Interpreting Vibration Spectrum and TWF Patterns

(Understanding Motion Through Pattern Recognition)

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Patterns

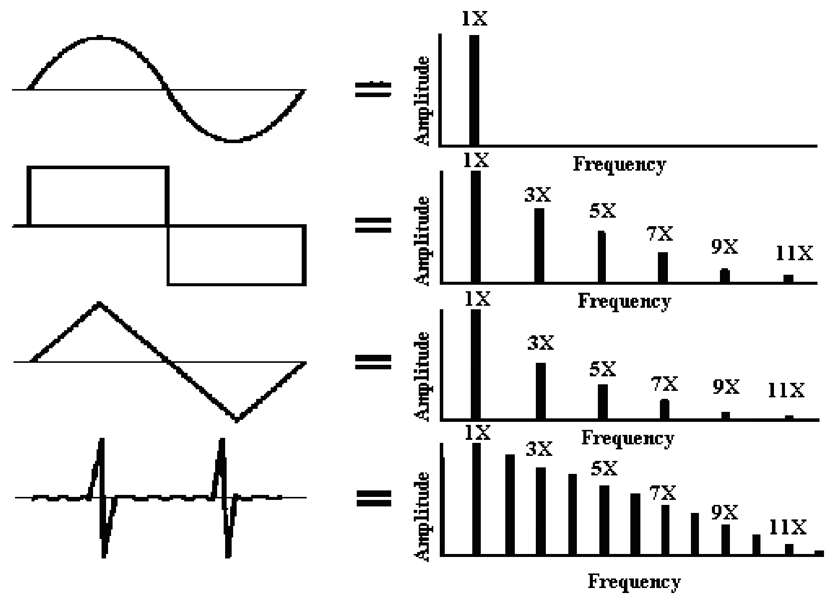
- When reduced to it's most basic concept, Vibration Analysis can be thought of as looking for 'Patterns' in the vibration data.
- We use the same concepts that we learned in kindergarten:
  - Even spacing (harmonics)
  - Mirror image (sidebands)
  - Comparing objects (baseline, other directions or similar machine)
  - "Odd Man Out" (group comparison)

Spectrum Patterns

Spectrum Patterns

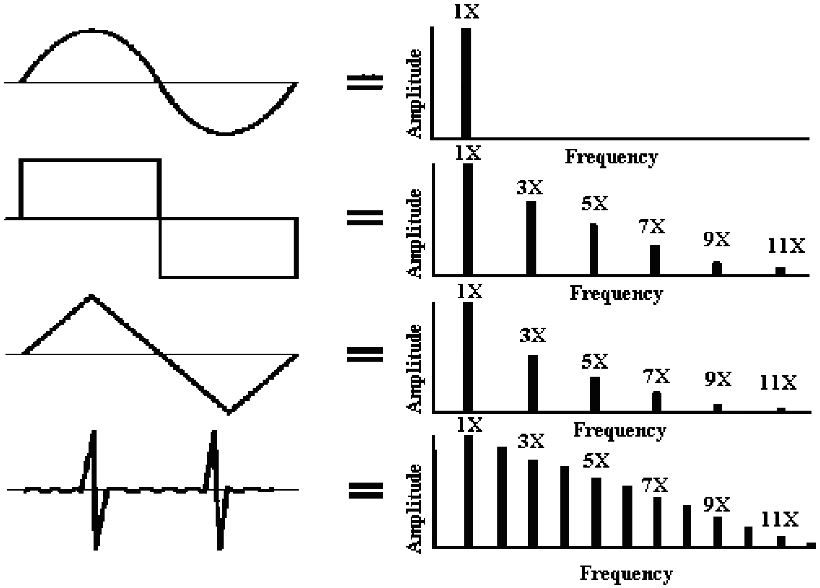
- There are four <u>basic</u> spectrum patterns:
  - Harmonics - Almost always caused by the TWF shape
  - Sidebands - Due to Amplitude or Frequency Modulation
  - Mounds/Haystacks - Random vibration occurring in a frequency range
  - Raised Noise Floor - White noise or large random events

Spectrum Harmonics



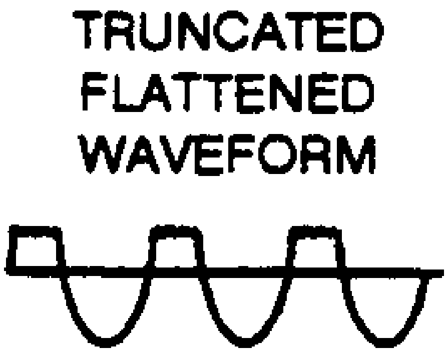
- The FFT is breaking down the TWF into a combination of **sinusoidal** frequencies
- The only motion that can be represented by one sine wave **is** a sine wave!
- For any other shape of motion, the FFT will **ADD** harmonics of this motion to the Spectrum
- Square or Triangular motion produces odd harmonics, while impactive or spike motions will produce odd and even harmonics
- The harmonics <u>caused by the shape</u> of the motion **do not "physically" exist** in the machine. However, since the FFT math needs them to break down the motion, it <u>removes amplitude from the fundamental</u> to give to the harmonics

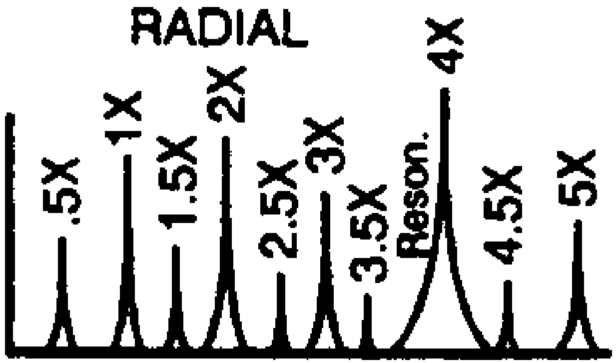
Spectrum Harmonics



- A sinusoidal motion is usually due to a force that is smoothly applied and released or present continuously
- Squared motion is usually due to a truncation or rubbing event
- Triangular motion is usually due to a sliding (slop), binding or rocking motion
- Spikes are usually due to impacting or pulsations (such as air or fluid pulsations in a pump)
- Since the majority of TWFs are not saved, understanding the relationship between the harmonic pattern and the motion that produced it is vital to visualizing the machine motion (problem)

Spectrum Subharmonics

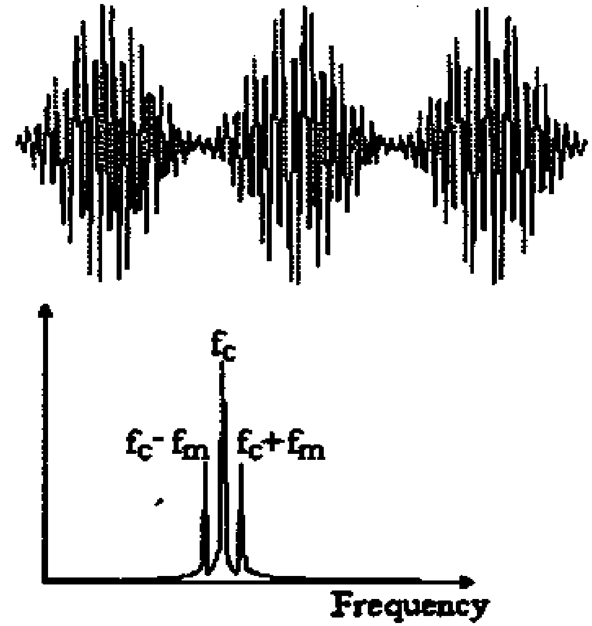


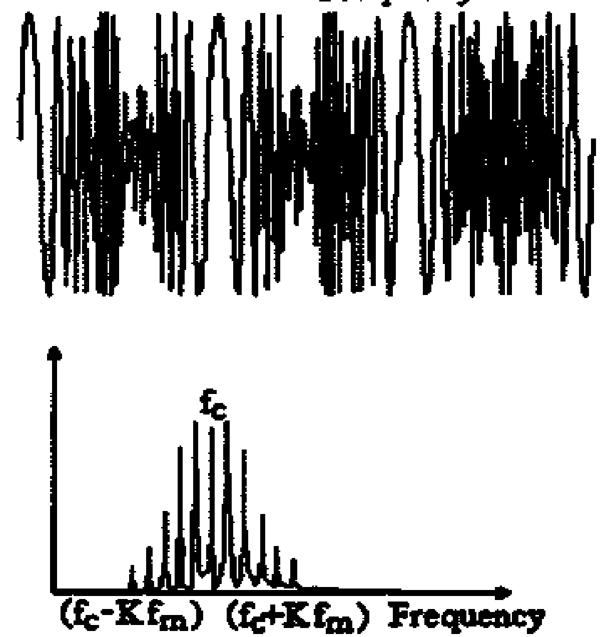


- A subharmonic will be generated when the TWF is truncated on one side, or nonsymmetrical
- Just like harmonics, subharmonics caused by a truncated or nonsymmetrical TWF **do not exist** as real motion! They are generated by the FFT math
  – In trying to flatten only one side of the TWF, the FFT requires a sine wave that is a fraction of the actual motion frequency, and multiples of this fraction

Spectrum Sidebands

- Amplitude Modulation (AM)
  - One frequency (carrier) is getting <u>louder and softer</u> at another frequency (modulating freq)
  - AM is mono. Mono is ‘one’, which implies **one** sideband on each side of the carrier
- Frequency Modulation (FM)
  - One frequency (carrier) is <u>speeding up and slowing down</u>
  - FM is stereo. Stereo is ‘more than one’, which implies **more than one** sideband on each side of the carrier (usually a linear amplitude reduction)





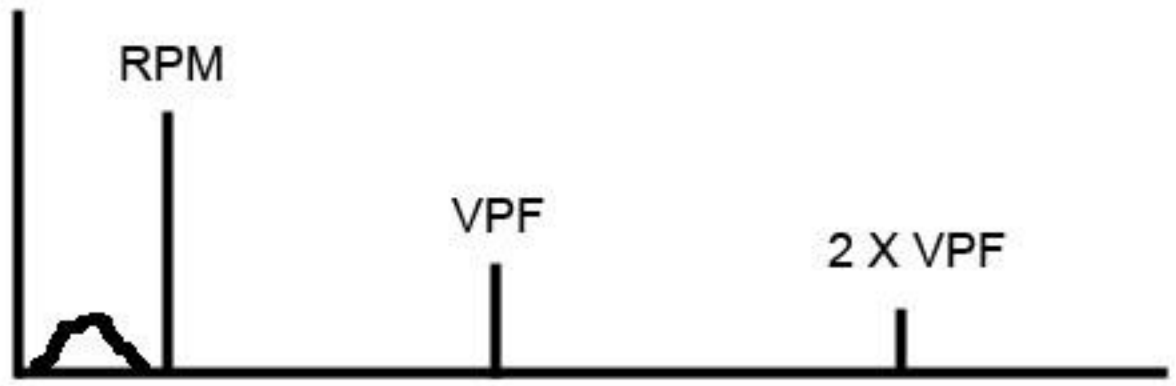
Spectrum Sidebands

- Frequencies can have AM sidebands, FM sidebands or both
- Sideband spacing is ‘how often’ the center frequency (called the carrier) is changing
- Sideband spacing should be matched to a specific component, whenever possible
  - RPM of the applicable shaft
  - Bearing Cage
  - Etc.

Mounds or Haystacks

- Mounds are most commonly due to:
  - Resonance amplification
    - Both frequencies and the noise floor will be mounded up in a volcano shape
  - Looseness
    - Low levels of looseness will have the noise floor mounded up in the region of natural frequencies, even if no discrete frequency is in the region
  - Flow induced vibration
    - Turbulence or recirculation
    - Cavitation (centrifugal pumps only)
  - Sidebands with low spectrum resolution
    - Frequencies will tend to blur together
    - Common example is Ball Spin with Cage sidebands

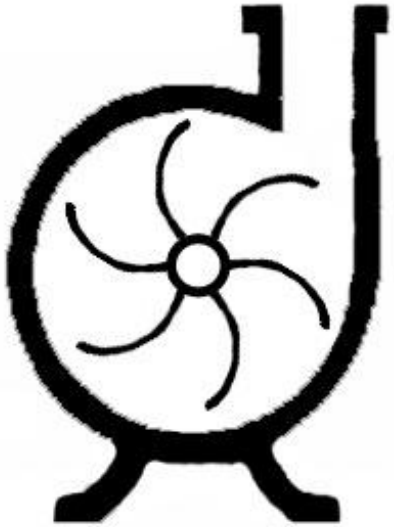
Flow Induced Mounds

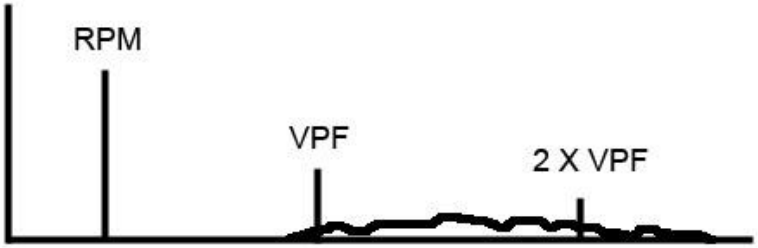


- **Turbulence or Recirculation**
  - Turbulent flow due to piping obstructions, nicks, burrs, etc.
  - Operating near Shutoff causes high recirculation through wear rings
  - Causes a mound to appear below RPM

Flow Induced Mounds

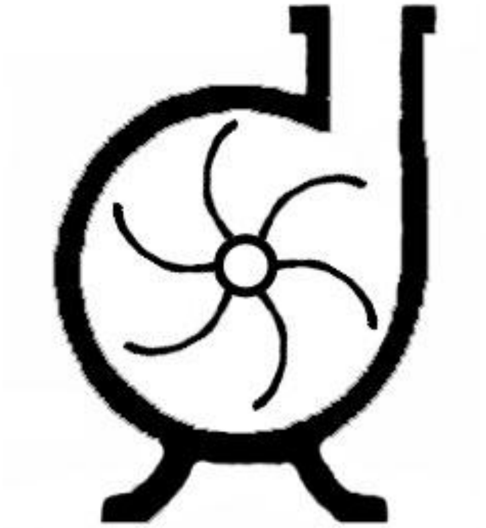
- **Blade Tip Cavitation**
  - Low backpressure inside pump cavity
  - Front side of blades are higher pressure
  - Back side of blades are lower pressure
  - All fluid is moving outwards
  - Bubbles form in low pressure on back side of blades
  - Bubbles collapse when they hit the high pressure flow from the front side of the blades - at the tips
  - This usually causes a mound to appear starting at Vane Pass Frequency (VPF), extending up to around 2x to 3x VPF

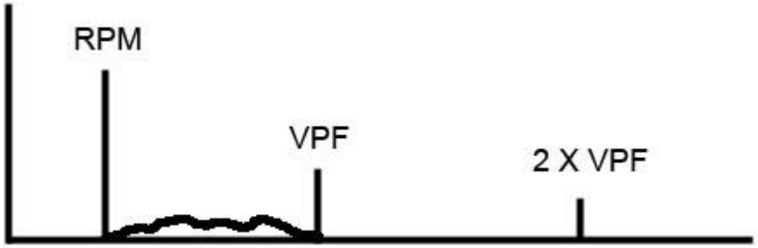




Flow Induced Mounds

- **Suction Cavitation**
  - Centrifugal pumps pull fluid into the pump
  - If the pump is pulling faster than the suction pipe can supply, a low pressure is formed at the eye of the pump (insufficient NPSH)
  - Bubbles form in the eye, **before** they enter the pump
  - These bubbles collapse on the leading edge of the blades (1/3-2/3 down the blade)
  - The mound will usually appear between RPM and VPF (fewer bubbles)





Raised Noise Floor

- A raised noise floor is due to extremely high noise levels or severe random impacting levels
  - Severe looseness
  - Stage 4 bearing defect
  - Solids passing through pump impeller

Six Questions For Spectrum Pattern Analysis

1. What is the predominate frequency?
2. What other frequencies are present?
   a. What patterns are these?
   b. What motion made these patterns?
3. Can I isolate this to one shaft or one bearing?

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4. On each bearing, is the horizontal or vertical amplitude more than 4x bigger than the other?
5. On each bearing, is the axial amplitude more than 50% of the highest radial amplitude?
6. Do I need phase?

ALL PROBLEMS

COMMON FREQ.'S

Six Questions For Spectrum Pattern Analysis

1. What is the predominate frequency?

   - Some (especially beginning) analysts have a difficult time deciding where to start their analysis
   - The vast majority of the time, the largest amplitude will be the machine problem
   - On rare occasions, the highest amplitude will not be in the same location as the problem (e.g. misalignment causing the free end of the motor to waggle), so this question pertains to the **entire machine**

Six Questions For Spectrum Pattern Analysis

2. What other frequencies are present?
   a. What patterns are these?

- Identify all patterns present: frequencies with no harmonics (beyond 3x), fundamentals with harmonics (beyond 3x), sidebands, mounds, raised noise floor
- There may be more than one of each type of pattern, such as two harmonic patterns
- Are there unexpected frequencies, such as nonsynchronous or subsynchronous?

Six Questions For Spectrum Pattern Analysis

2. What other frequencies are present?
   b. What motion made these patterns?

- Identify the machine part(s) associated with each pattern
- Visualize the waveform motion that generates each type of pattern visible in the data
- What problems could make this part of the machine move in that motion?

Six Questions For Spectrum Pattern Analysis

3. Can I isolate this to one shaft or one bearing?

   - Of the frequencies identified as the problem or problems, are they obviously higher or more identifiable on one shaft or bearing?
   - Can we see more harmonics on one shaft than the other?
   - Etc.

Six Questions For Spectrum Pattern Analysis

4. On each bearing, is the horizontal or vertical amplitude more than 4x bigger than the other?
   - Questions 4, 5 and 6 are for common frequencies, and pertain to the affected bearings from Question 3
   - This question is trying to identify whether the radial motion at the common frequency is obviously direction
   - If one radial motion is more than 4x bigger than the other direction, phase is not required to identify this motion as directional
   - In most cases, the ratio will be less than 4:1, but it never hurts to check at this point

Six Questions For Spectrum Pattern Analysis

5. On each bearing, is the axial amplitude more than 50% of the highest radial amplitude?

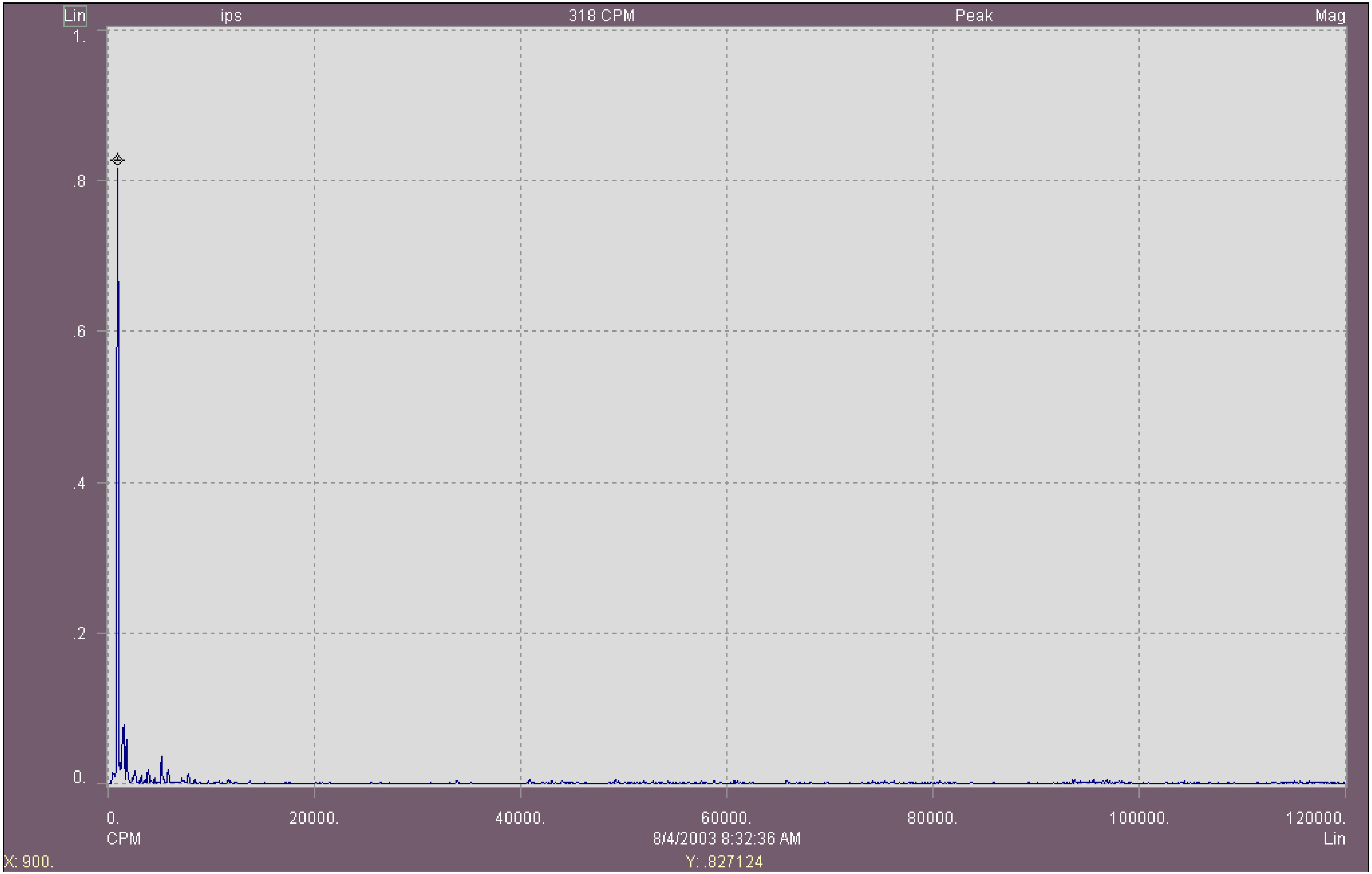
- On each bearing identified in question 3, find the highest radial amplitude and cut it in half (50%)
- On the same bearing, find the axial amplitude and compare them to each other
- If the axial amplitude is more than 50% of the highest radial on that bearing, we are looking for an axial problem. If less than 50%, we are looking for a radial problem

Six Questions For Spectrum Pattern Analysis

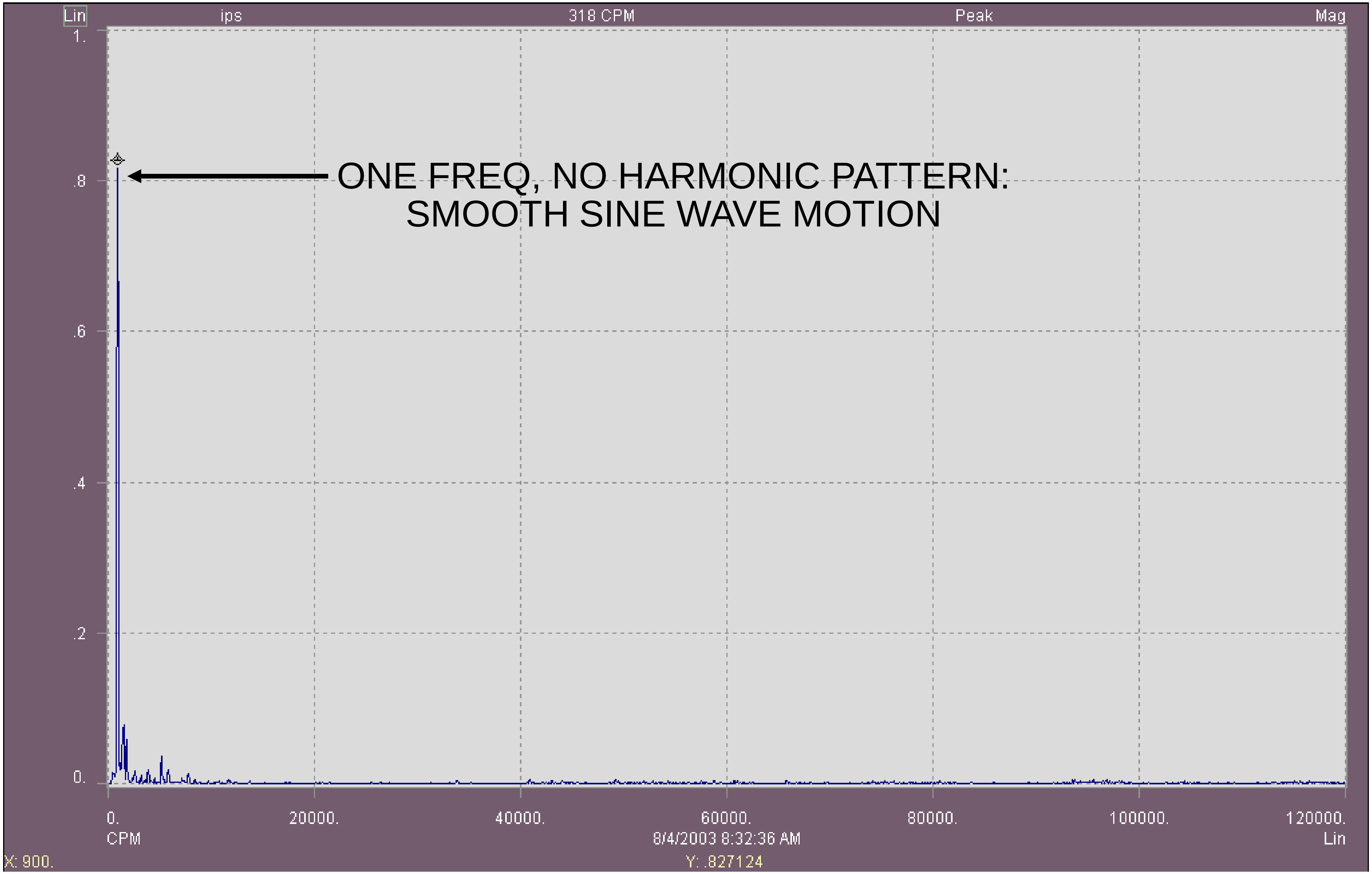
6. Do I need phase?

- If the problem frequency is 1 X RPM, the answer to question 6 will **always be yes!**
- There are simply too many problems that make RPM for us to identify the exact problem without phase
- Using our pattern analysis, we may be able to narrow it down to four, three, or even two problems. Phase will be required to identify which of these is the real problem

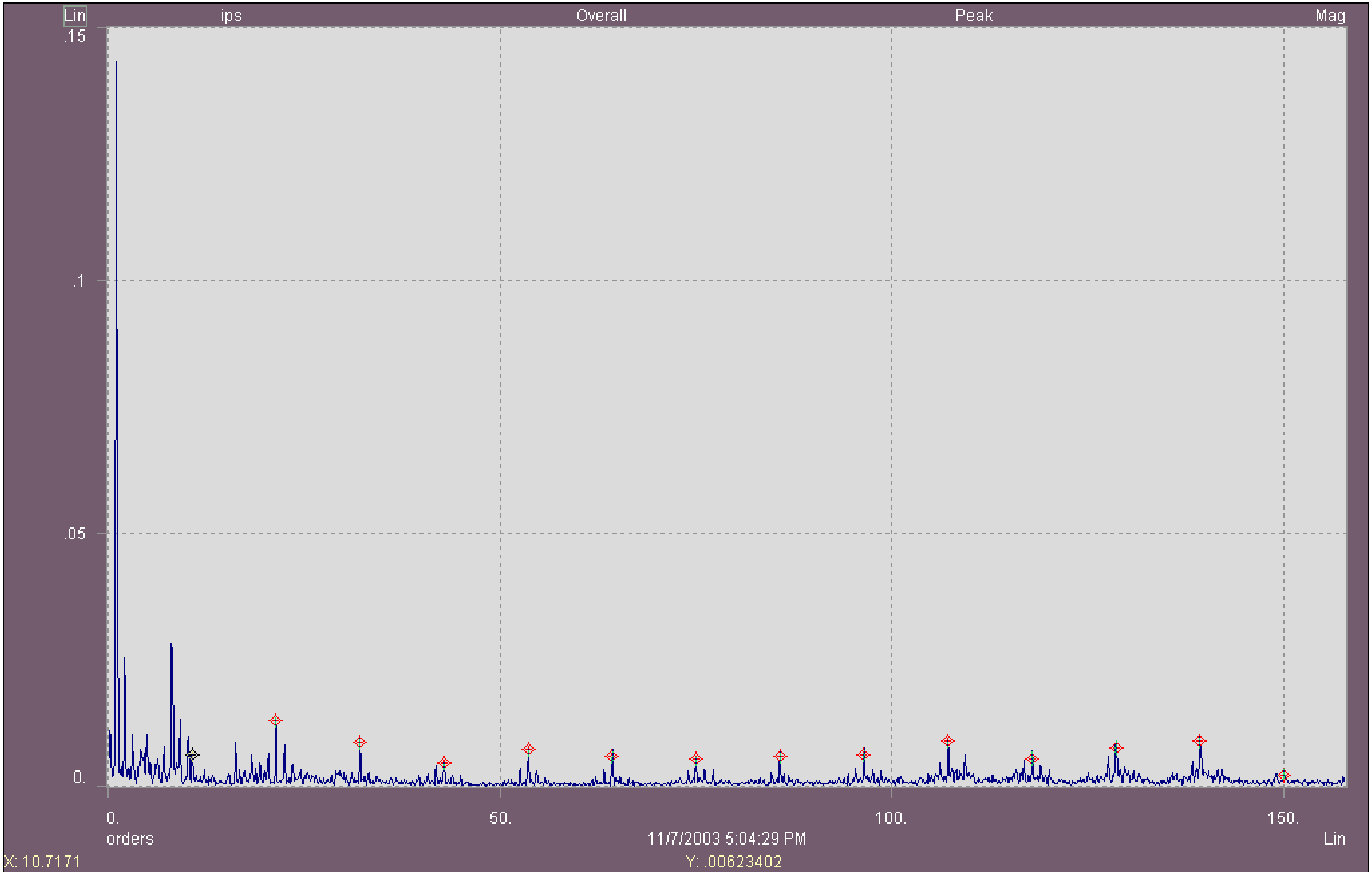
Visualizing Motion Through Patterns



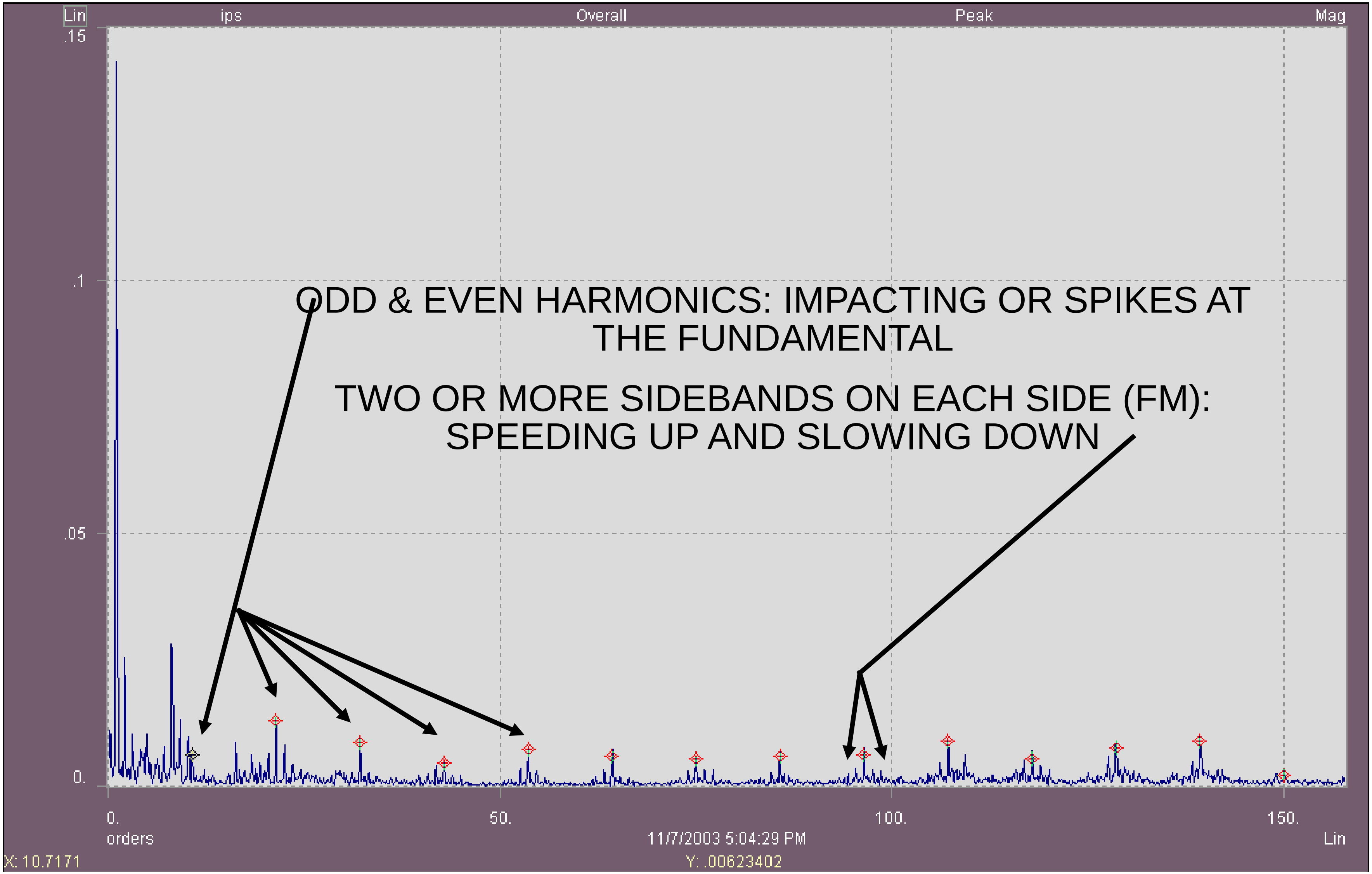
Visualizing Motion Through Patterns



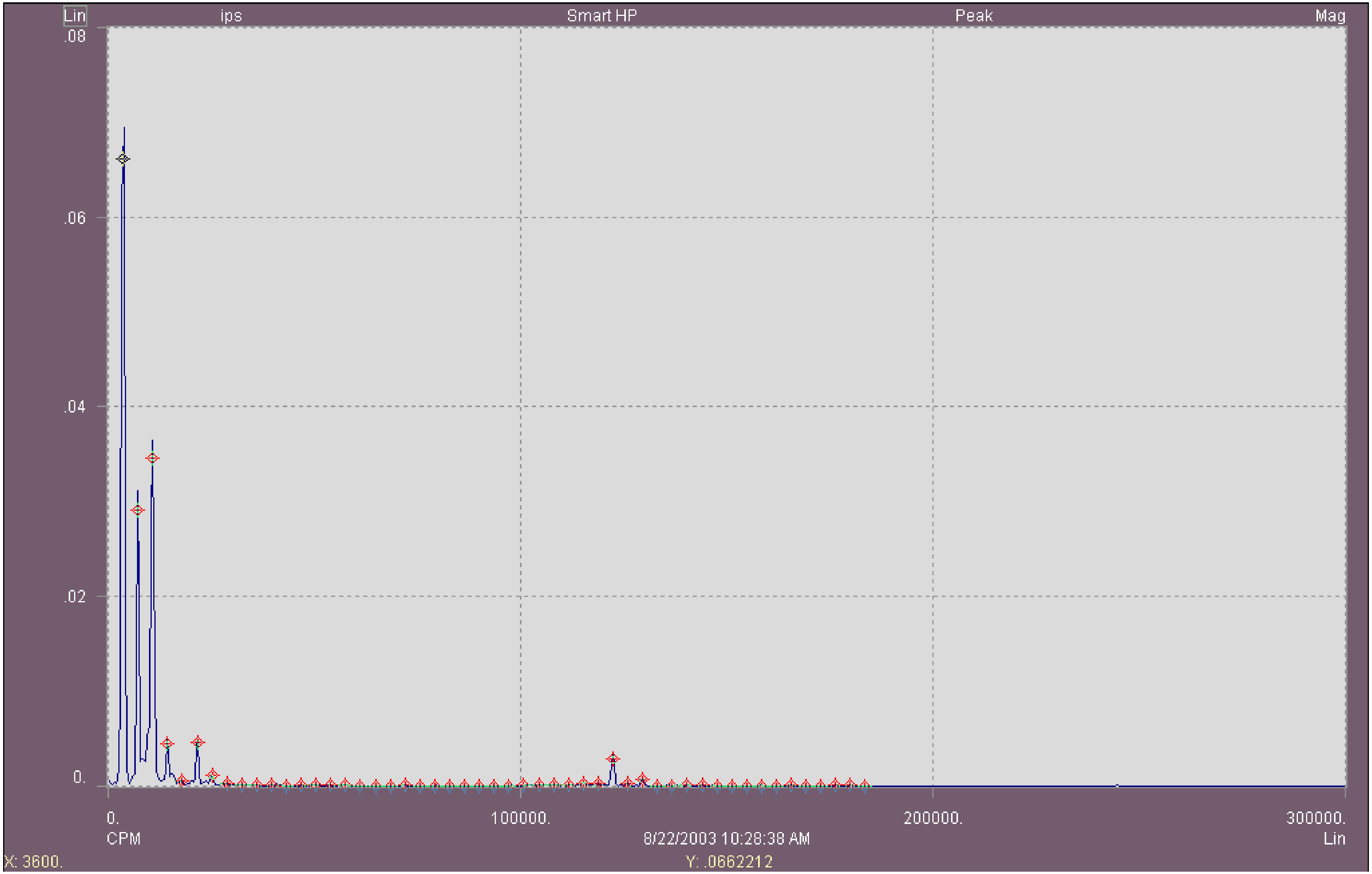
Visualizing Motion Through Patterns



Visualizing Motion Through Patterns



Visualizing Motion Through Patterns



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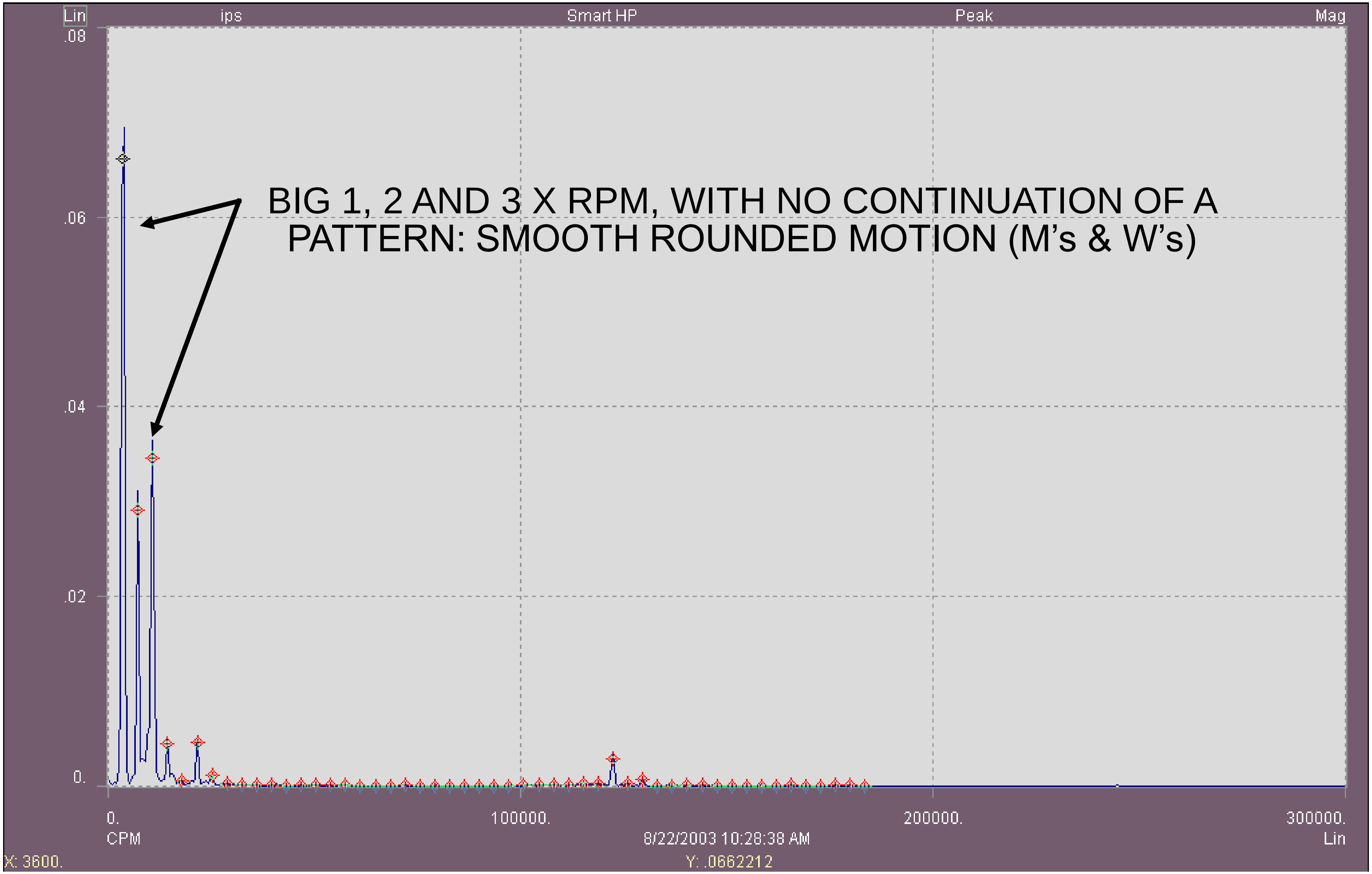

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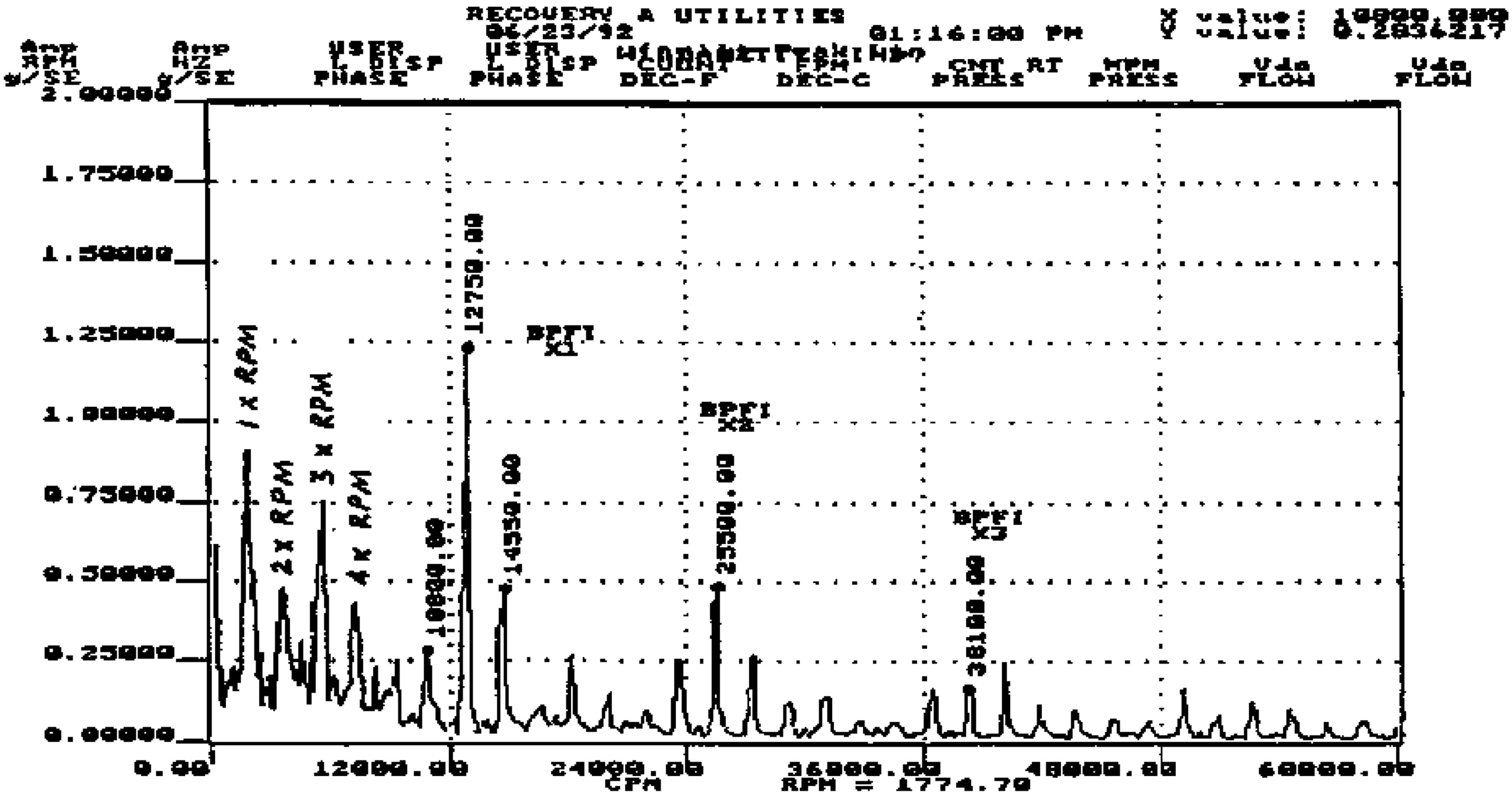
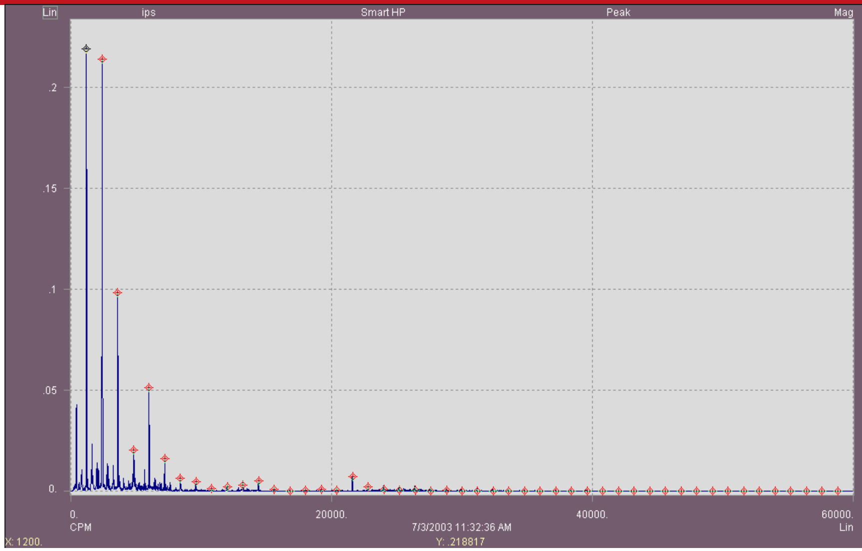


Visualizing Motion Through Patterns

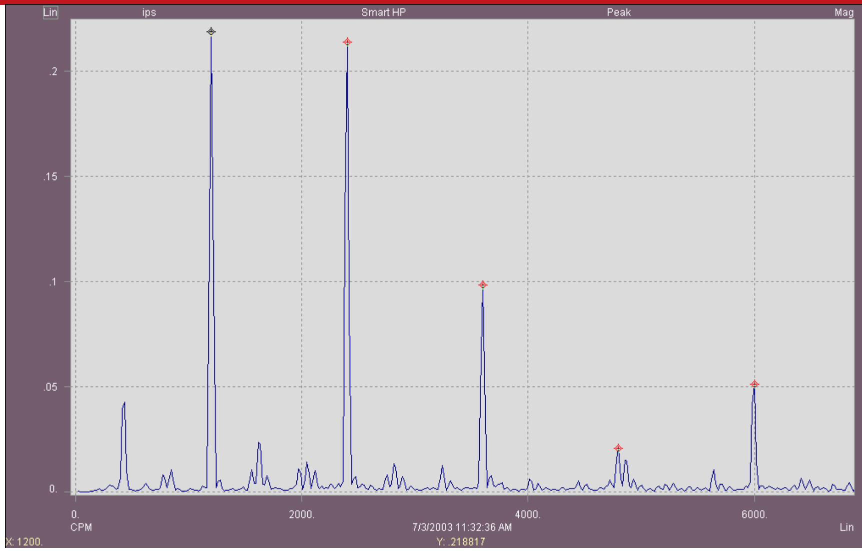
- Predominate Frequency (matches calculated inner race frequency):
  - Odd and even harmonics – Impacting
  - One tall sideband on each side – AM (louder/softer)
  - Spacing is RPM – Louder/softer each rotation
  - More than one sideband visible on each side – FM (speeding up and slowing down)
- RPM:
  - Odd and even harmonics – Impacting
  - Odd harmonics taller – Also squared off or triangled out
  - Subharmonic (1/2 x RPM) with harmonics – Truncated or nonsymmetrical motion
- Mounding under RPM and harmonics – combined with other symptoms, most likely due to looseness

Problem: Cracked inner race - (harmonics and AM sidebands), which will slip or move on the shaft, causing low level FM sidebands and rubbing symptoms (RPM impacting, truncation and likely mounding)

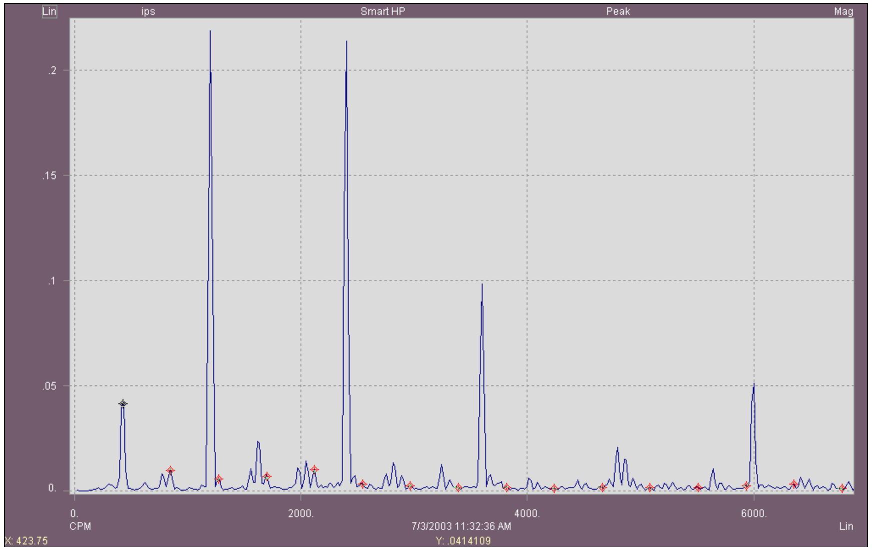
Visualizing Motion Through Patterns

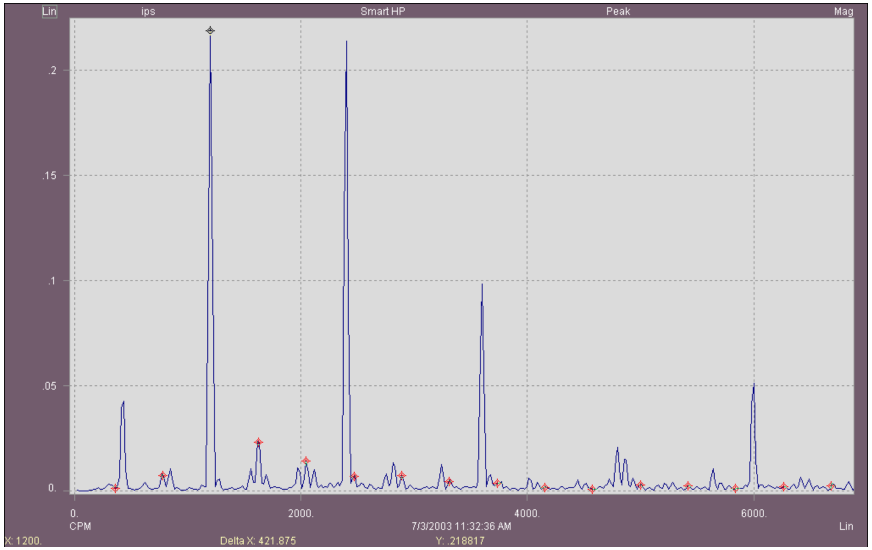


Numerous Frequencies



Apparent Sidebands of Sidebands?





No – Actually Harmonics of Output Speed and Output Sidebands Around Input Harmonics

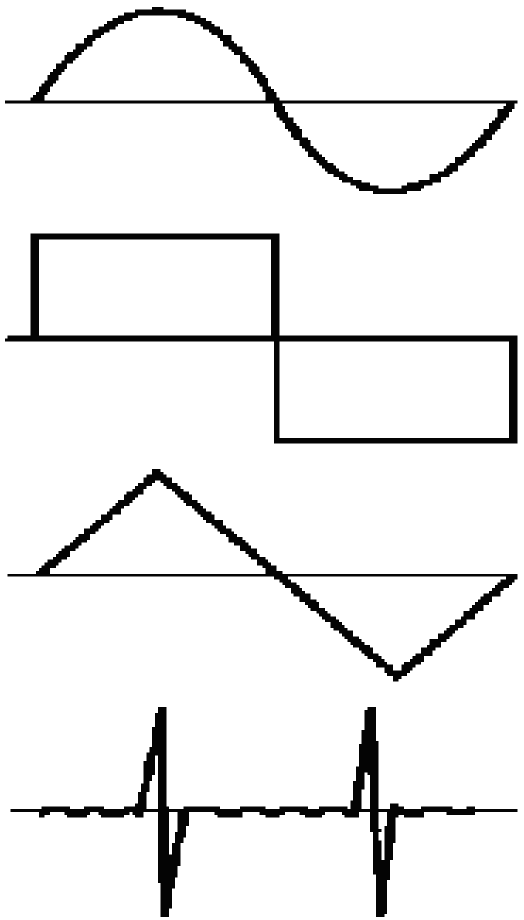
TWF Patterns

TWF Motion Direction Versus Displayed Data

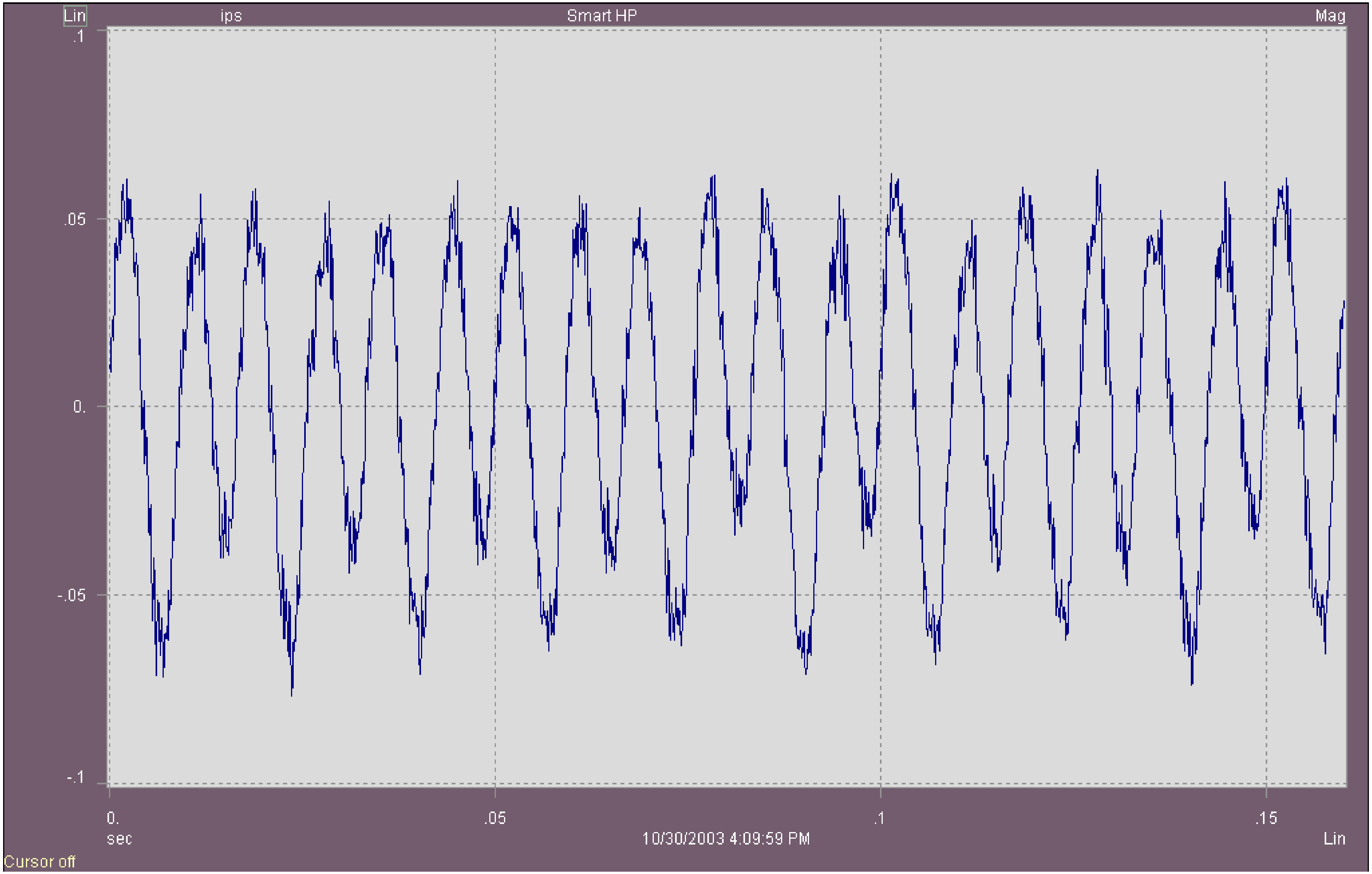
- For almost all accelerometers, the following is true:
- **Velocity or Acceleration TWF** taken with an accelerometer:
  - **Negative numbers are motion towards sensor**
  - Positive numbers are motion away from sensor
- **Displacement TWF** taken with an accelerometer:
  - Negative numbers are motion away from sensor
  - **Positive numbers are motion towards sensor**
- The motion can be thought of as starting at the left side of the TWF, progressing across and ending at the right side of the TWF

TWF Patterns

- There are four <u>main</u> TWF patterns:
  - Sinusoidal - Smooth motion
  - Square or Truncated - Flattened on one or both sides
  - Triangular - Rapid motion between two extremes
  - Spikes or Impacts - The shape of the spike or impact is vital

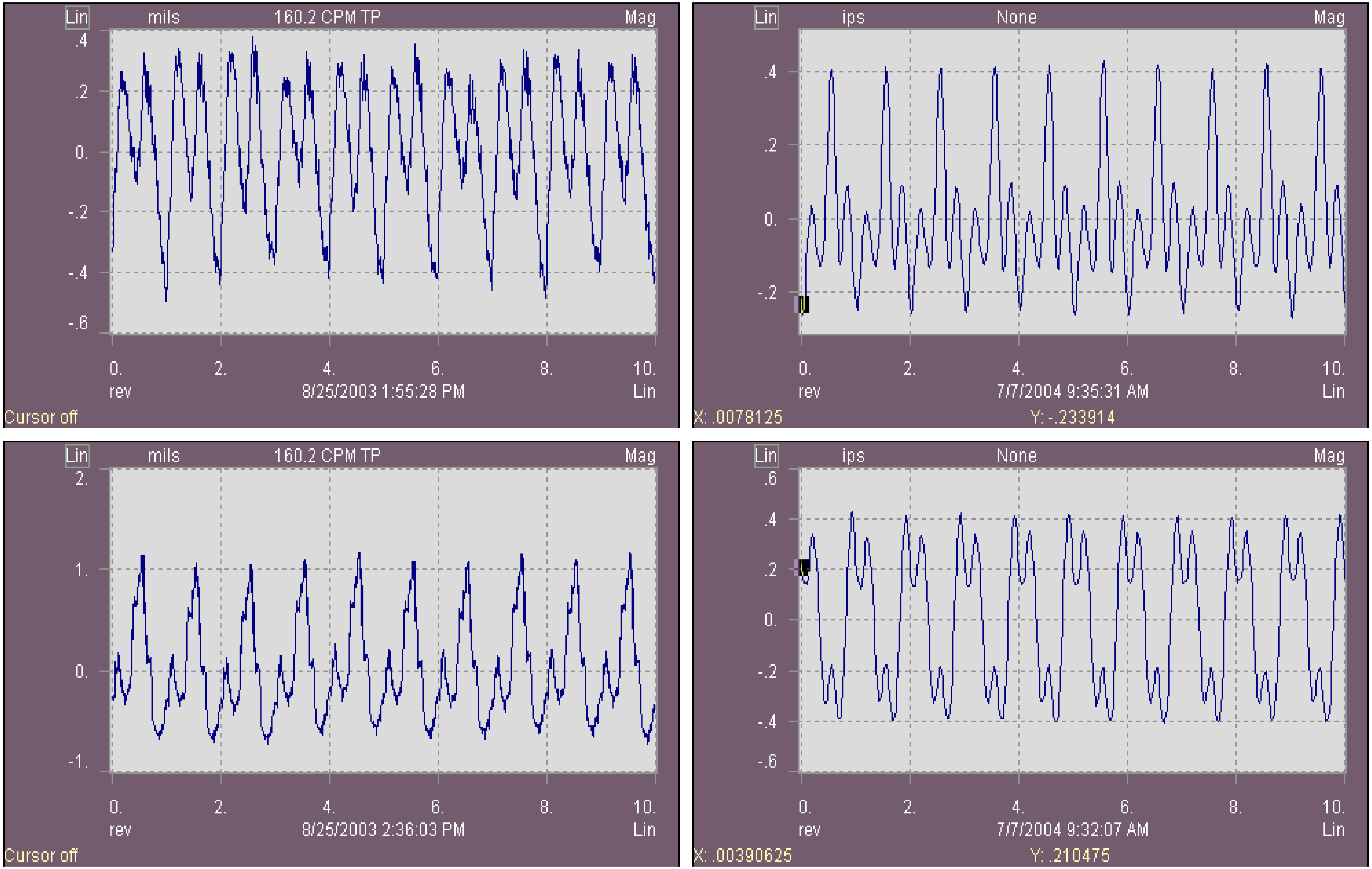


TWF Patterns - Sinusoidal



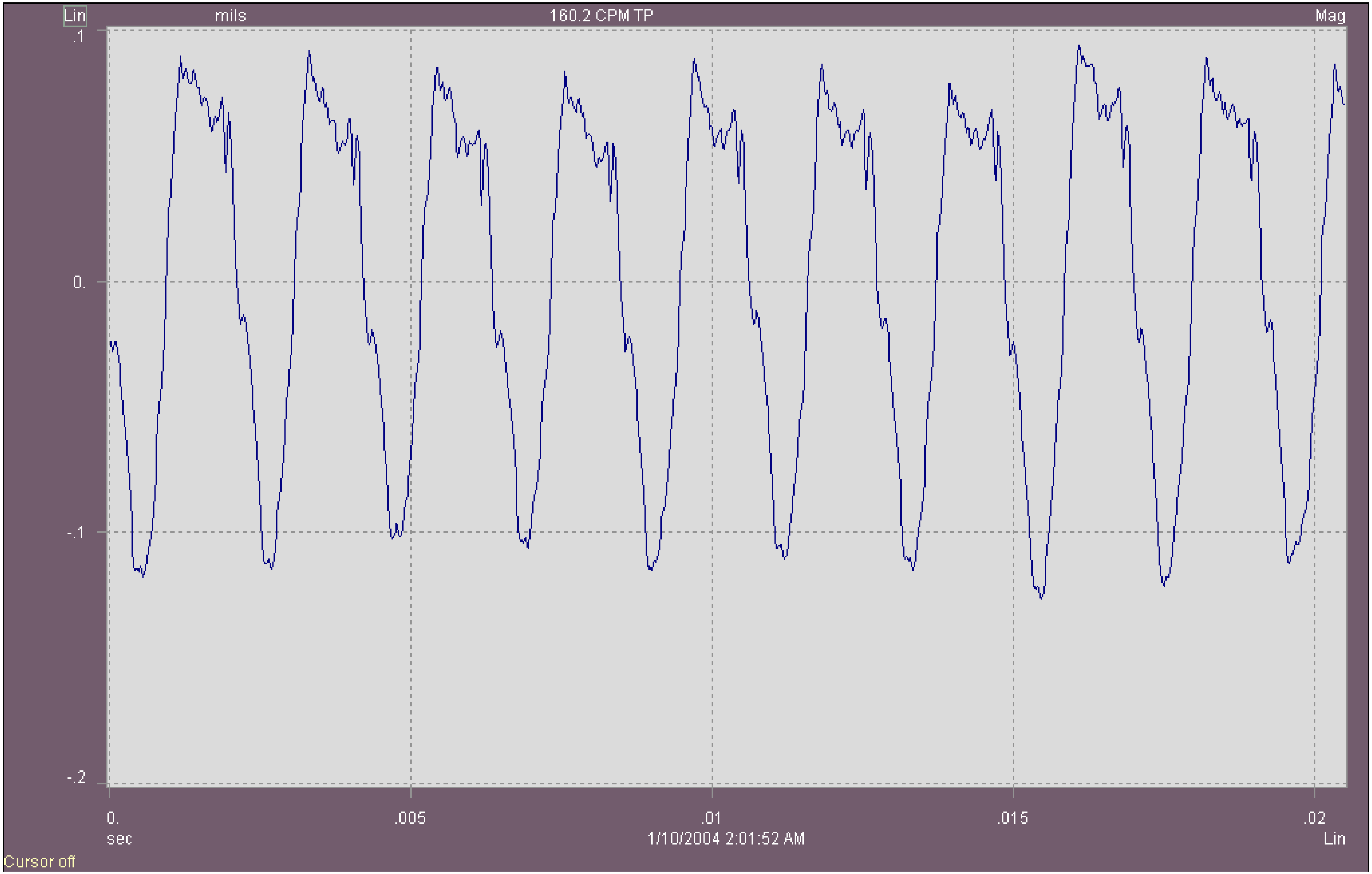
Misalignment with 1 x RPM and 2 x RPM (Classic M or W Shape)

TWF Patterns - Sinusoidal



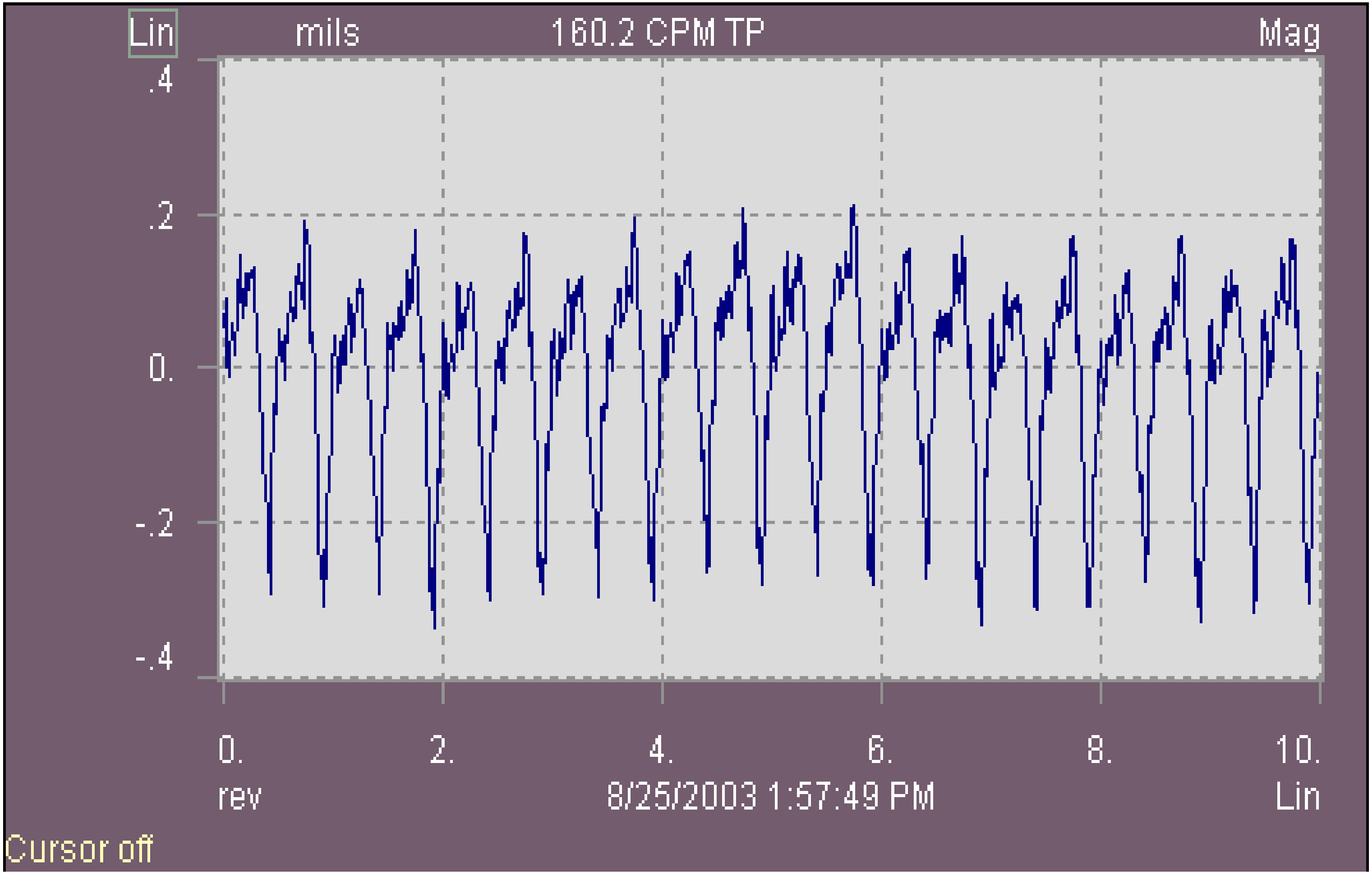
Misalignment Examples in TWF

TWF Patterns - Squared or Truncated



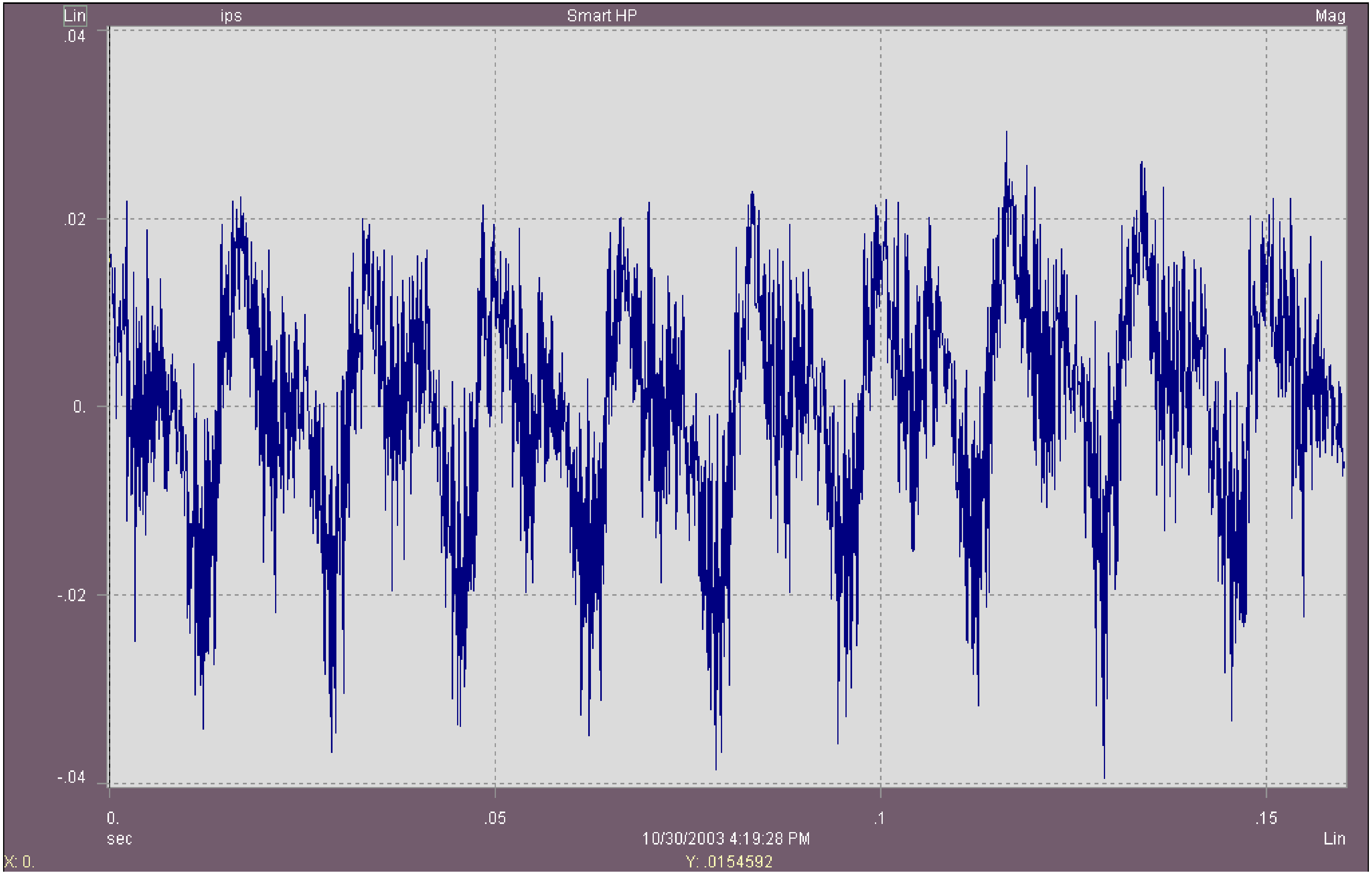
Rubbing Turbine Shaft

TWF Patterns - Squared or Truncated



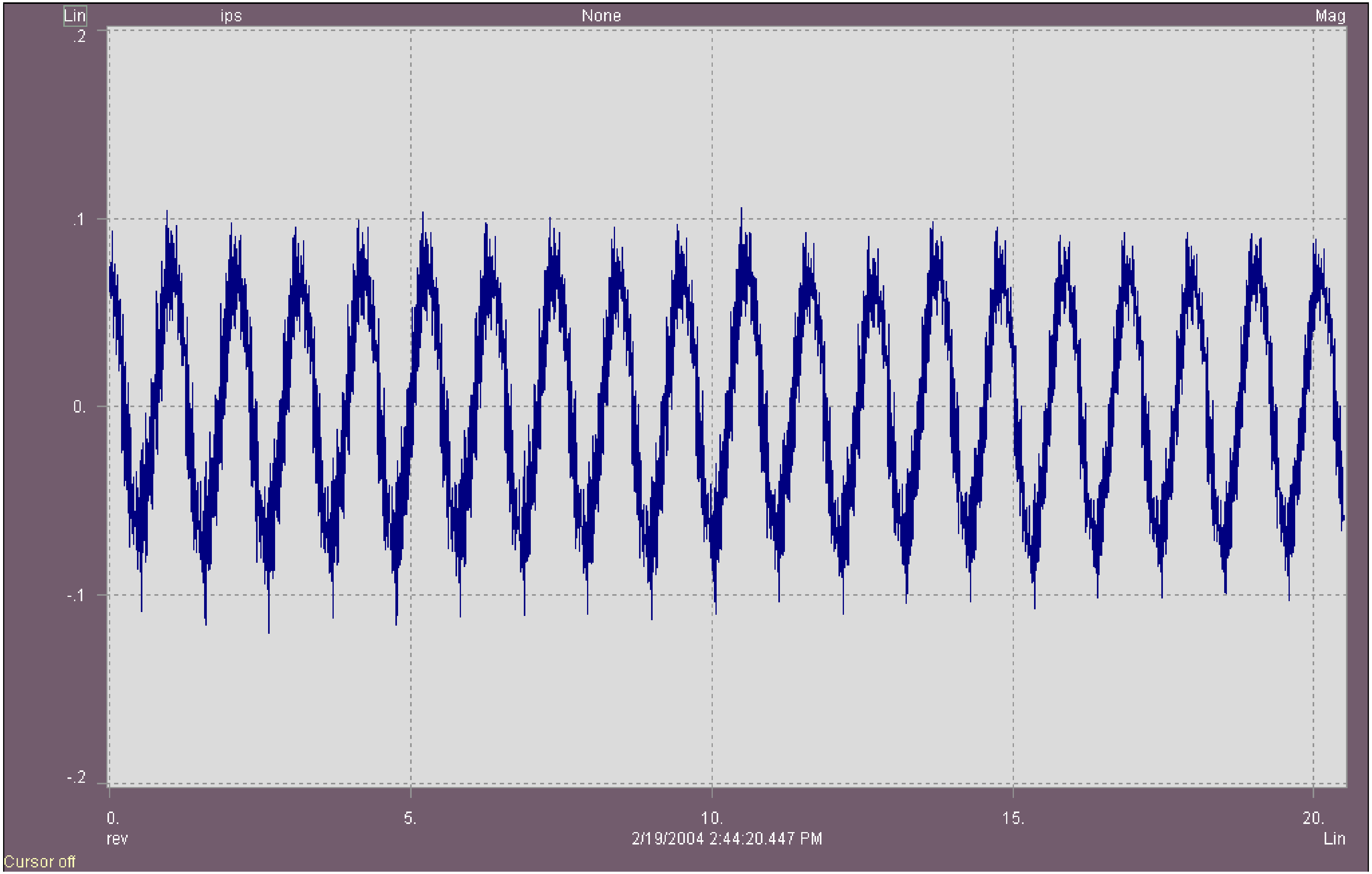
Extreme Misalignment Causing Coupling to Bind

TWF Patterns - Triangular



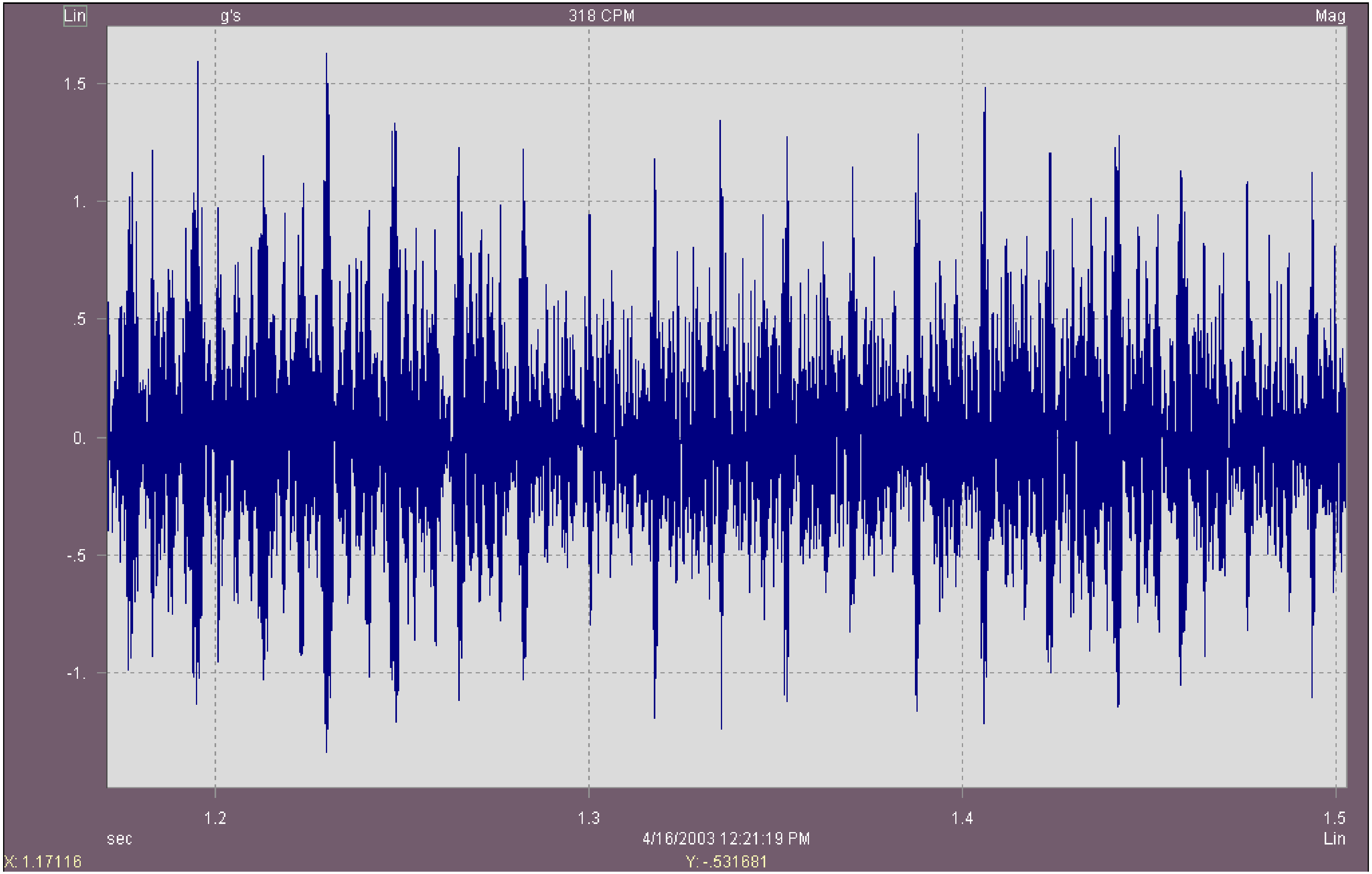
Motor Shaft Climbing and Then Falling Inside Sleeve Bearing - Kinked Shaft

TWF Patterns - Triangular



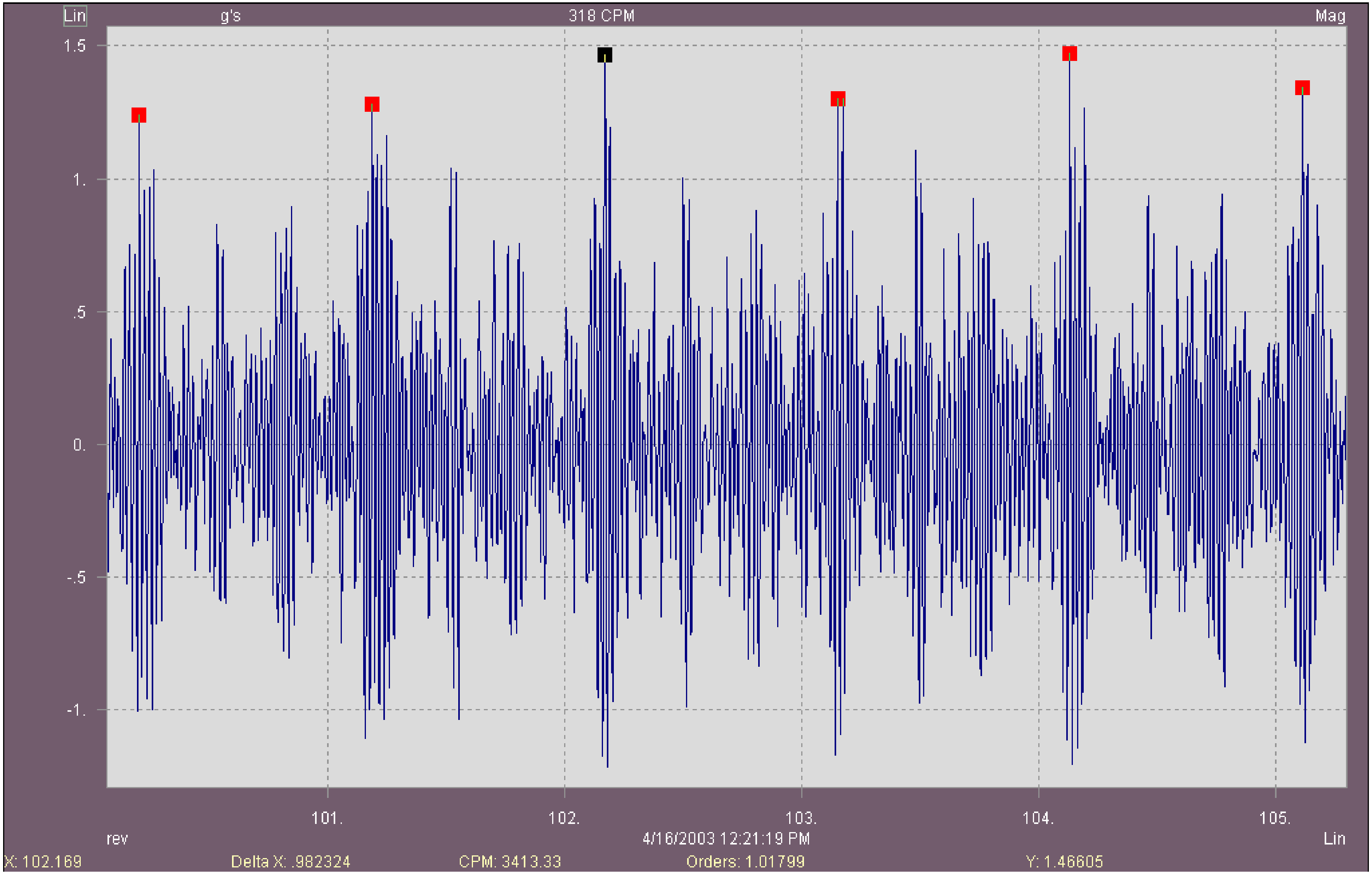
Rocking Gearbox Turning Sine Into Triangle, With Impacts at Extreme Motion

TWF Patterns - Spike or Burst Events



Improperly Machined Worm Gear - High Flute on Worm Jerking Brass Gear

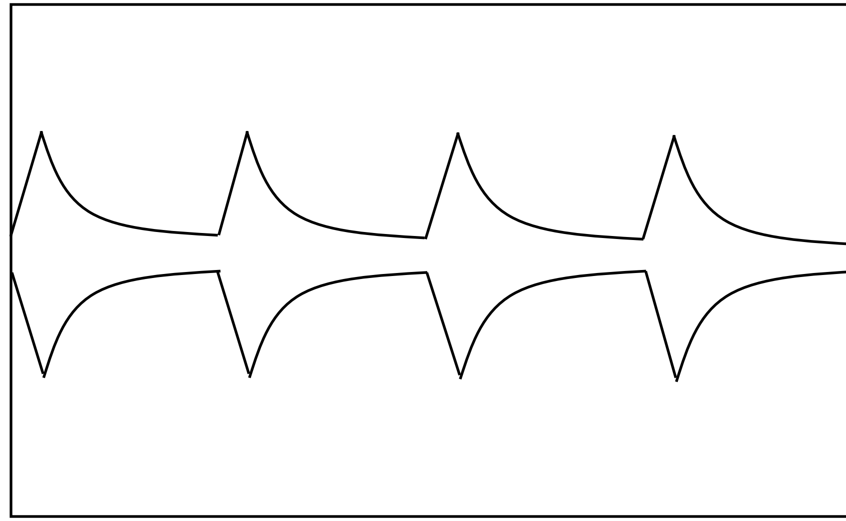
TWF Patterns - Burst Event



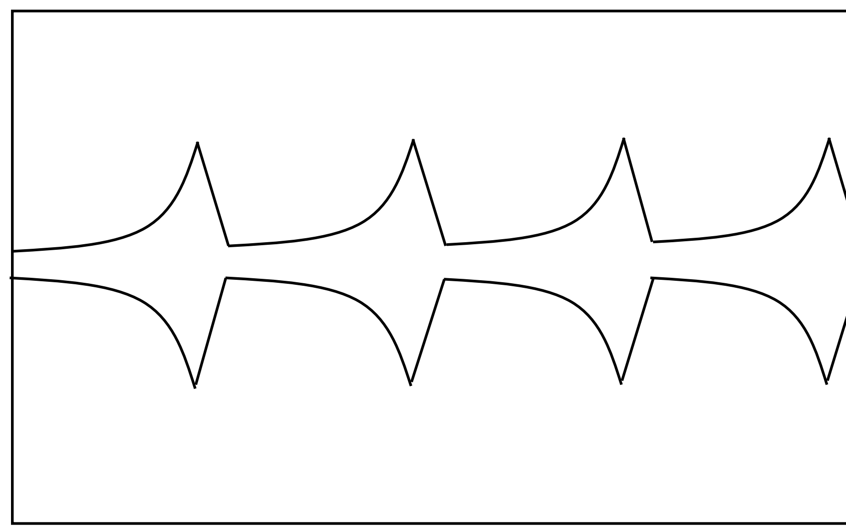
Zoom Shows Rubbing (Friction) Each Flute (3 Flutes), With One Excessively High

TWF Patterns - Spike or Binding

- An impact and ring down is sometimes referred to as an “Angel Fish” pattern, where the tall section is the head and the tapered section is the tail
- The direction these “Angel Fish” are swimming determines the type of motion event
  - Left (event, then taper off)
    - Impact and ring down
  - Right (buildup and release)
    - Binding event or relief valve

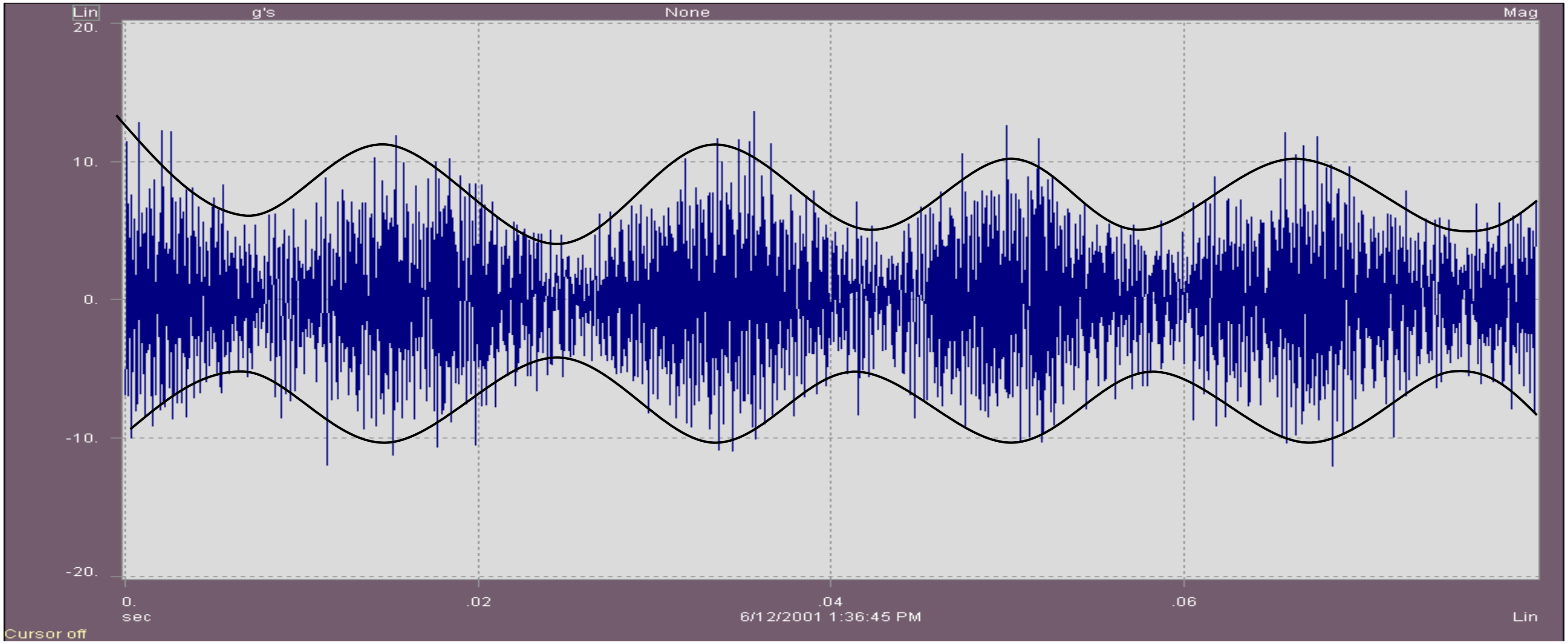


Start --> End



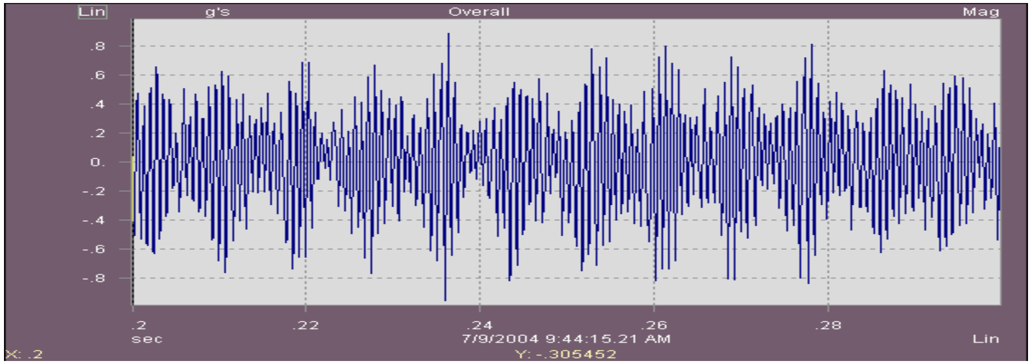
TWF Patterns - Amplitude Modulation (AM)

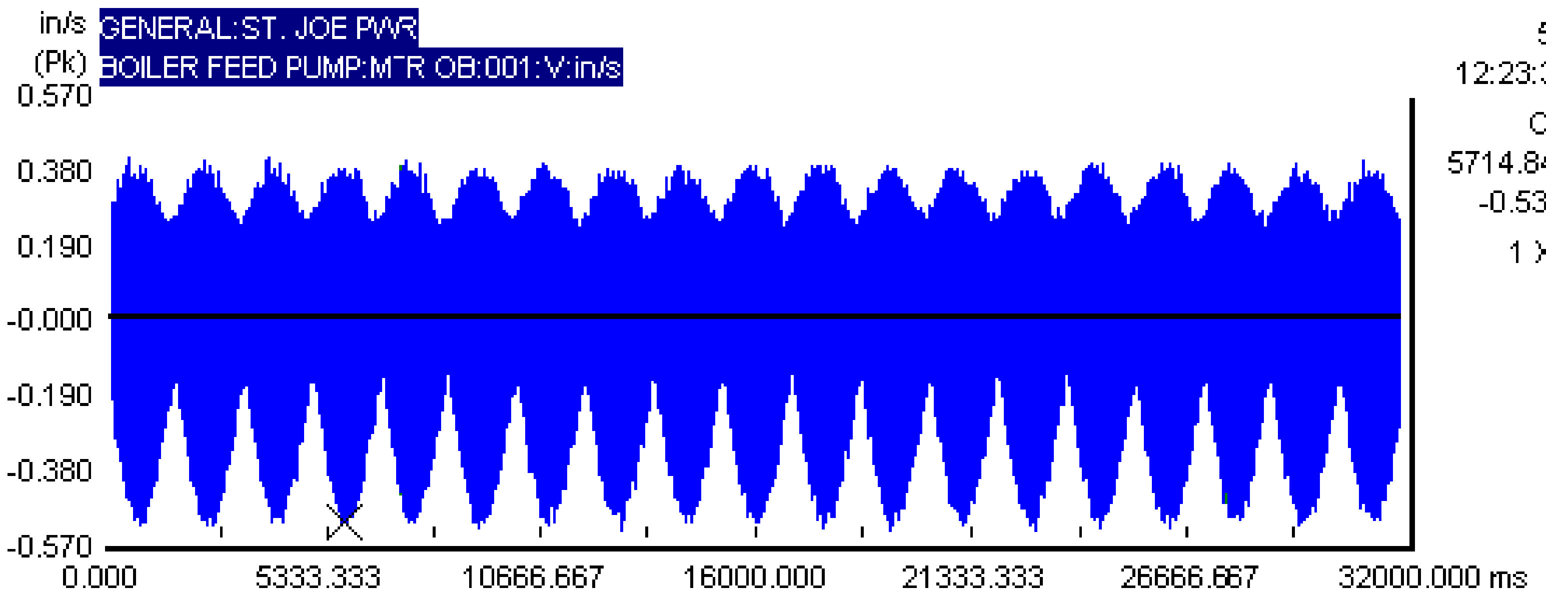
- Amplitude Modulation:
  - Louder and softer
  - Rounded high spots
  - Rounded low spots



TWF Patterns - Beat Problem

- Beats:
  - Similar to AM
  - Rounded high spot
  - <u>Pointed</u> low spot





Conclusion

- Analyzing in the same pattern (of steps) each time prevents the analyst from skipping steps that might contain vital clues
- Looking for and understanding patterns in both the Spectrum and TWF data is a vital step in the Vibration Analysis process
- Visualizing the motion of each identified pattern in the data helps identify the possible sources of the problem
- Understanding the flow of motion in the TWF display helps the analyst visualize the motion