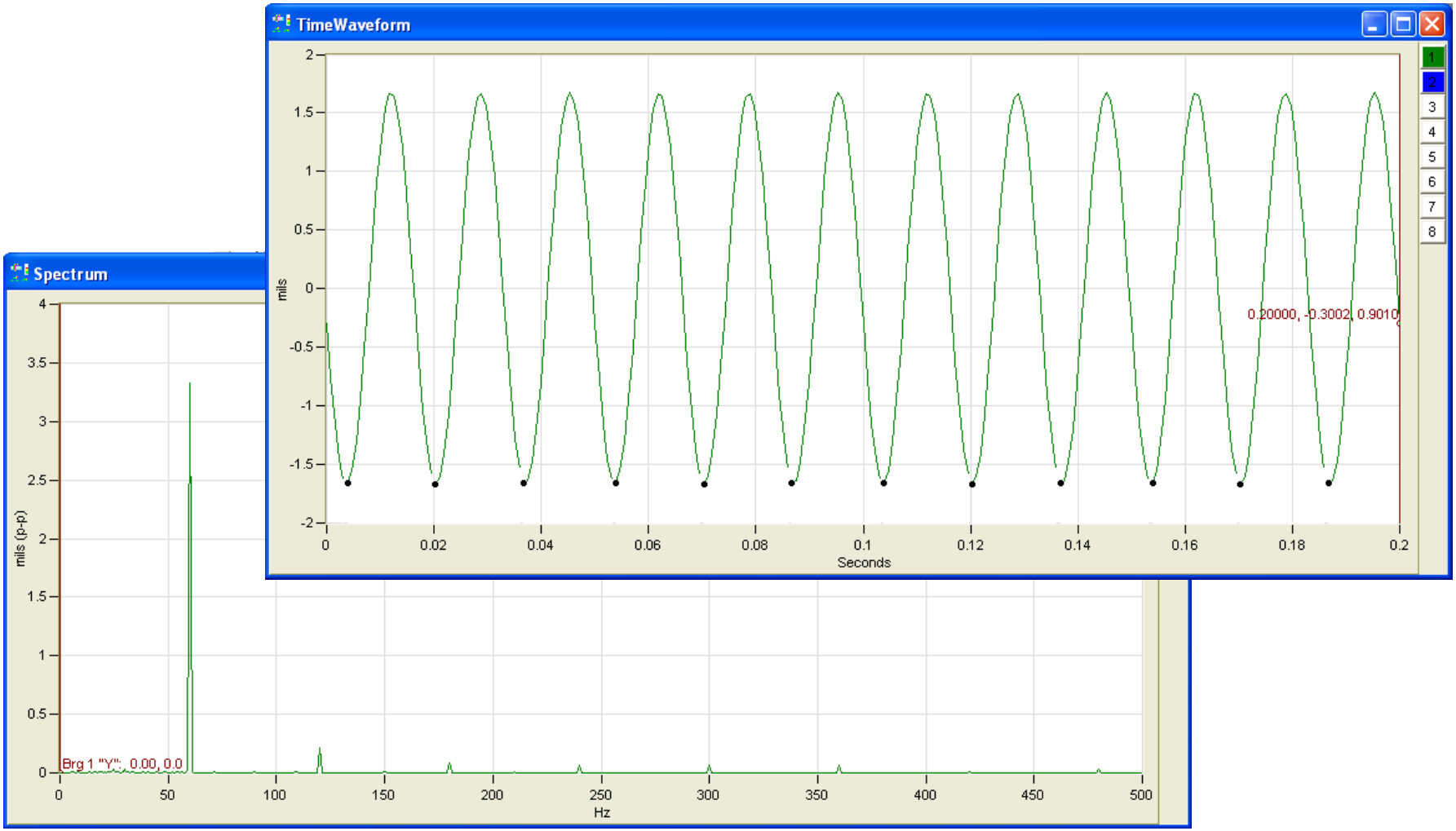
What are the Components of Vibration?

- Amplitude
  - Maximum value of vibration
- Frequency
  - Number of events or cycles per unit time
- Phase
  - Time relationship between vibrations of the same frequency

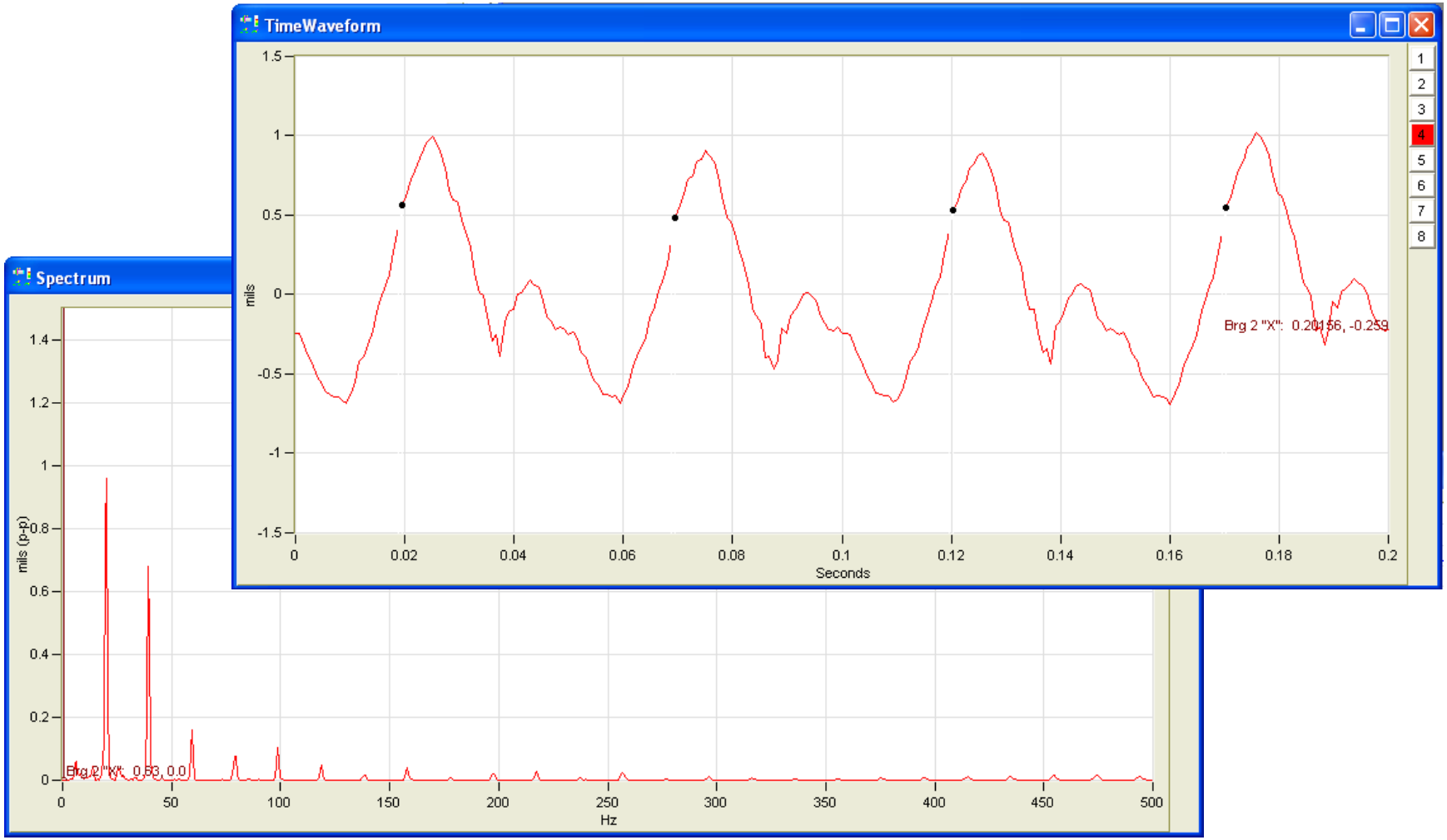
Types of Vibration

- Harmonic
- Periodic
- Impulsive
- Pulsating
- Random

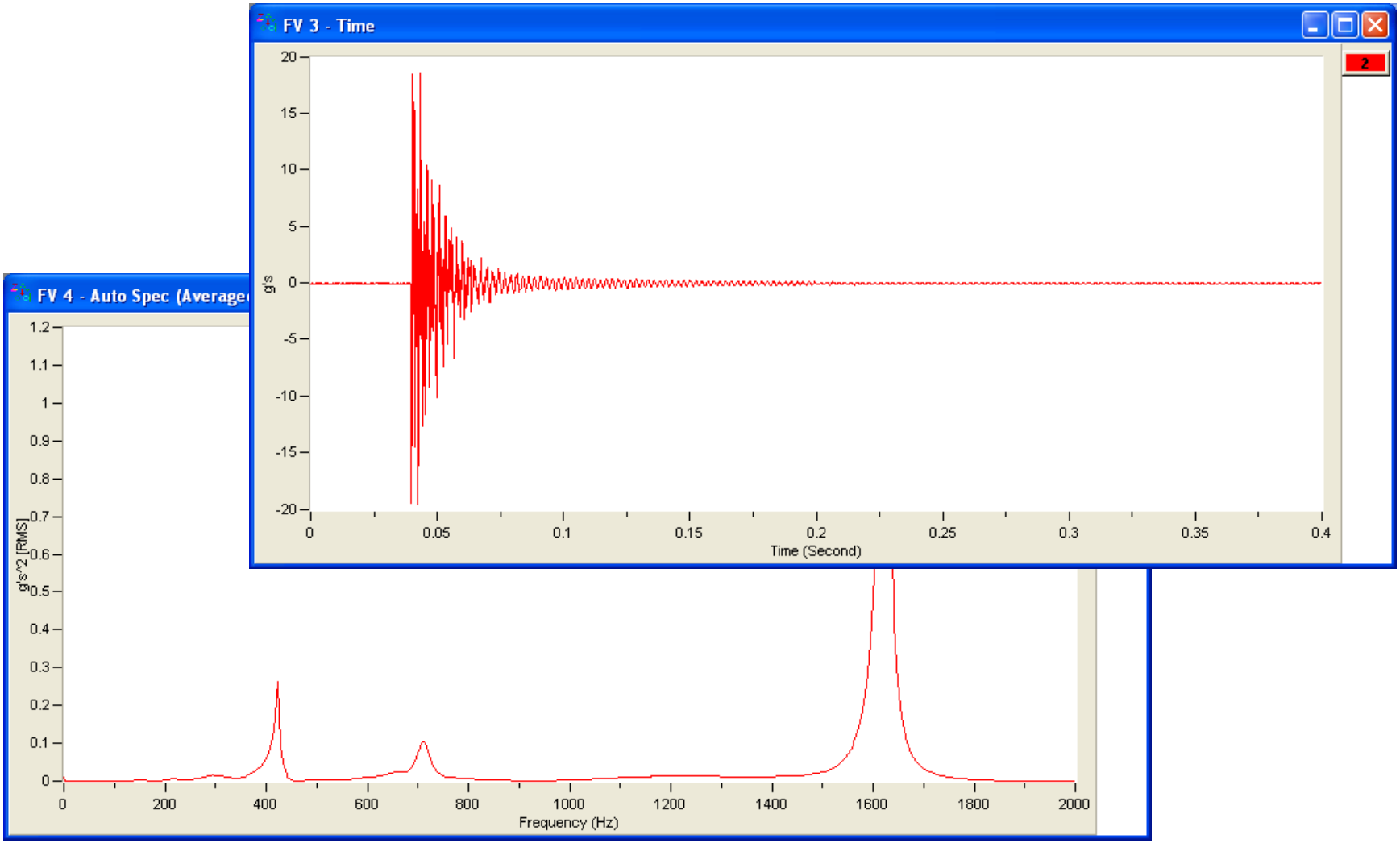
Harmonic Frequencies



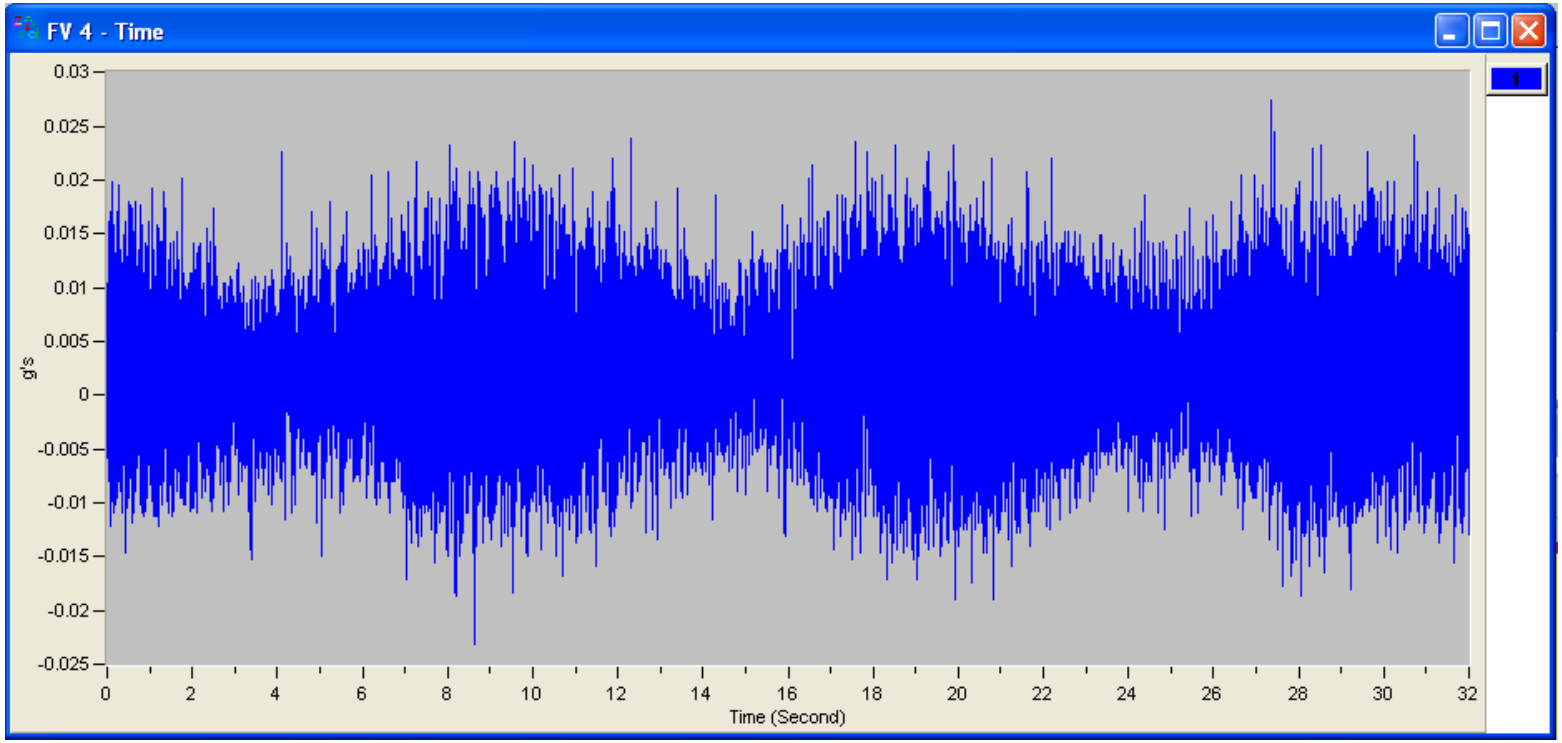
Periodic Frequencies



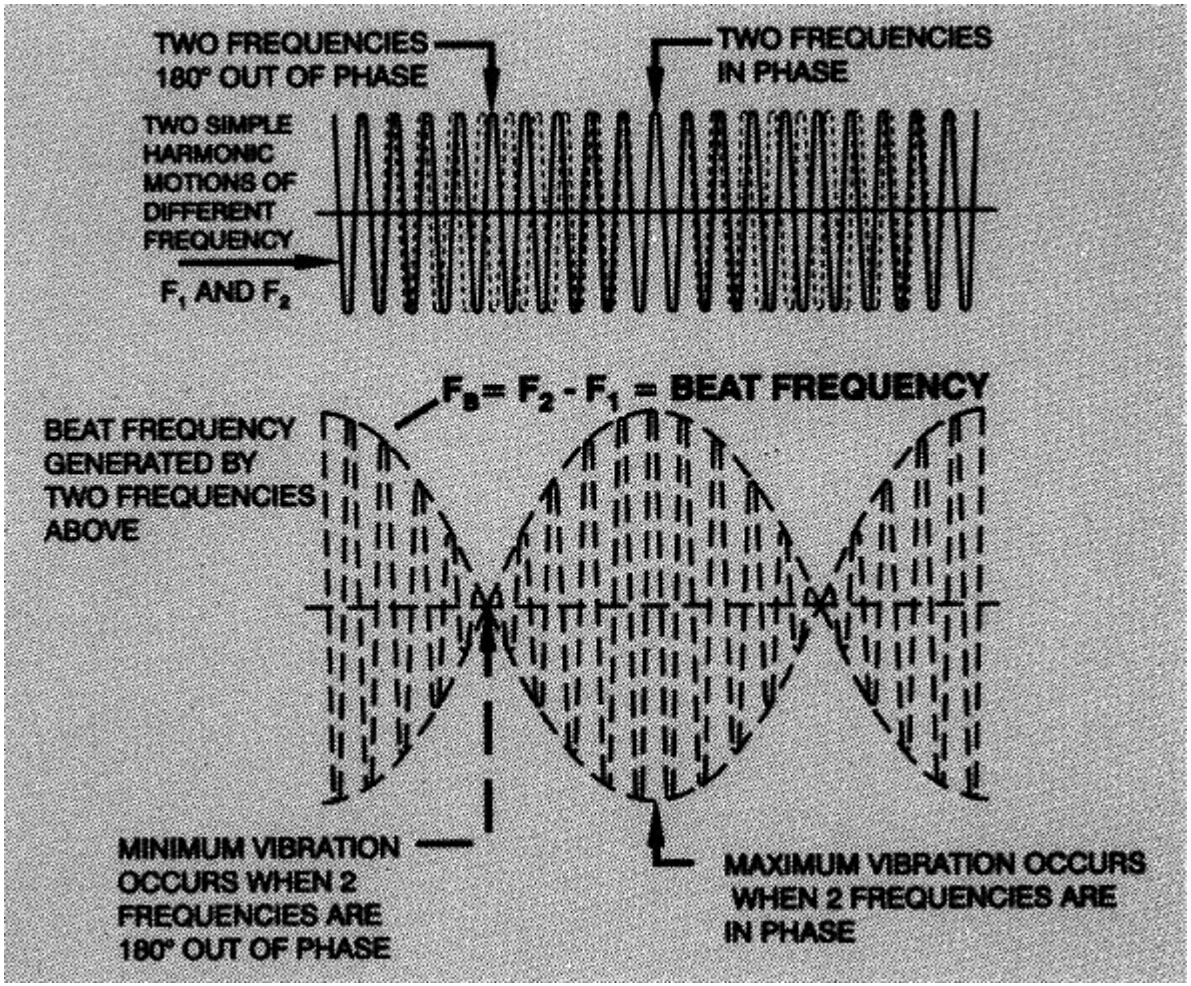
Impulsive / Impact Frequencies



Pulsating / Beat Frequencies

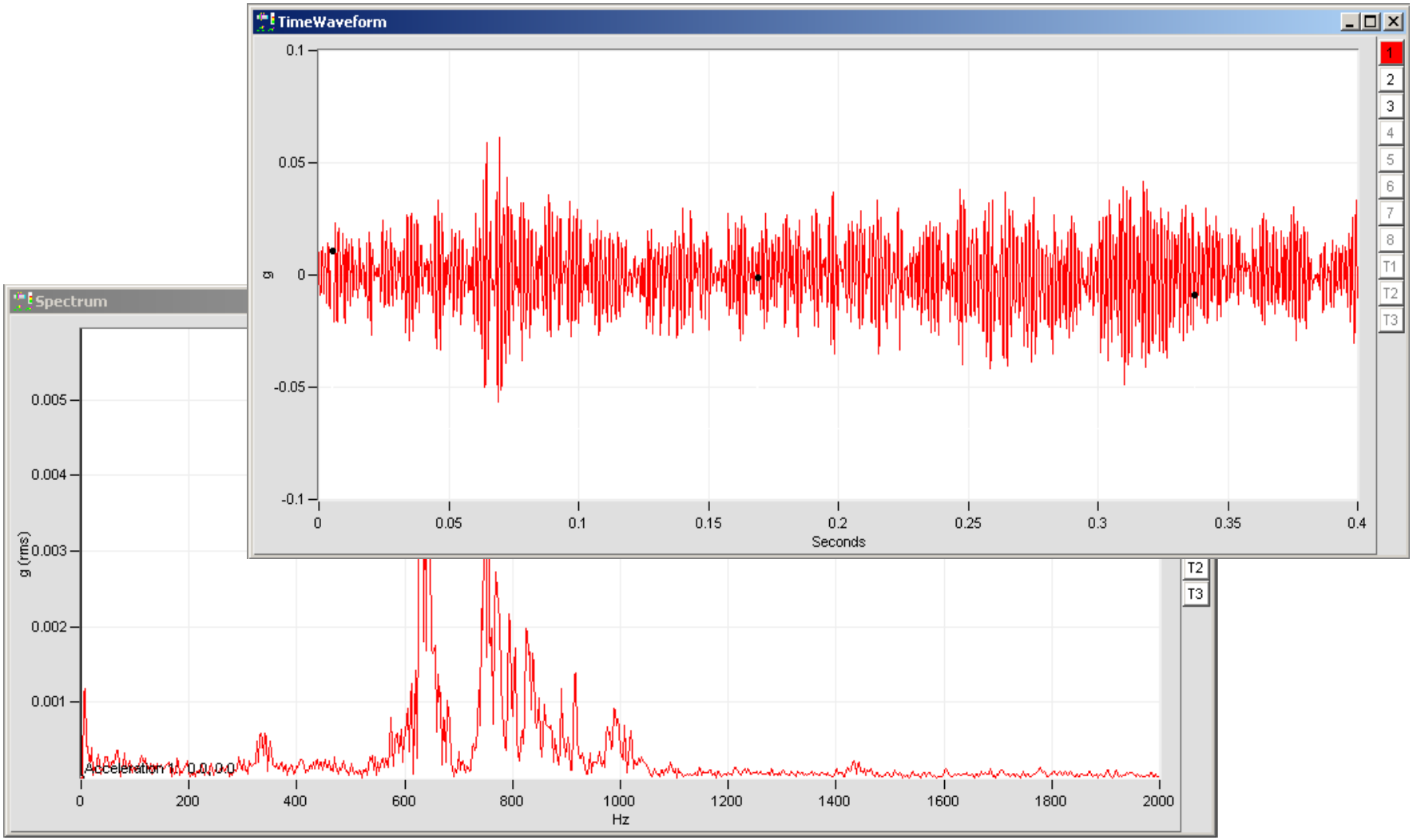


Pulsating / Beat Frequencies



Credit: Technical Associates of Charlotte, Table 1 Vibration Diagnostics Chart

Random Frequencies



Vibration Sources
Natural Frequencies / Resonance

- Machine Design Induced - Natural Frequencies
  - Machine Structure
  - Mass and Stiffness
  - Damping

- Resonance
  - When a forcing frequency excites a natural frequency
  - In rotating machinery, “Critical Speed”

Vibration Sources
Forcing Frequencies

- Machine Design
  - Universal Joints
  - Asymmetrical Shafts, Cams
  - Gear Mesh
  - Couplings
  - Bearings
  - Pumps & Fans
  - Reciprocating Machines
  - Motors / Generators
- Machine Faults
  - Mass Unbalance
  - Misalignment
  - Bent Shaft
  - Mechanical Looseness
  - Casing / Foundation Distortion
  - Bearing Faults
  - Motor Faults

How is Vibration Measured?

- Primitive, Qualitative Methods / Senses
  - Can you actually *SEE* movement?
  - Can you *HEAR* something different?
  - What does it *FEEL* like?
  - Does it *SMELL* funny?
  - *TASTE*? (not really recommended!)
- Don’t ignore what your body tells you!

How is Vibration Measured?

- Better, Quantifiable Methods / Amplitude
  - Movement / Displacement
  - Speed / Velocity
  - Acceleration

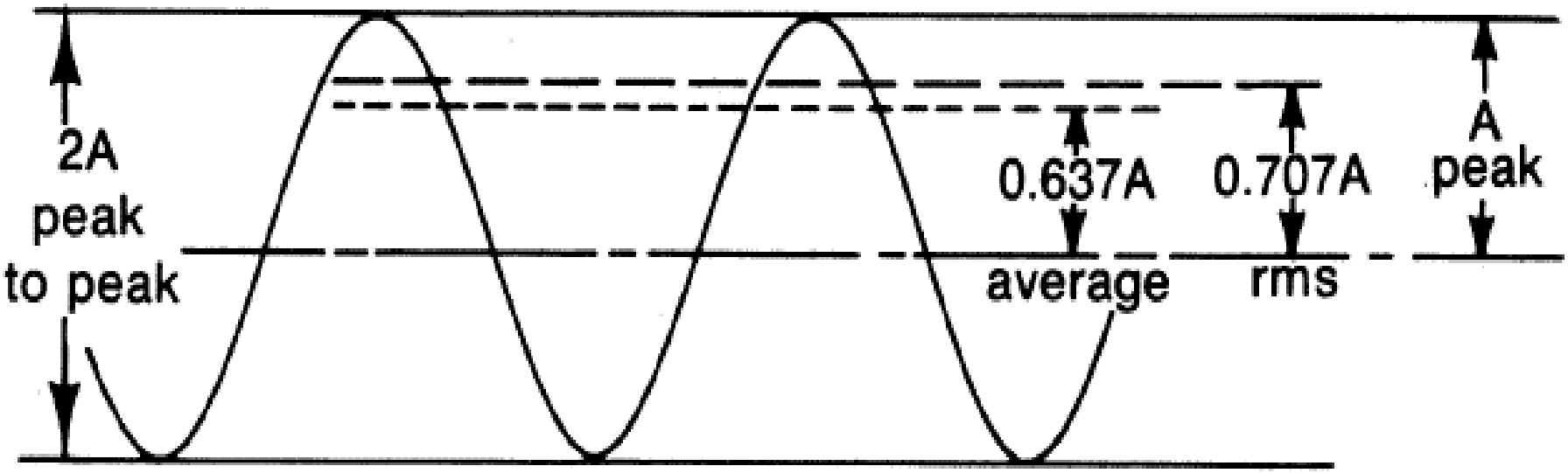
Sensors

- Physical Movement / Displacement
  - Proximity Probes
- Velocity / Speed
  - Velocity Transducers
- Acceleration
  - Accelerometers

Vibration Units

- 'English' Units
  - Pounds (lb) / Inch (in.) / Second (sec)
  - Displacement in mils, 1 mil = 1/1000th Inch
    - Peak-to-peak measure
  - Velocity in Inches per second (in/sec or ips)
    - Peak or RMS measure
  - Acceleration in g's, 1 g = 386.1 in/sec ^{2}
    - Peak or RMS measure

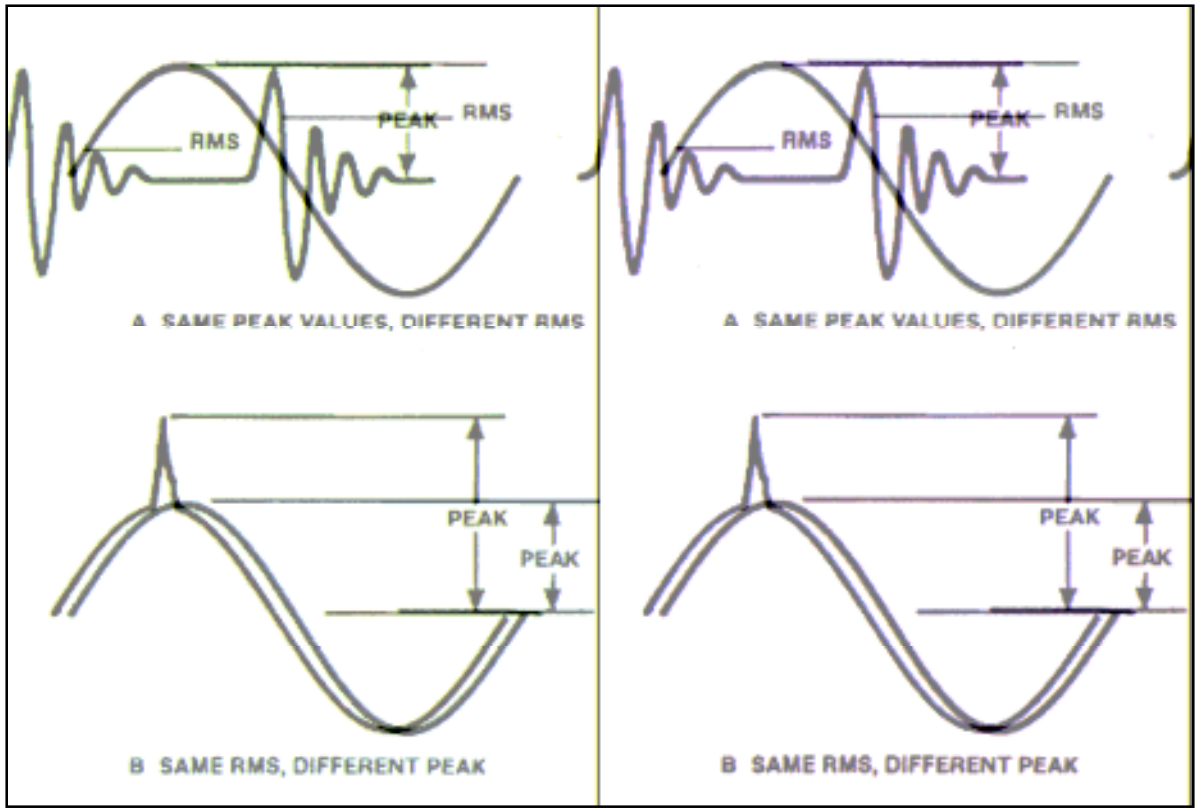
Measures
Peak to Peak, Peak & RMS



Credit: John S. Mitchell, Machinery Analysis and Monitoring 2nd edition

Measures
Peak vs. RMS

- Calculated RMS Only Valid for Harmonic Waveforms

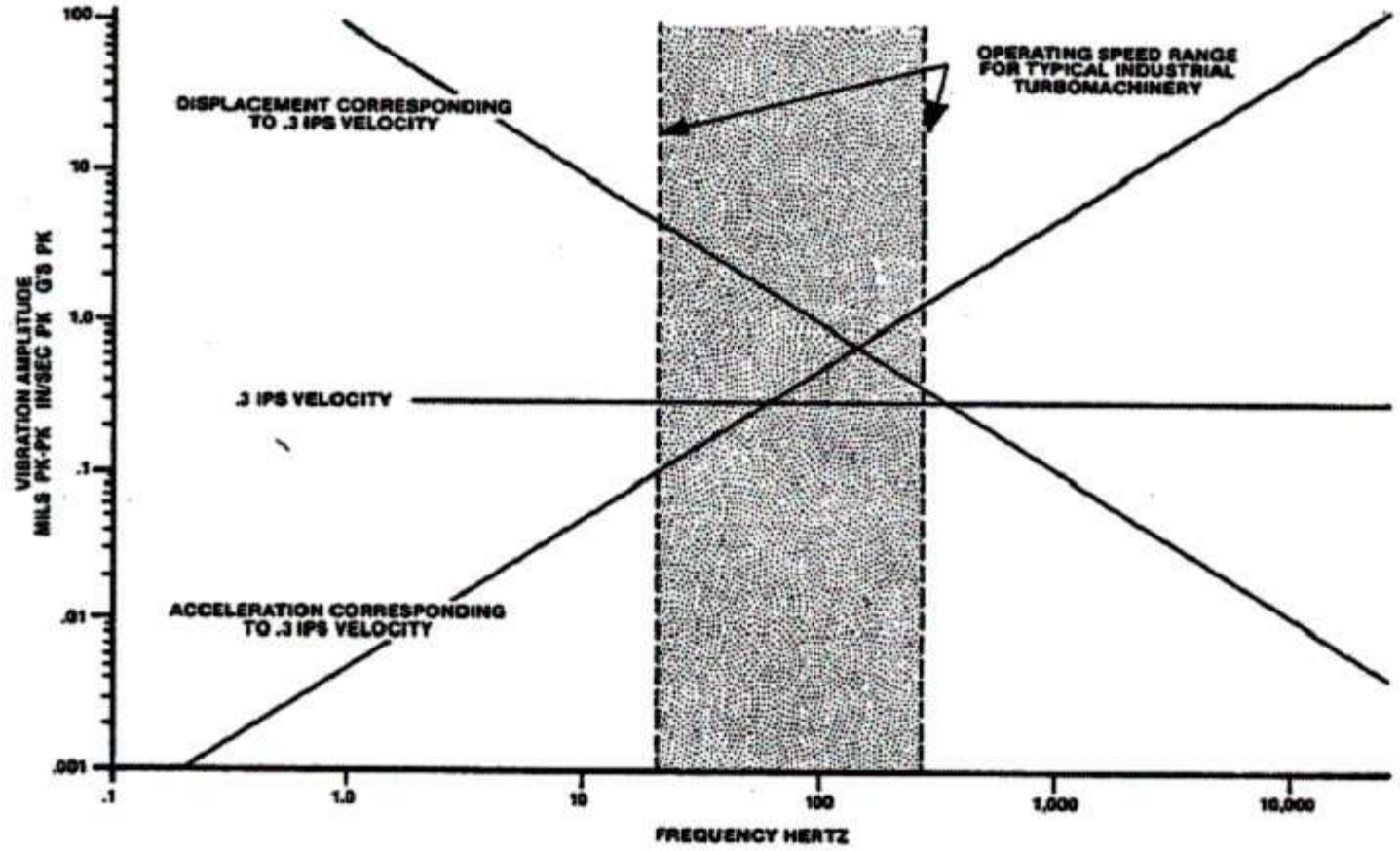


Credit: John S. Mitchell, Machinery Analysis and Monitoring 2nd edition

Frequency / Rotational Units

- Vibration Frequencies are expressed as:
  - Cycles per Minute (CPM) or
  - Cycles per Second (HZ)
- Machine or Shaft Speed:
  - Revolutions per Minute (RPM)
- Phase is expressed as:
  - Degrees, 360 degrees per revolution.
  - May also be expressed as Leading or Lagging

Frequency Range Relationships



Credit: John S. Mitchell, Machinery Analysis and Monitoring 2nd edition

Relationship of Amplitude, Velocity & Frequency

Any Quantity can be Calculated

If the remaining two Quantities are Known

Oh man… MATH??

- Mathematical Relationships / Displacement to Velocity
  - $V = (2 \pi f) D$
    - V = Velocity in Inches per second (ips)
    - π (pi) = 3.14159 (or, the button on your calculator)
    - f = Frequency in Hz
    - D = Displacement in mils *peak*

Worst… Algebra!

- Mathematical Relationships / Velocity to Displacement
  - If… $V = (2 \pi f) D$
  - Then… $D = V / (2 \pi f)$
- Velocity to Acceleration
  - $A = (2 \pi f) V / 386.1$
- Acceleration to Velocity
  - $V = A * 386.1 / (2 \pi f)$

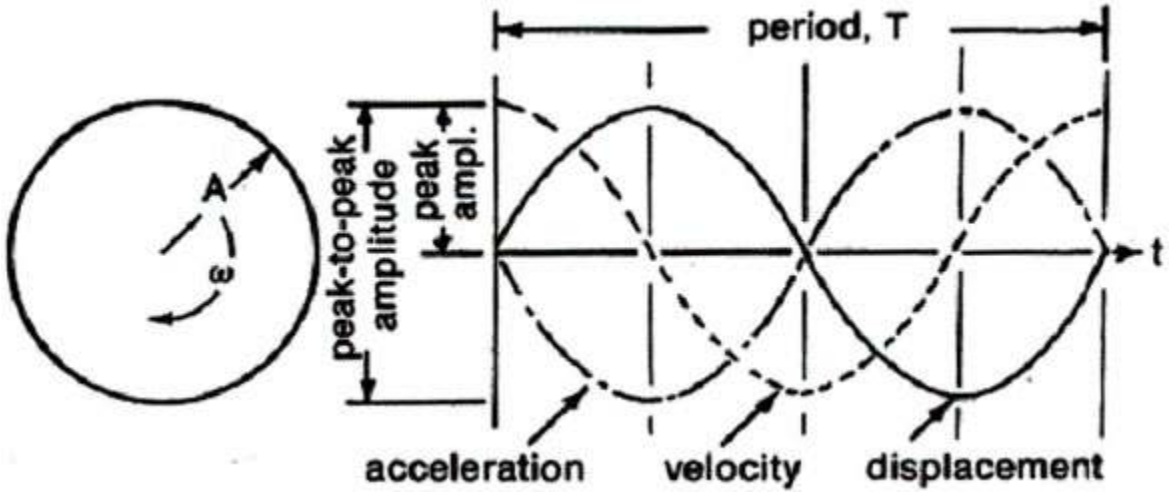
And Finally…

- Mathematical Relationships / Acceleration to Displacement
  - $A = D (2 \pi f)^2 / 386.1$
  - $D = A * 386.1 / (2 \pi f)^2$

(we're done now… you can all relax!)

Rotation and Phase Relationships

- Expressed on Degrees, 360 degrees per cycle
- Displacement Leads
- Velocity Lags Displacement by 90˚
- Acceleration Lags Velocity by 90 & Displacement by 180˚



Credit: John S. Mitchell, machinery Analysis and Monitoring 2nd edition

Machine Vibration Measures

MEASURE	USEFUL FREQ. SPAN	PHYSICAL PARAMETER	APPLICATION
Relative Displacement (proximity probes)	0-1000 Hz	Stress / Motion	Relative Motion in bearings / casings
Absolute Displacement (seismic)	0-10 Hz	Stress / Motion	Machine Condition
Velocity (seismic)	10 – 1000 Hz	Energy / Fatigue	General Machine Condition, medium-high frequency vibrations
Acceleration (seismic)	> 1000 Hz	Force	General Machine Condition, medium-high frequency vibrations

Machine Design
Vibration Sources

- Eccentric Shafts / Cams
- Reciprocating Components
- Pumps & Fans
- Gears
- Bearings
- Couplings
- Universal Joints
- Motors & Generators

Machine Design
Vibration Frequencies

- Eccentric Shafts / Cams
  - Shaft Speed (1 X) and Multiples (Orders)

Machine Design
Vibration Frequencies

- Reciprocating Machines
  - ½ and Full Multiples of Shaft Speed

Machine Design
Vibration Frequencies

- Pumps & Fans
  - Vane Pass & Blade Pass Frequencies
    - Shaft Speed X Number of Vanes
    - Shaft Speed X Number of Blades
    - Flow Noise / Cavitations

Machine Design
Vibration Frequencies

- Gearboxes
  - Gear Mesh Frequencies
    - Shaft Speed X Number of Teeth

Machine Design
Vibration Sources

- Bearing Frequencies, Rolling Element Bearings
  - BPFI – Ball Pass Freq. Inner Race
  - BPFO -- Ball Pass Freq. Outer Race
  - BSF – Ball Spin Frequency
  - FTF -- Fundamental Train Frequency

Max Range Approximation:

Shaft Speed X Number of Elements X 0.6

Machine Design
Vibration Sources

- Bearings, Fluid Film / Sleeve
  - Oil Whirl
    - 0.40 – 0.48 X of Shaft Speed
  - Oil Whip
    - Machinery Operating at >> 2 X Critical Speed
    - Oil Whirl Locks onto 2 X Critical

Machine Design
Vibration Sources

- Couplings
  - Shaft Speed X Number of Jaws
  - Sidebands

Machine Design
Vibration Sources

- Universal Joints
  - 2 X Shaft Speed

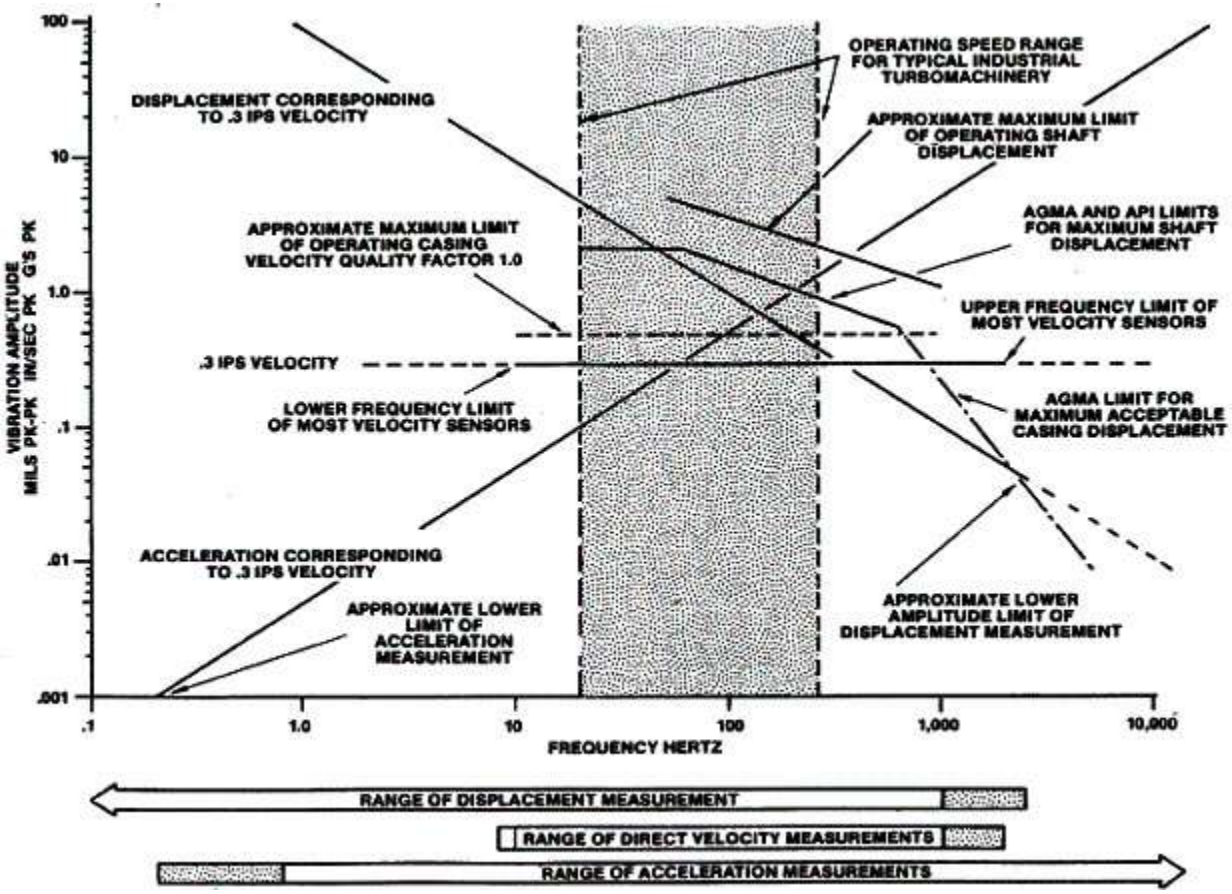
Machine Design
Vibration Sources

- Motors & Generators
  - Synchronous Motor Speed (SMS)
    - 2 X Line Frequency / Number of Poles
  - Slip Frequency
    - SMS – Actual Speed
  - Variable Speed Drives

Minimum Acquisition Frequencies

COMPONENT / MACHINE	SPAN
Shaft Vibration	10 X RPM
Gearbox	3 X Gear Mesh
Rolling Element Bearings	10 X Ball Pass Freq. Inner
Pumps	3 x Vane Pass
Motors / Generators	3 X Line Freq X 2
Fans	3 X Blade Pass
Sleeve Bearings	10 X RPM

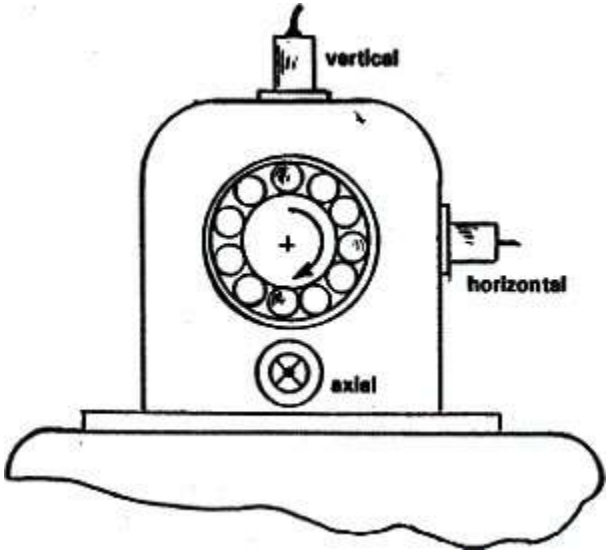
Applicable Sensors & Limits

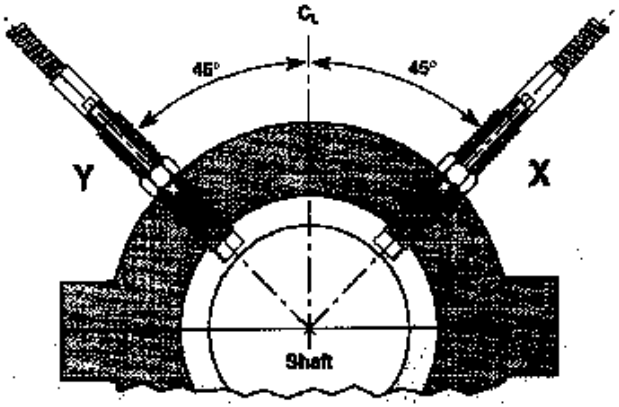


Credit: John S. Mitchell, machinery Analysis and Monitoring 2nd edition

Sensor Mounting Conventions

- Position Referenced from DRIVEN end of Shaft
- Horizontal 90˚ CLOCKWISE from Vertical
- Direction of Rotation Not Considered
- Axial Transducers In the Load Zone





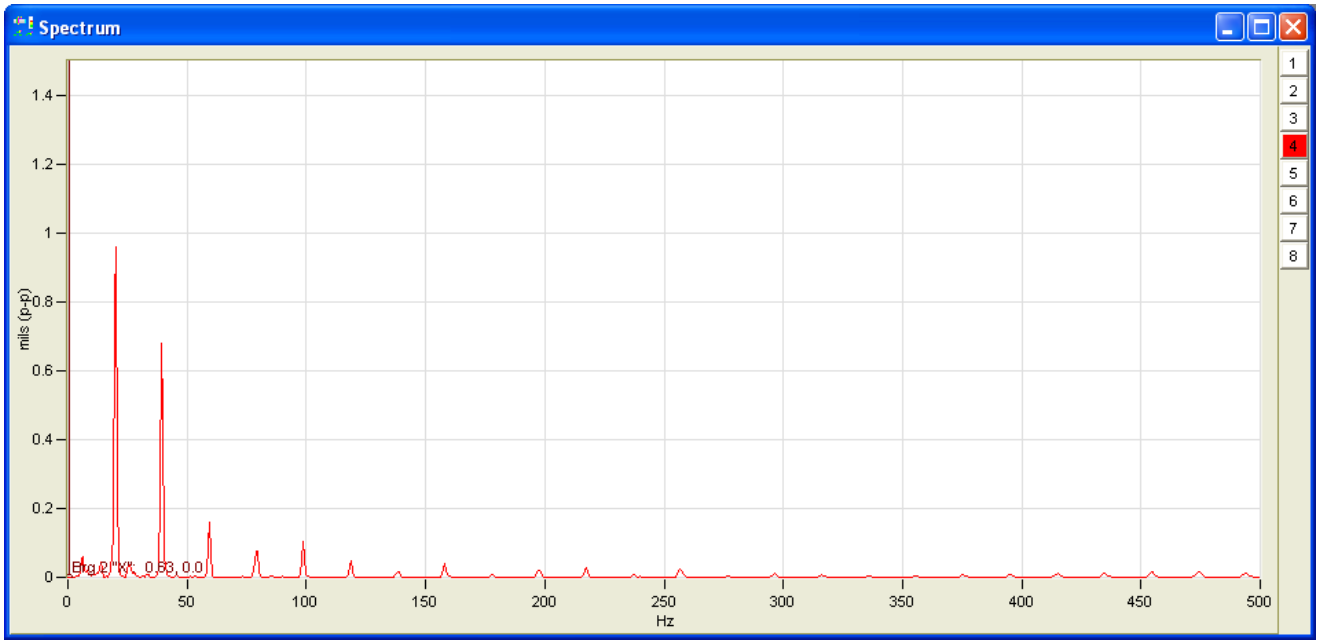
Credit: Ronald L. Eshleman, Basic Machinery Vibration

Useable Frequency Spans For Accelerometer Mounting Methods

METHOD	FREQUENCY LIMIT
Hand Held (stinger)	500 Hz
Magnetic Mount	2,000 Hz
Adhesives	2,500 – 4,000 Hz (dependent on compound)
Bees Wax	5,000 Hz (watch surface temp!)
Stud Mount	6,000 – 10,000 Hz

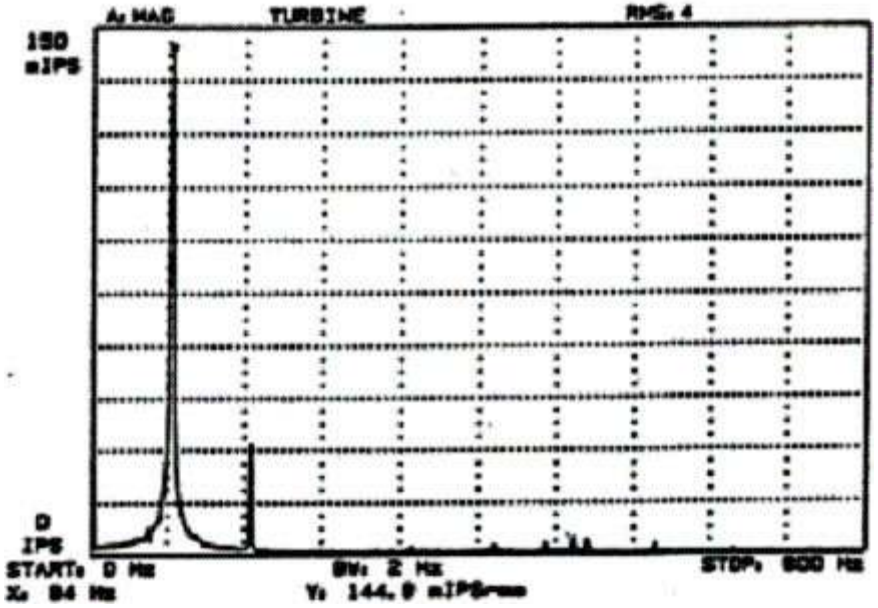
Signal Processing
Spectrum Analysis / FFT

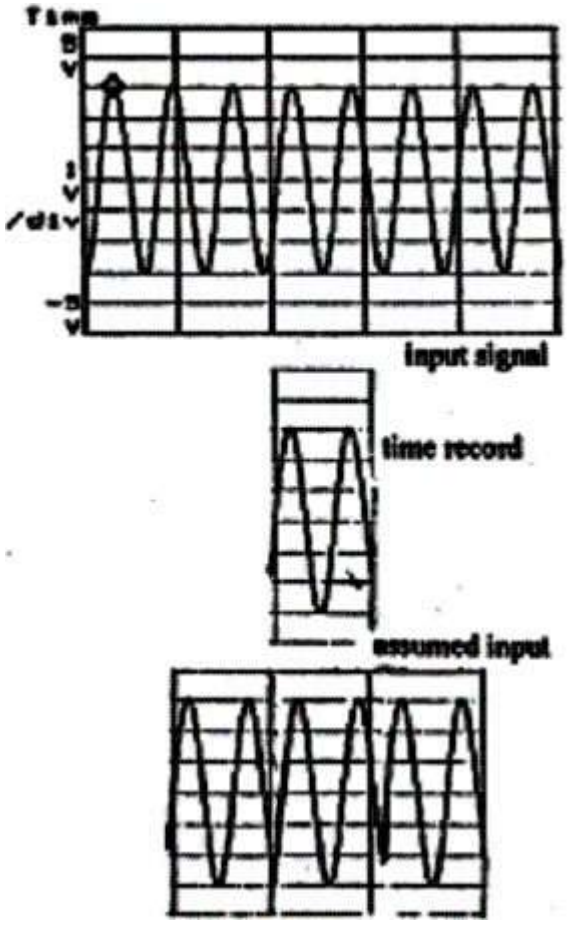
- Presents Frequency Components of Time Domain Data
  - Frequency Range Determined by Acquisition Sample Rate
  - Resolution Determined by Acquisition Duration



Signal Processing
FFT Windowing / Leakage

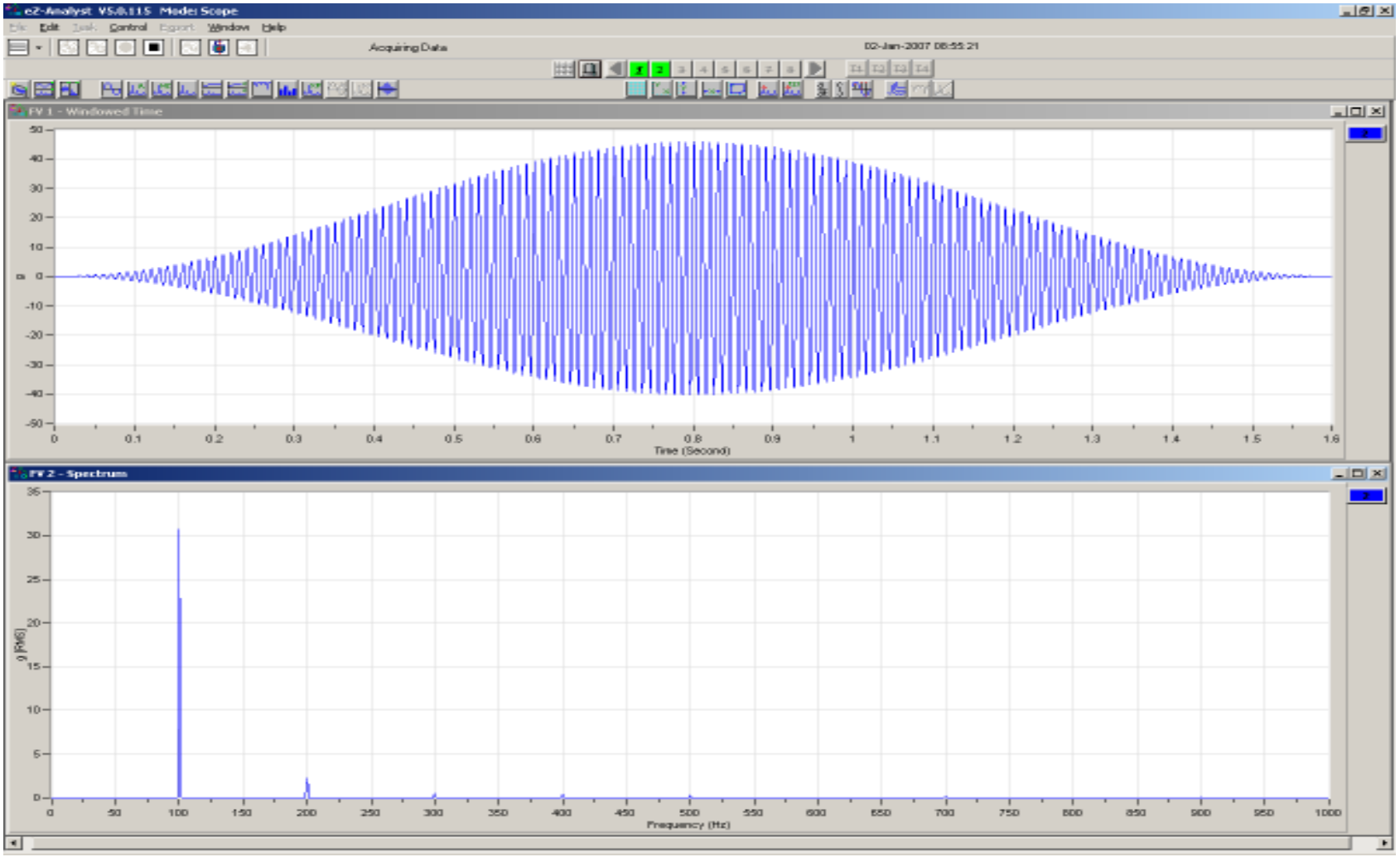
- Time Data Does Not Begin / End at Zero
- Reconstructed Time Domain Data Not Contiguous
- Leakage, "Skirt" on Spectrum Plot



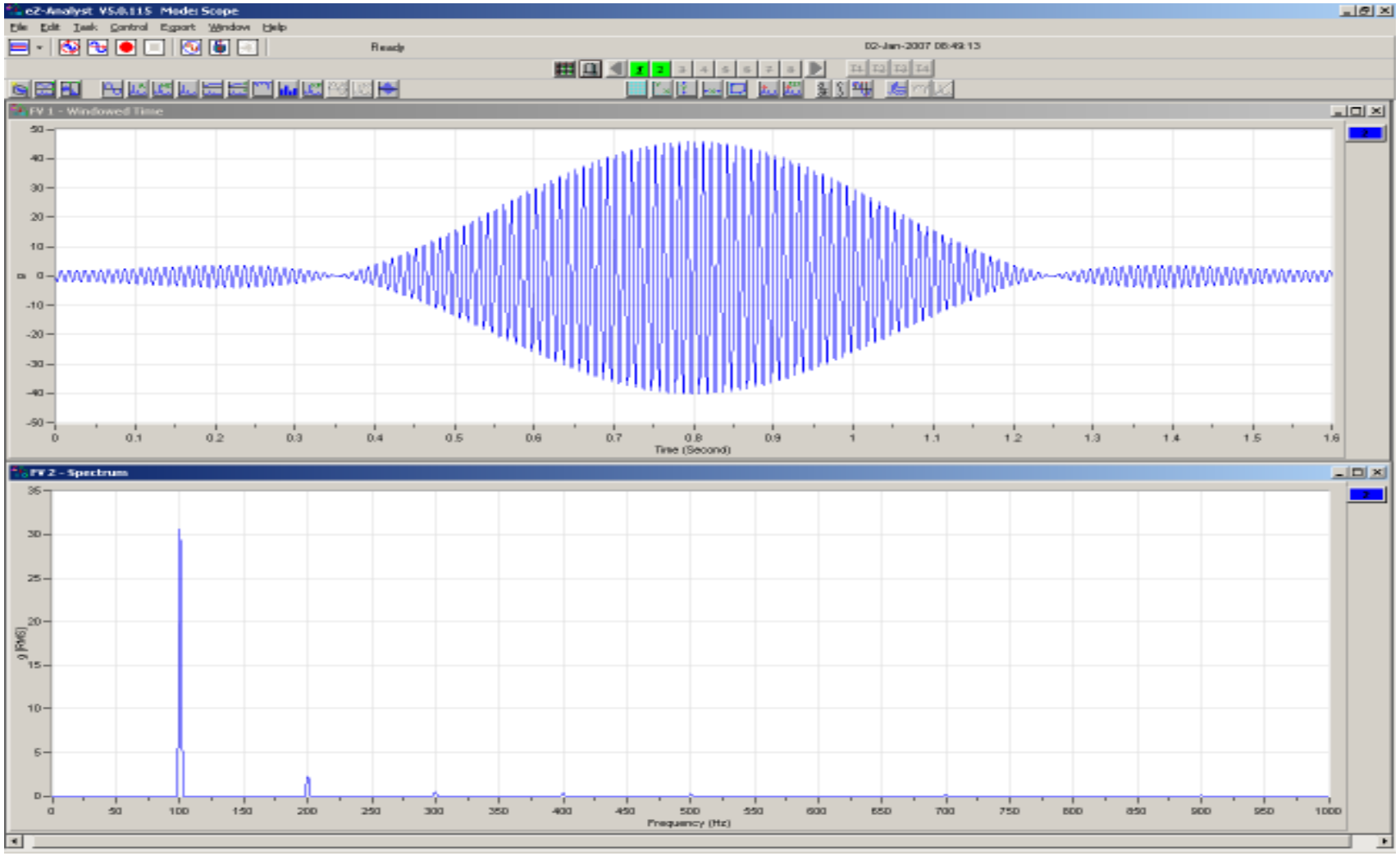


Credit: Ronald L. Eshleman, Basic Machinery Vibration

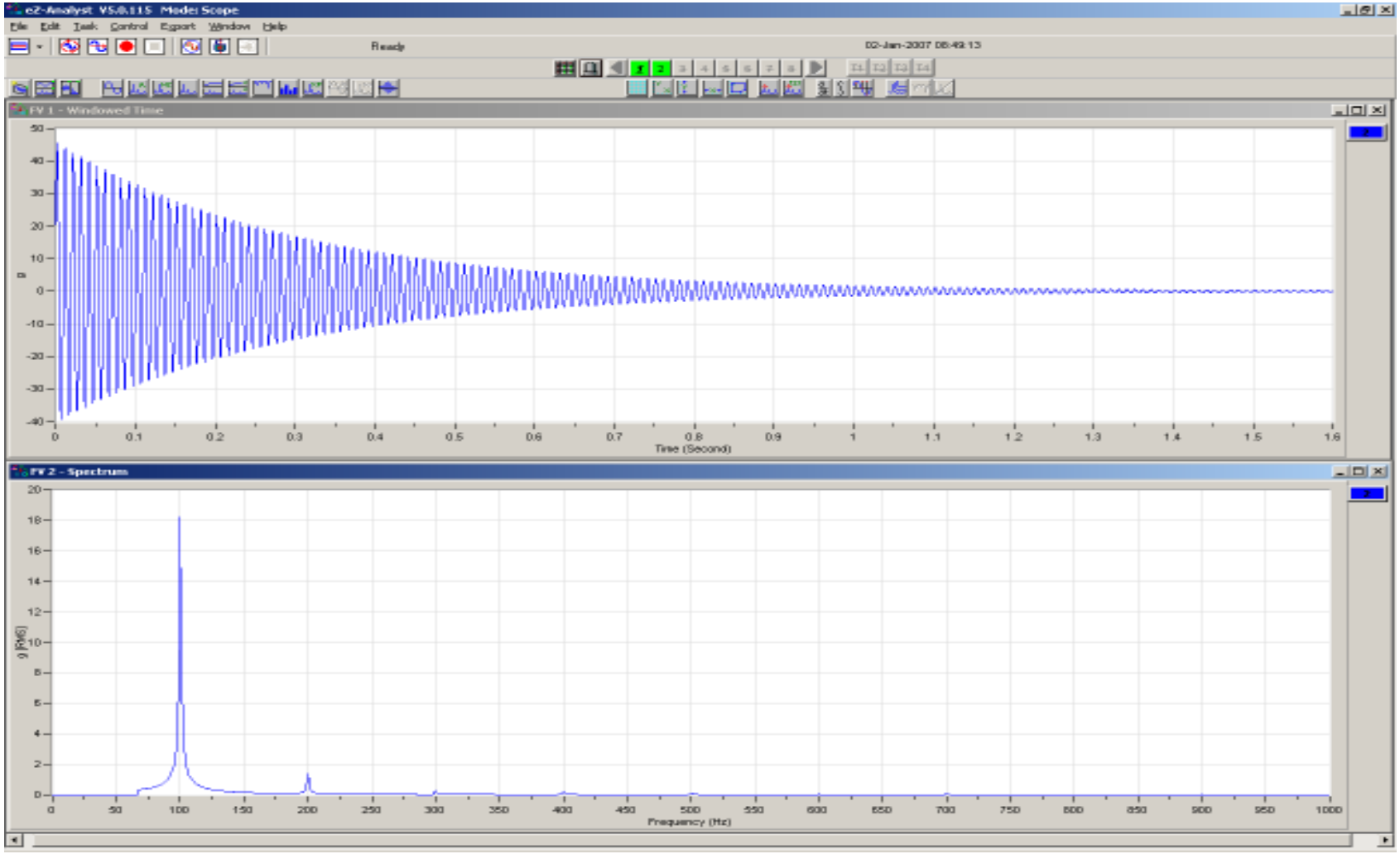
FFT Windows
Hanning ('standard' window)



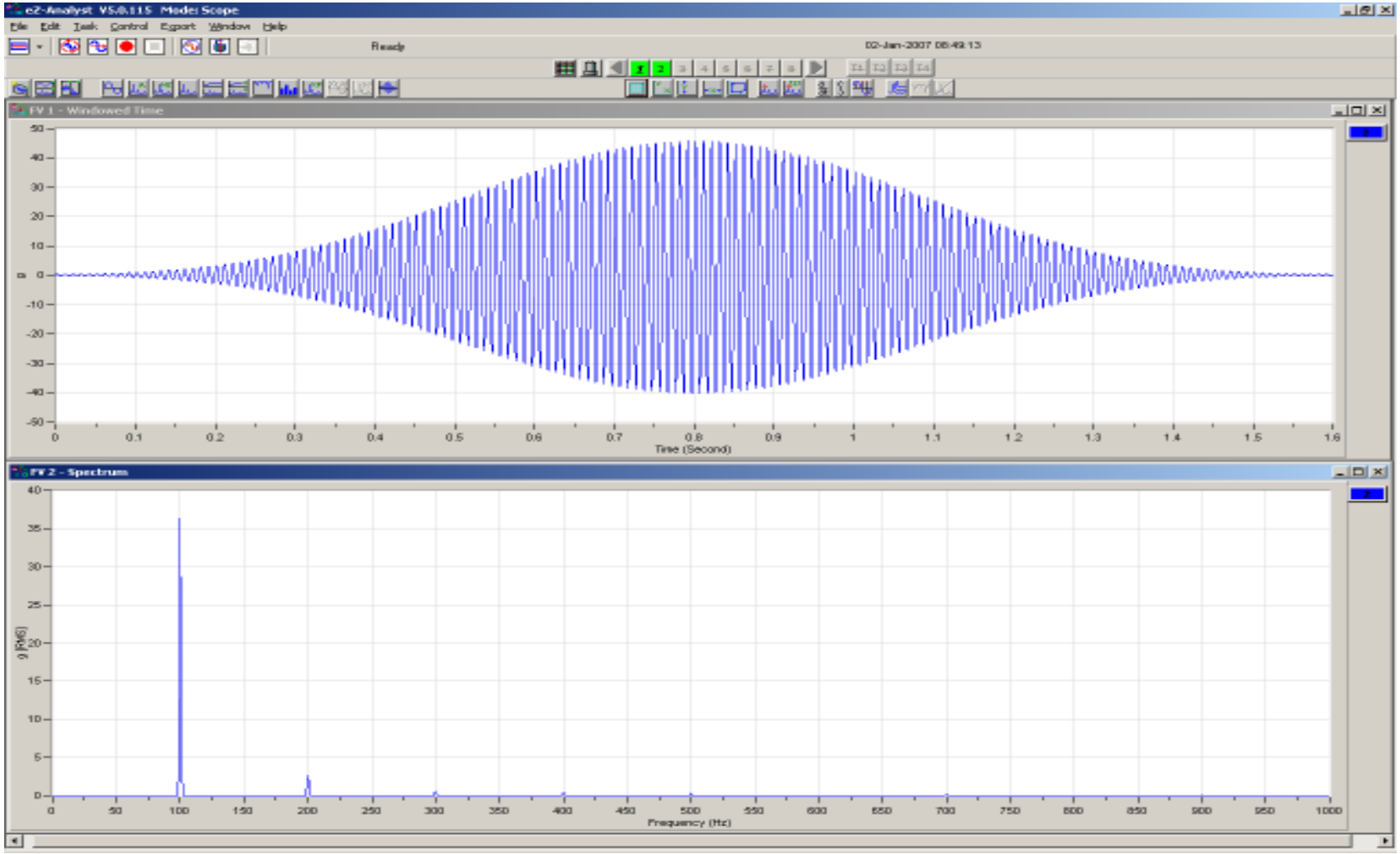
FFT Windows
Flat Top, best for amplitude resolution



FFT Windows
Exponential (programmed decay to zero)



FFT Windows
Blackman Harris



FFT Averaging
Why Average FFT Data?

- Reduce or eliminate random frequencies
- Capture transient frequencies
- Remove frequencies from adjacent equipment

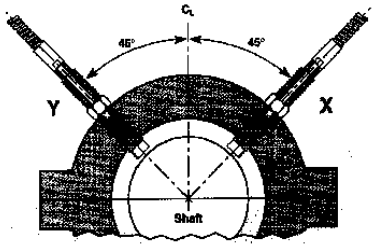
FFT Averaging
Averaging Methods

- Linear (+)
  - True mathematical mean
- Exponential
  - Weighted Average, most recent has highest weight
- Peak Hold
  - Maximum value of each bin maintained
- Linear (-)
  - Special case for Resonance determination
- Time Synch
  - Eliminates frequencies not related to machine speed and phase

ZonicBook/618E
Data Acquisition, Recording & Analysis

- Getting Started
  - Machine Condition
  - Instrumentation
  - NEW 600 Series DSA
  - ZonicBook/618E System
- Vibration Recording and Analysis
- Impact / Resonance Testing
- Rotating Machinery Monitoring and Analysis

ZonicBook/618E
Machine Condition & Instrumentation



- Test Plan based on Machine Condition
- Acceleration > 1 KHz Analysis
- Velocity / Displacement < 1 KHz Analysis
- Microphone
- Tachometer
- Impact Hammer or 2x4

Vibration Seminar
Hardware – 600 Series DSA

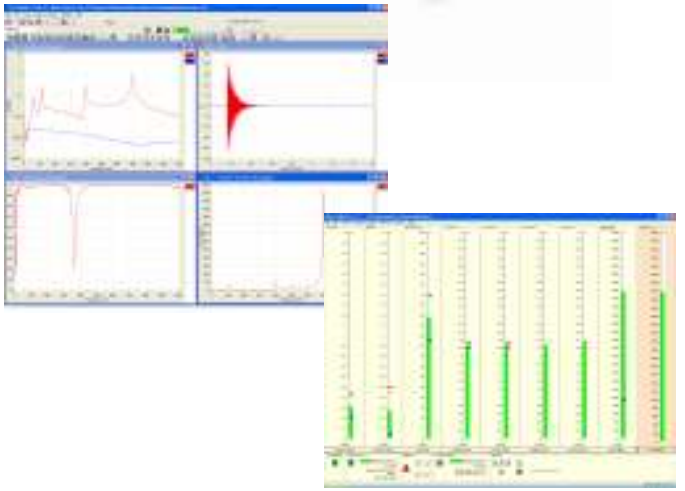
- 640 Series Features
  - 24 Bit Sigma Delta ADC per channel
  - 4 +/- 10 Volt Inputs, 1 Analog Output
  - Analysis Range to 40,000 Hz
  - IEPE Excitation, per channel selectable
  - Selectable AC or DC Coupling (1.0 Hz)
  - Anti-aliasing Filter, 3 Pole, 360kHz
  - Programmable FIR Filter
  - Spurious Free Dynamic Range of 107 dB
  - Total Harmonic Distortion -100 dB
  - Channels Phase Matched to <0.12˚
  - USB 2.0 or Ethernet Versions

Vibration Seminar
Hardware – 600 Series DSA

- 650 Series Features
  - 24 Bit Sigma Delta ADC per channel
  - 5 +/- 40 Volt Inputs, 4 IEPE Capable Channels, 1 Tach Channel
  - Analysis Range to 40,000 Hz
  - Selectable AC or DC Coupling (0.1 Hz)
  - Anti-aliasing Filter, 3 Pole, 360kHz
  - Programmable FIR Filter
  - Spurious Free Dynamic Range of 107 dB
  - Total Harmonic Distortion -100 dB
  - Channels Phase Matched to <0.12˚
  - USB 2.0 or Ethernet Versions

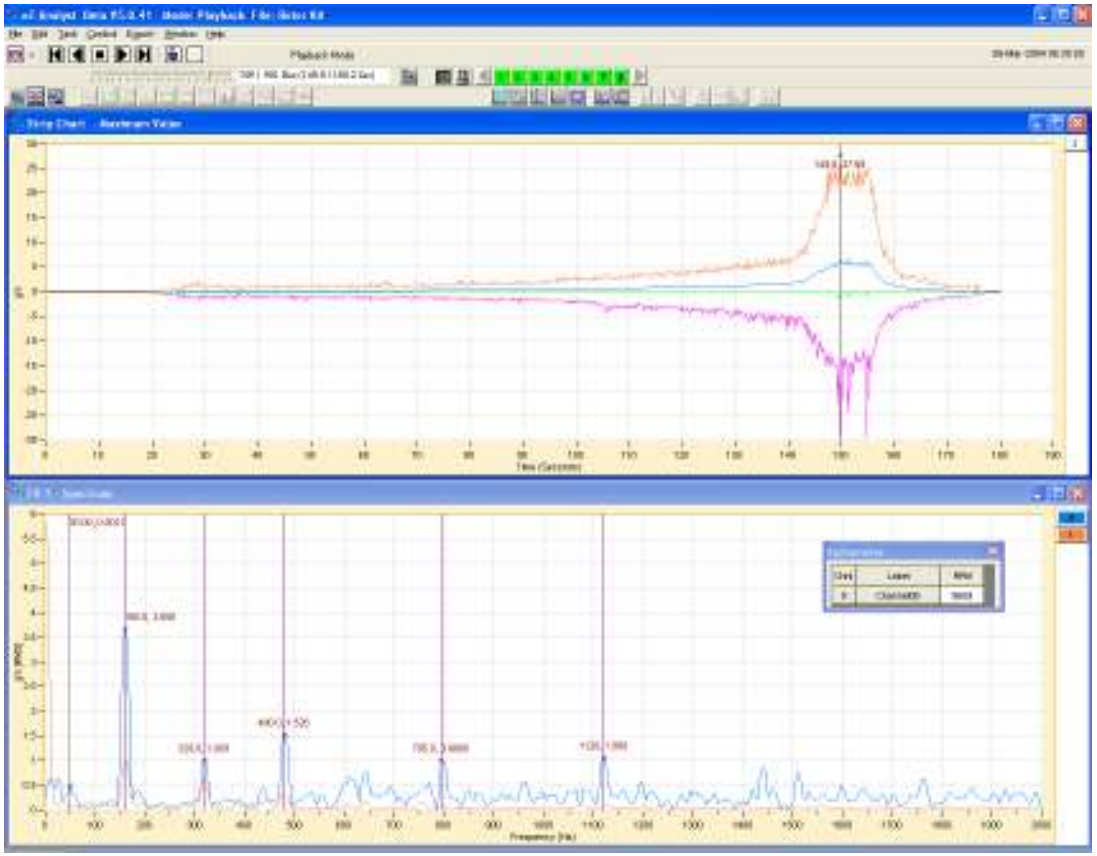
Vibration Seminar
Hardware – ZonicBook System

- 8 Channel Dynamic Signal Analyzer
- 4 Tach Inputs
- Ethernet
- WBK18 Expansion to 56 Channels
- 1 MSample / Sec.
- FSV: +/- 25 mV to +/- 25 V
- ICP / TEDS / Coupling
- EZ-Analyst: Data Recording and Impact Measurement
- EZ-TOMAS: Rotating Machinery Monitoring and Transient Analysis



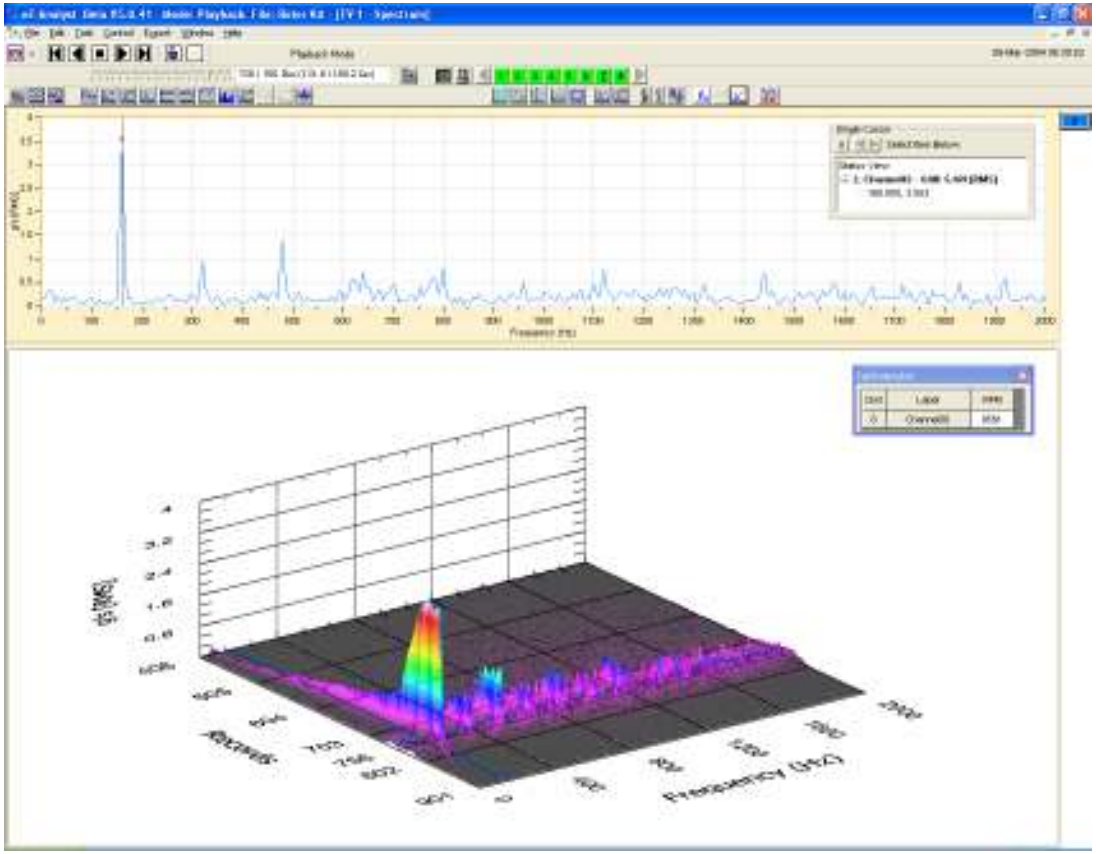
EZ-Analyst
Time History Recording

- Record Continuous Data
- Stripchart Overview
- Multiple Displays
- Multiple Traces / Display
- Harmonic, Sideband, Peak, Free Form Cursors
- Time Waveform, Spectrum, PSD



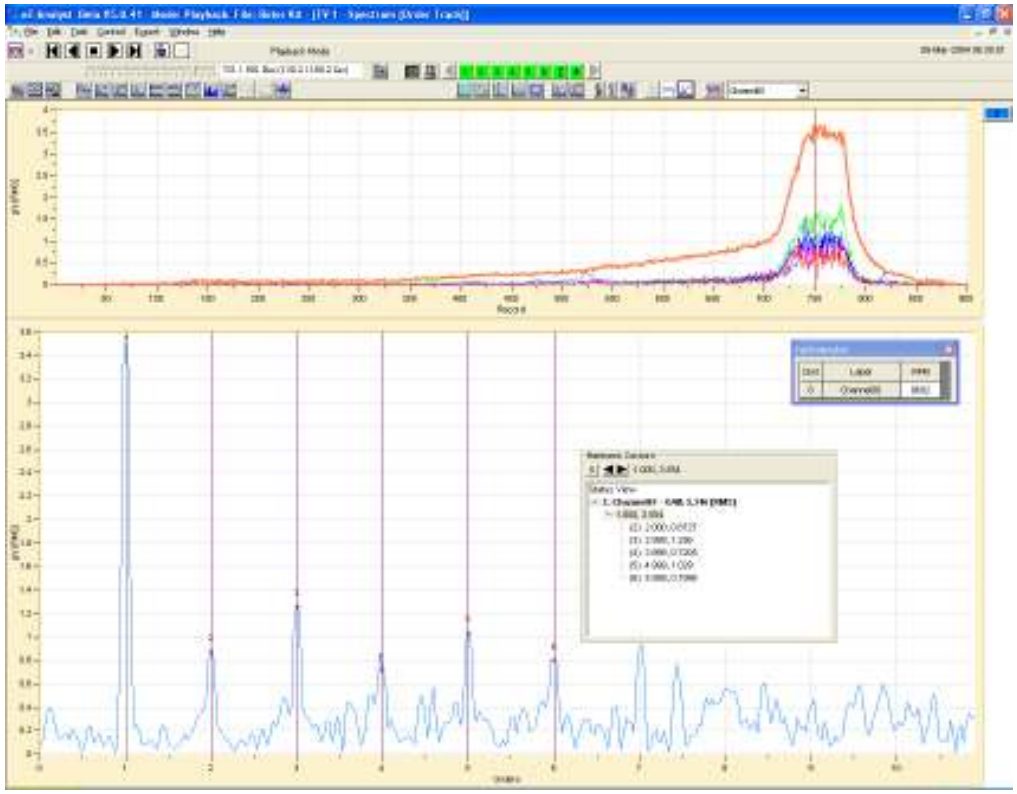
EZ-Analyst
Time History Recording

- Waterfall Displays
  - Spectral Data
  - Color Mapping
  - Cursor Annotation
  - Orientation
- Split Spectrum View
- Frequency Slice



EZ-Analyst
Time History Recording

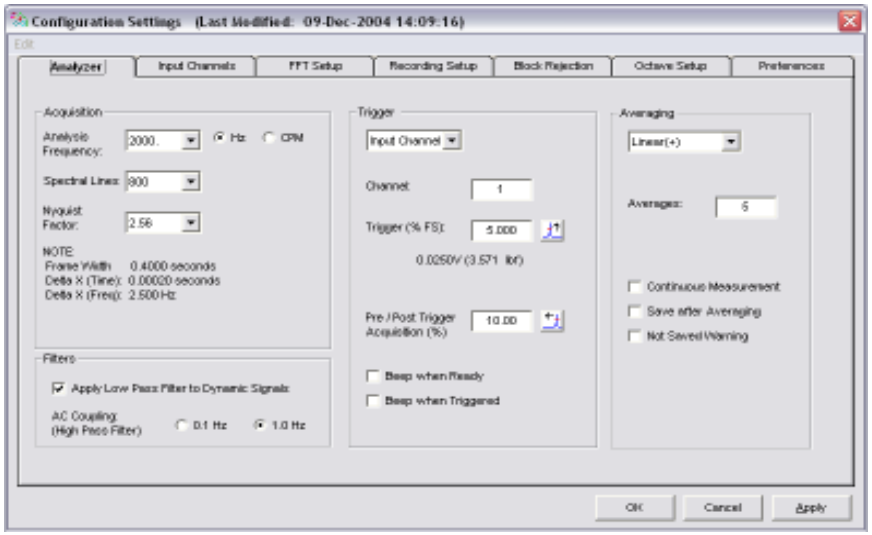
- Spectrum
  - Cursor Locations
  - Order Tracking
  - RPM Window
  - Annotation
- Split Order Slice View

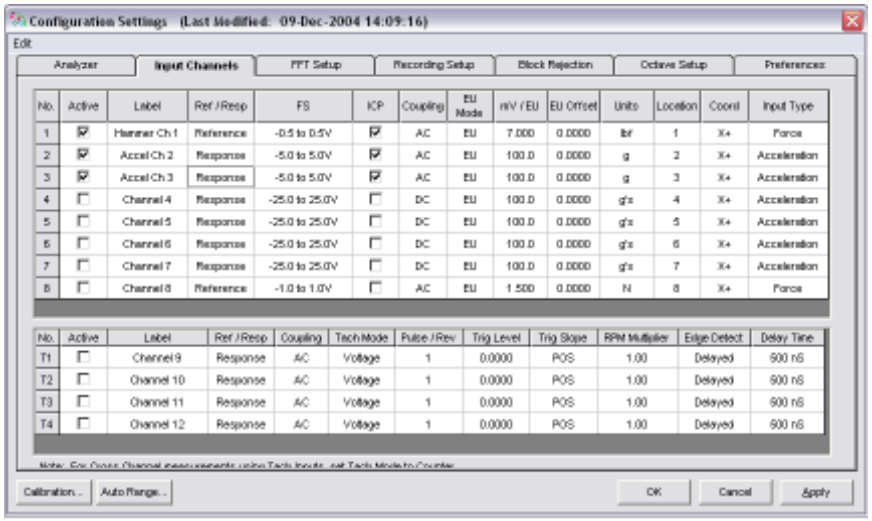


EZ-Analyst
Configuration Setup

- Analyzer Setup
  - Fmax: up to 50 KHz
  - Lines: up to 25,600
  - 0.1 Hz AC Coupling
  - Triggered Acquisition
  - Averaging

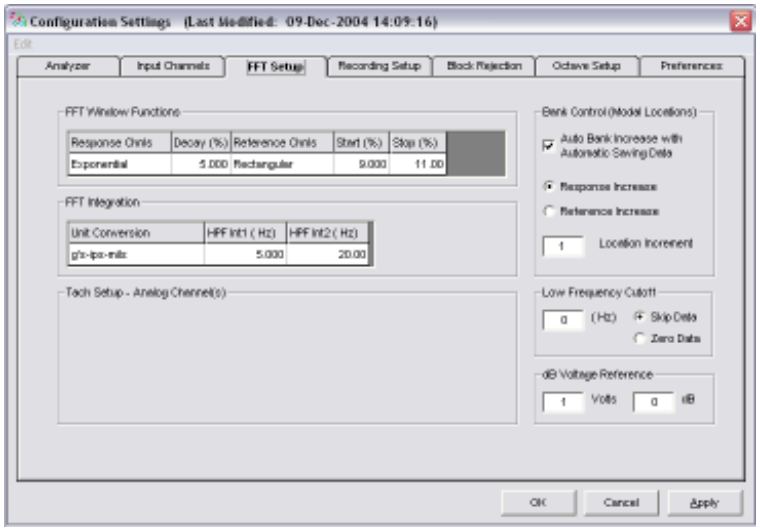
- Input Channels
  - Reference / Response
  - FSV / ICP / Coupling
  - Modal Locations



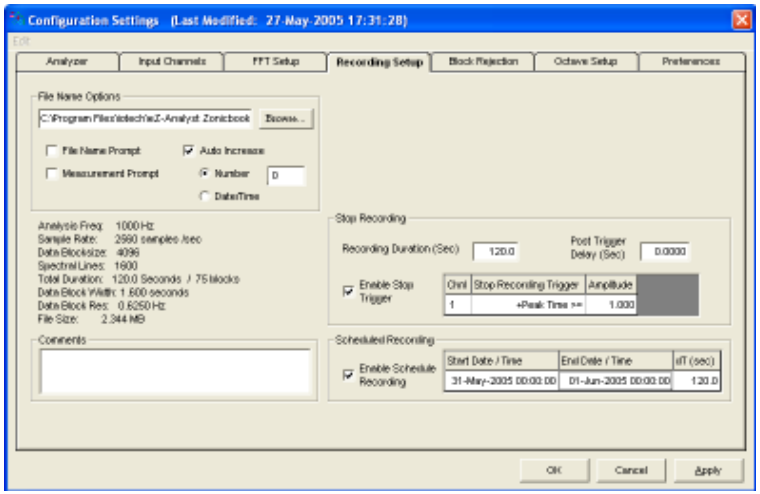


EZ-Analyst Configuration Setup

- FFT Setup
  - Hanning, Flat Top, Exponential, Rectangular
  - Increment Modal Location
  - HPF – Ski Slope effect

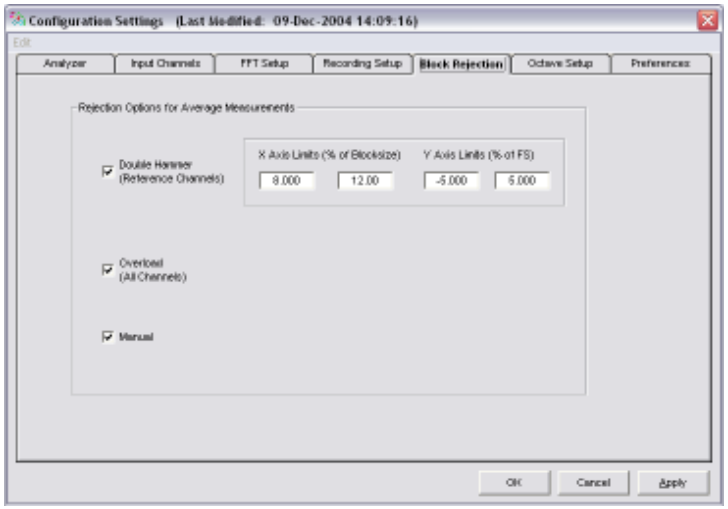


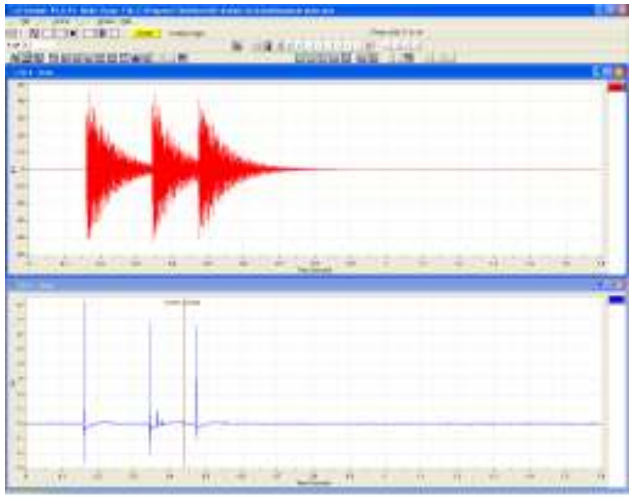
- Recording Setup
  - File Name, Increment
  - Duration: up to 100,000 sec
  - Stop Triggers
  - Scheduled Recording

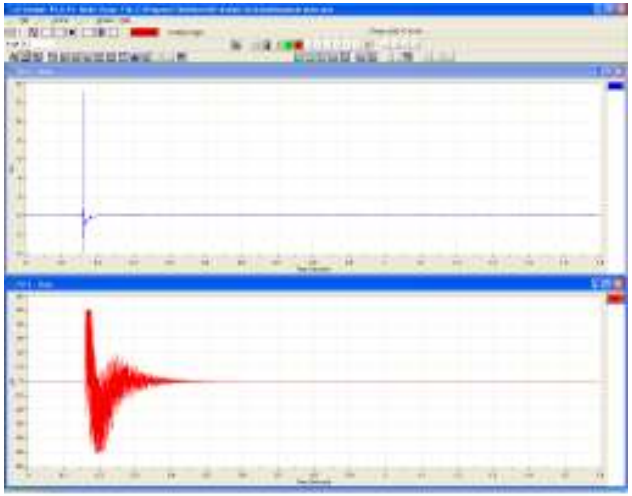


EZ-Analyst
Configuration Setup

- Block Rejection
  - Double Hammer
  - Overload
  - Manual

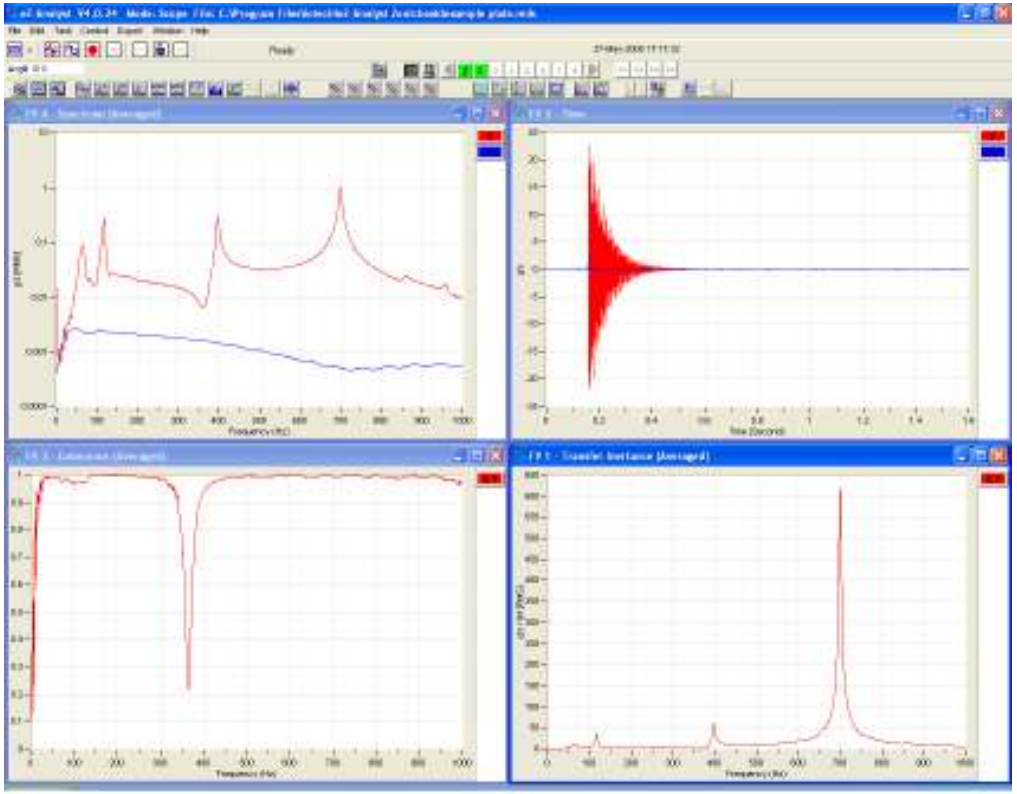






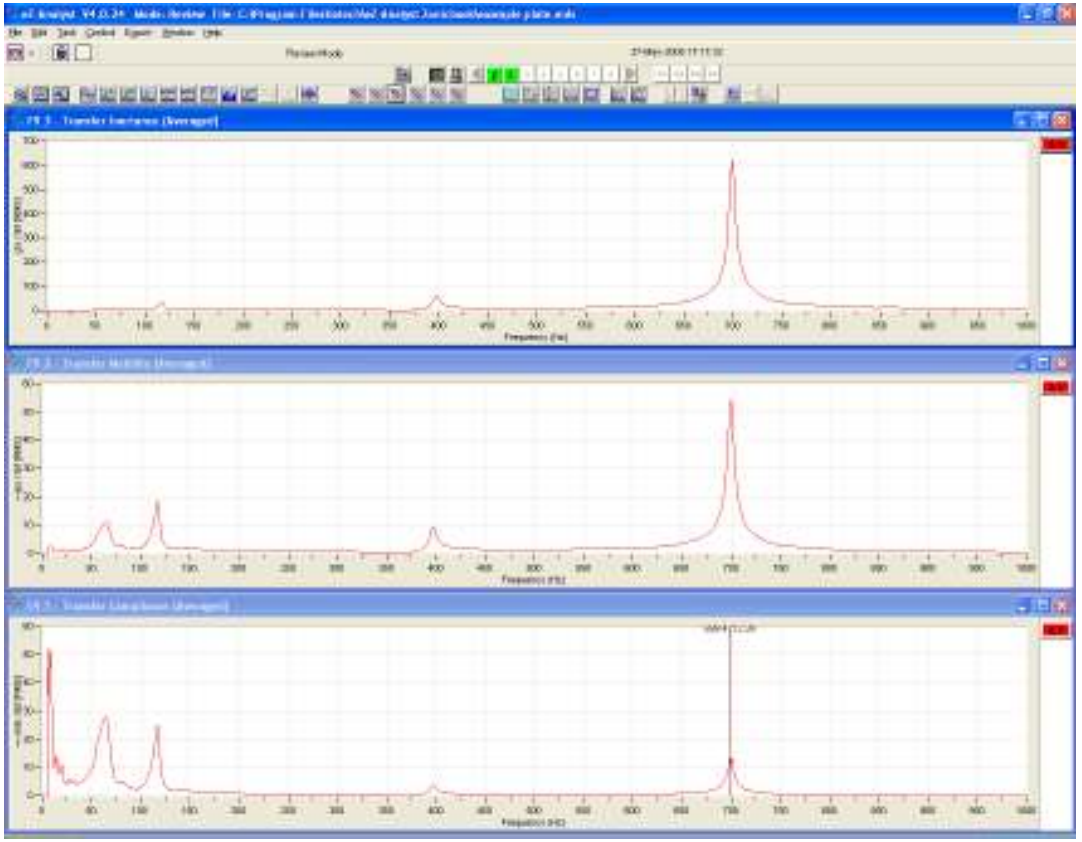
EZ-Analyst
Impact / Resonance Measurement

- Data Stored in MDS File
- Data Analysis:
  - Time, Spectrum
  - Coherence, FRF, and Transfer Function
- Export to XL; Overlay from XL
- Export to Modal Analysis Software



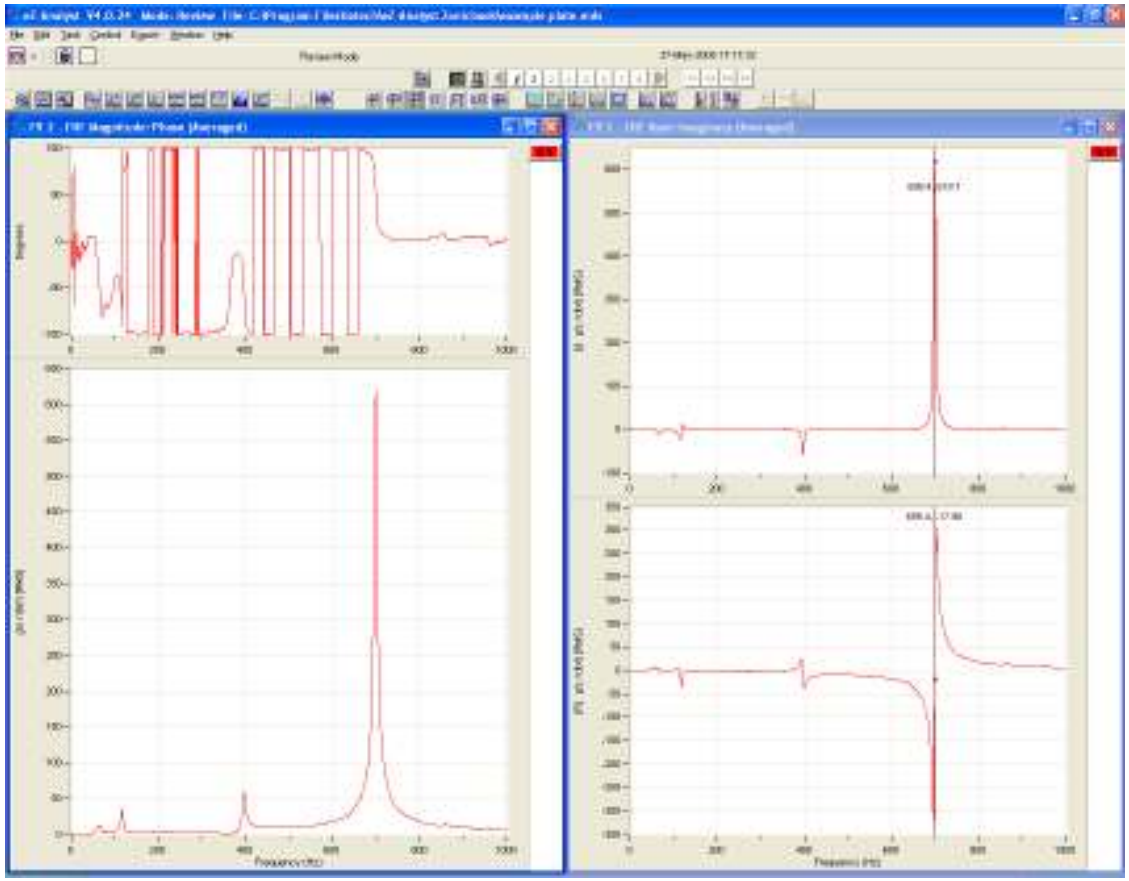
EZ-Analyst
Impact / Resonance Measurement

- Transfer Function
  - Inertance, Mobility, Compliance
  - A-V-D / Force
- Displacement:
  - Accentuates Low Freq
  - Attenuates High Freq.



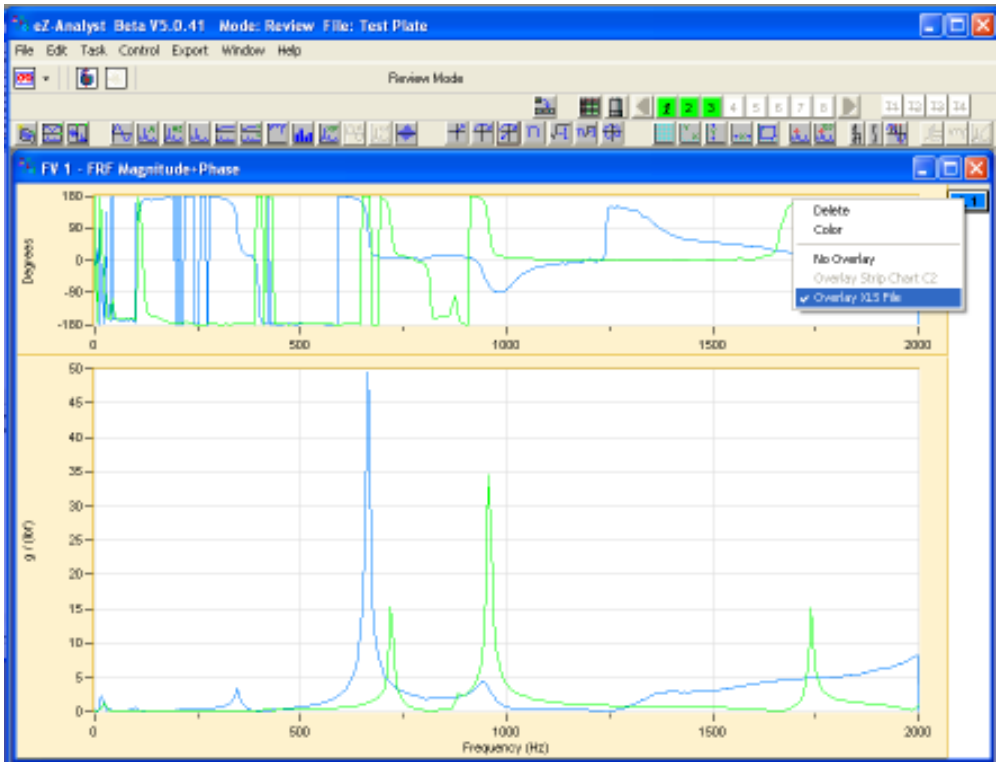
EZ-Analyst
Impact / Resonance Measurement

- FRF Magnitude / Phase
  - 180 Phase Shift
- FRF Real / Imaginary
  - Mode Shape
  - A / D use Imaginary
  - V use Real



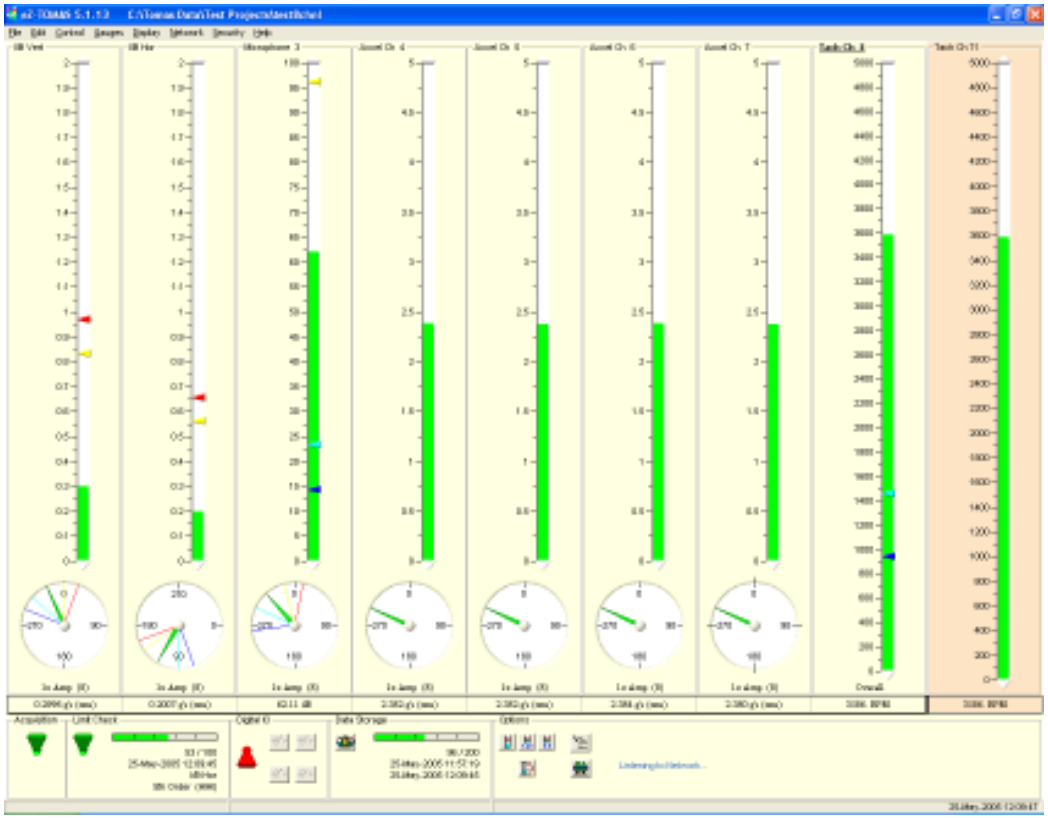
EZ-Analyst
Impact / Resonance Measurement

- Overlay Using XL
  - Compare Design Changes
  - Compare vs. Criteria



EZ-TOMAS
Monitoring Gauge Window

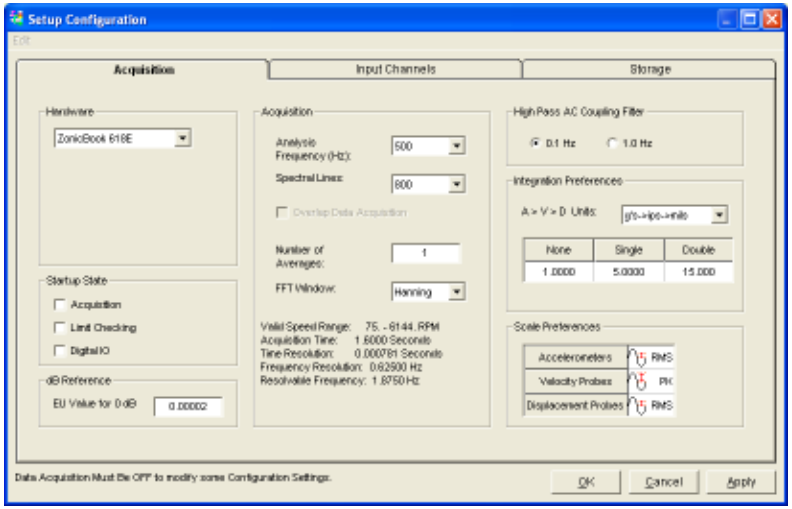
- Current Values & Status
- Vertical Amplitude
- Circular Phase
- Limit Checking / Log Events
- FIFO Storage
- High Water Marks
- Relay Outputs

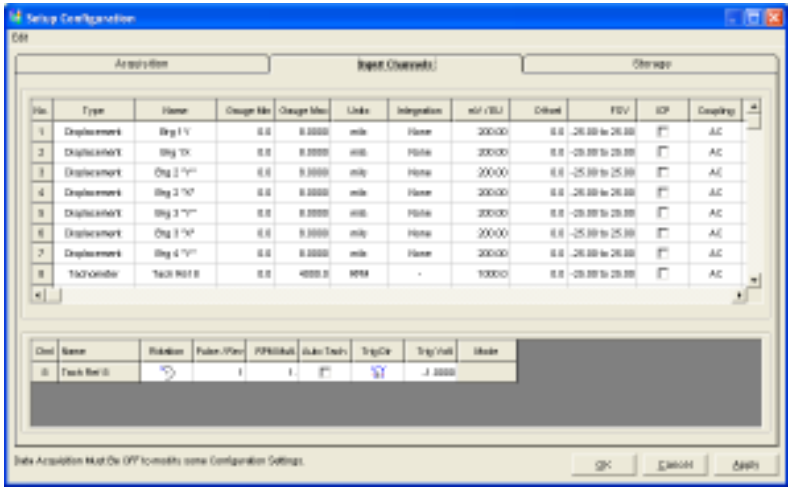


EZ-TOMAS
Configuration Setup

- Acqusition
  - Fmax: up to 20 KHz
  - Lines: up to 25,600
  - Hanning / Flat Top FFT
  - Scale Pref: RMS, PK, P-P

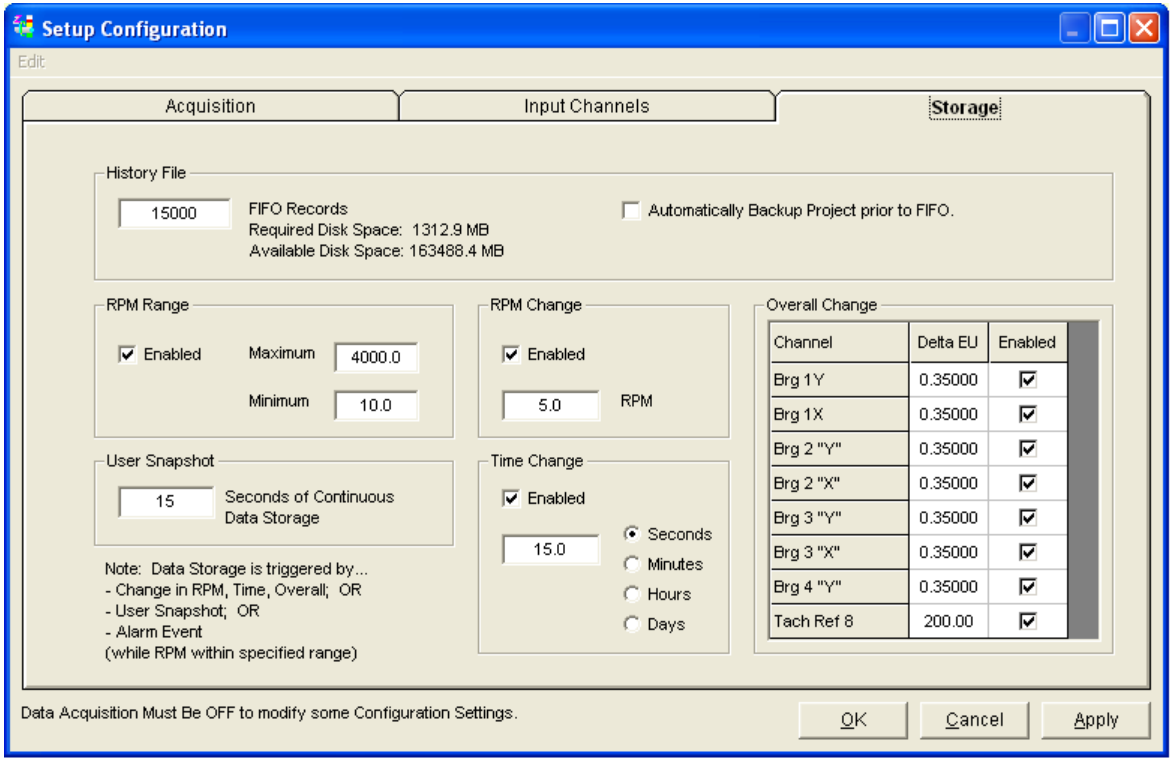
- Input Channels
  - D: DC Cplg, +/- 25V
  - A: ICP, AC Cplg, +/- 5V
  - Gap & Runout Ref.
  - Orbit / Tach Pairs





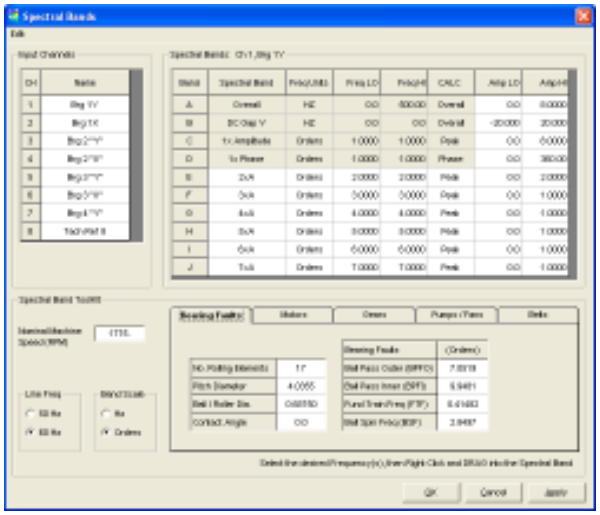
EZ-TOMAS
Configuration Setup

- FIFO Storage
  - Up to 200,000 Records / Channel
  - RPM Range
  - Change in RPM, Time, Vibration
  - Alarm Condition
  - User Snapshot

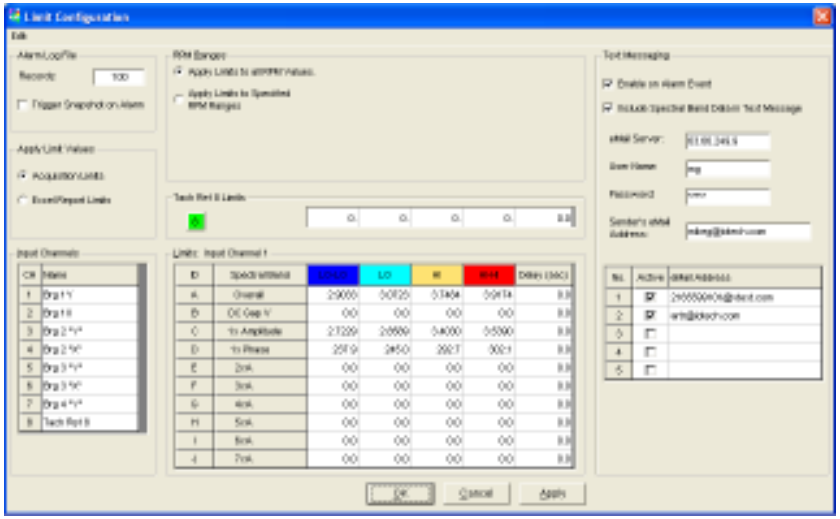


EZ-TOMAS
Configuration Setup

- Spectral Bands
  - OAll, Vdc, 1xA & 1xP
  - 6 User Defined
  - Overall, Peak, Phase
  - Fault Toolkit

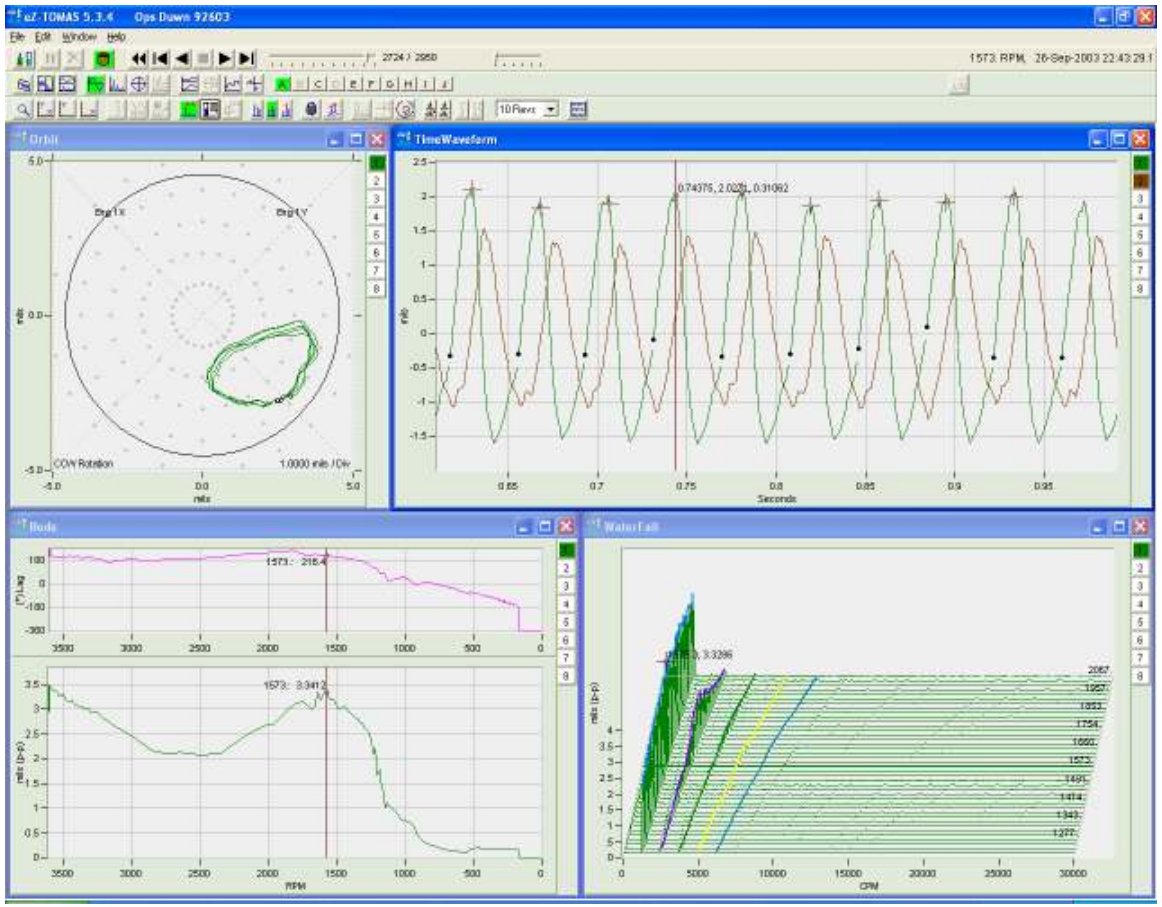


- Spectral Limits
  - 2 High / 2 Low
  - Delay
  - Text Message



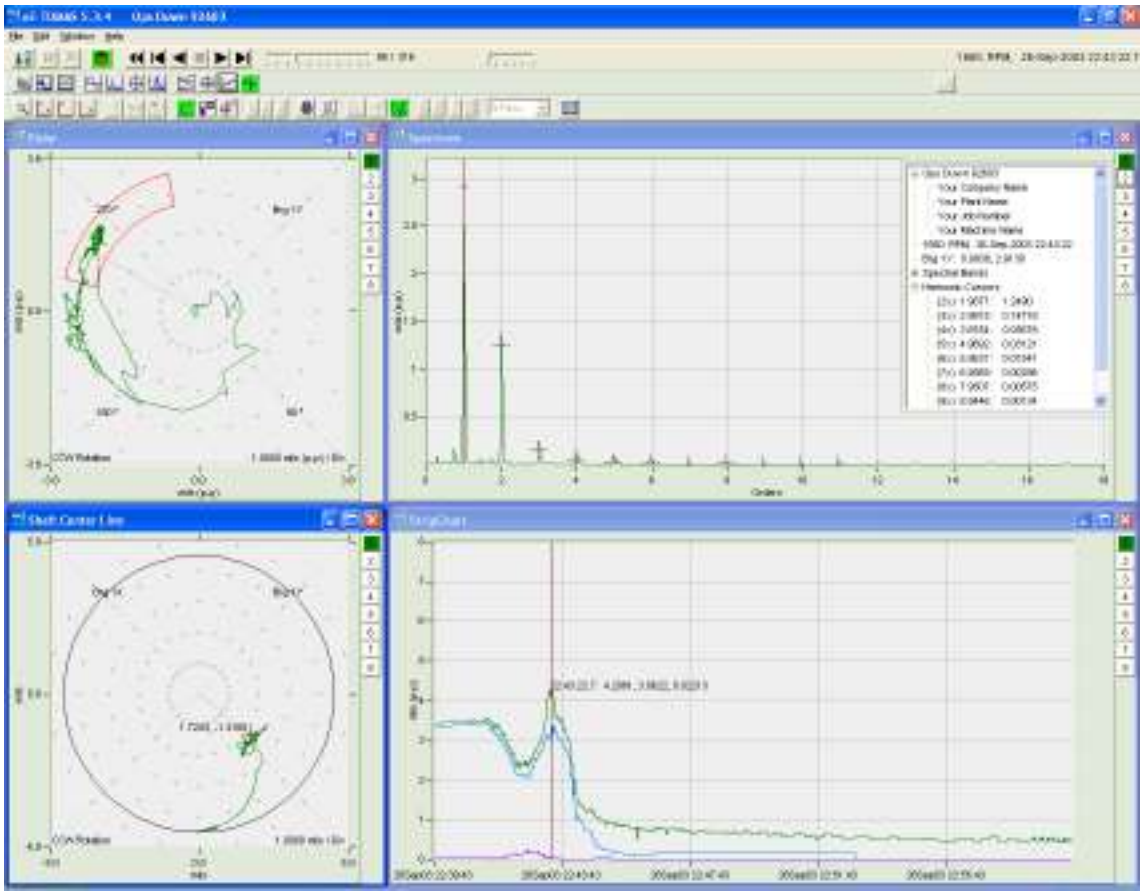
EZ-TOMAS
Rotating Machinery Analysis

- Orbit, Time Waveform
  - w/ or w/o Filtered
  - N Revolutions
- Bode
  - w/ or w/o Runout
  - OAll, 1x, nX
- Waterfall
  - Order Tracks
  - RPM Annotation



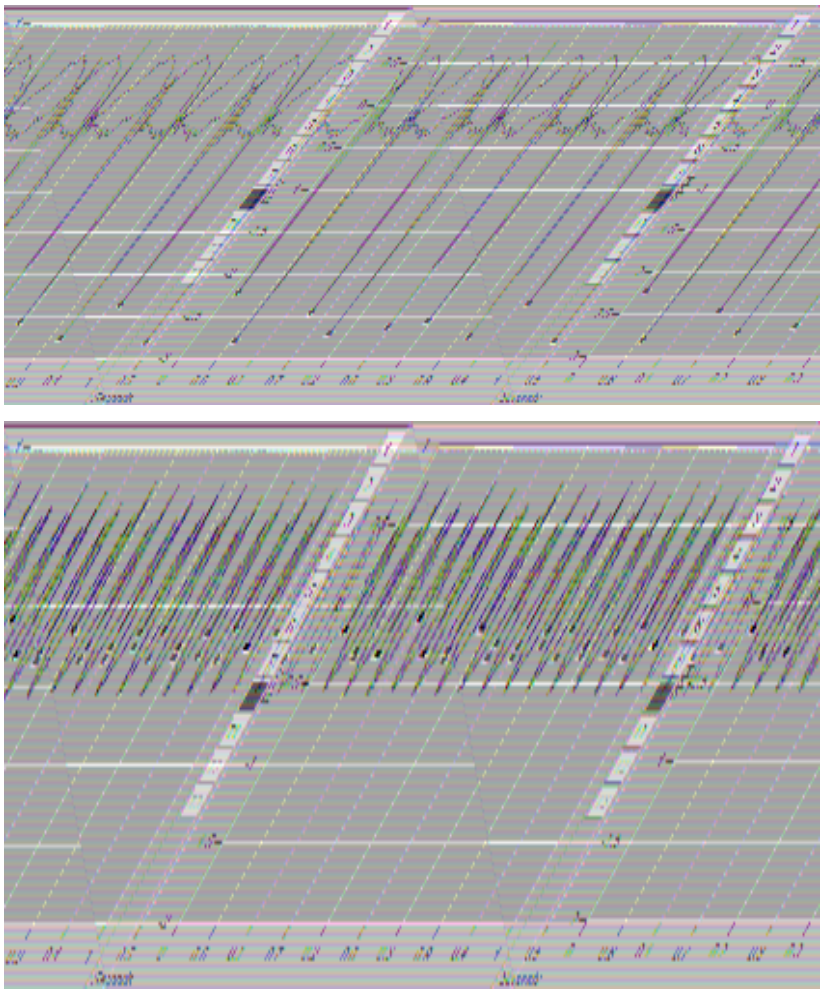
EZ-TOMAS
Rotating Machinery Analysis

- Polar
  - Runout, Limits
  - Annotation
- Spectrum
  - Harmonic, Sideband Peak Cursors
- Shaft Center Line
- Trend
  - OAll, 1x, nX
  - Cursor to History Location



EZ-TOMAS
Rotating Machinery Analysis

- Automatic Tach
  - Analog Inputs
  - Dynamically adjust trigger levels
  - Trigger Direction



EZ-TOMAS
Learning Limits

- Statistical Report
  - Steady State Condition
  - Min, Avg, Max, Dev
- Calculate Limits based on Normal Operation
- Before / After Shutdown comparisons