Machinery Vibration Forcing Functions

Calculating machine moves

- some computer based alignment systems do this automatically
- plot shaft center lines from movable and fixed machine
- difference between center lines on graph paper is the distance the movable machine must be moved
- check in vertical and horizontal directions

Machinery Vibration Forcing Functions

Vibration from misalignment

- causes excessive radial loads on bearings
- premature bearing failure
- high 1X vibration with high harmonics up to 6th
- also seen as one without the other
- this could be mistaken as unbalance, looseness or excessive clearance
- high horizontal to vertical vibration amplitude ratios (greater than 3 : 1) may also indicate misalignment

Machinery Vibration Forcing Functions

Distinguishing Unbalance from Misalignment

Unbalance	Misalignment
High 1X response in frequency spectra.	High harmonics of 1X relative to 1X.
Low axial vibration levels.	High axial vibration levels.
Measurements at different locations are in phase.	Measurements at different locations are 180° out of phase.
Vibration levels are independent of temperature.	Vibration levels are dependent on temperature (change during warm-up).
Vibration level at 1X increases with rotational speed.	Vibration level does not change with rotational speed.
Centrifugal force increases as the square of the shaft rotational speed.	Forces due to misalignment remain relatively constant with changes in shaft rotational speed.

Machinery Vibration Forcing Functions

- Other operating speed related faults
  - Looseness
    - Impacts are shown at 1X and higher orders in the spectrum plus ¼X, 1/3X, 1/2X orders
  - Eccentricity
    - Results in vibration at 1X (unbalance)
  - Distortion
    - Distortion of a machine casing causes internal preload on bearings
    - Results in 1X and higher-order vibrations

Machinery Vibration Forcing Functions

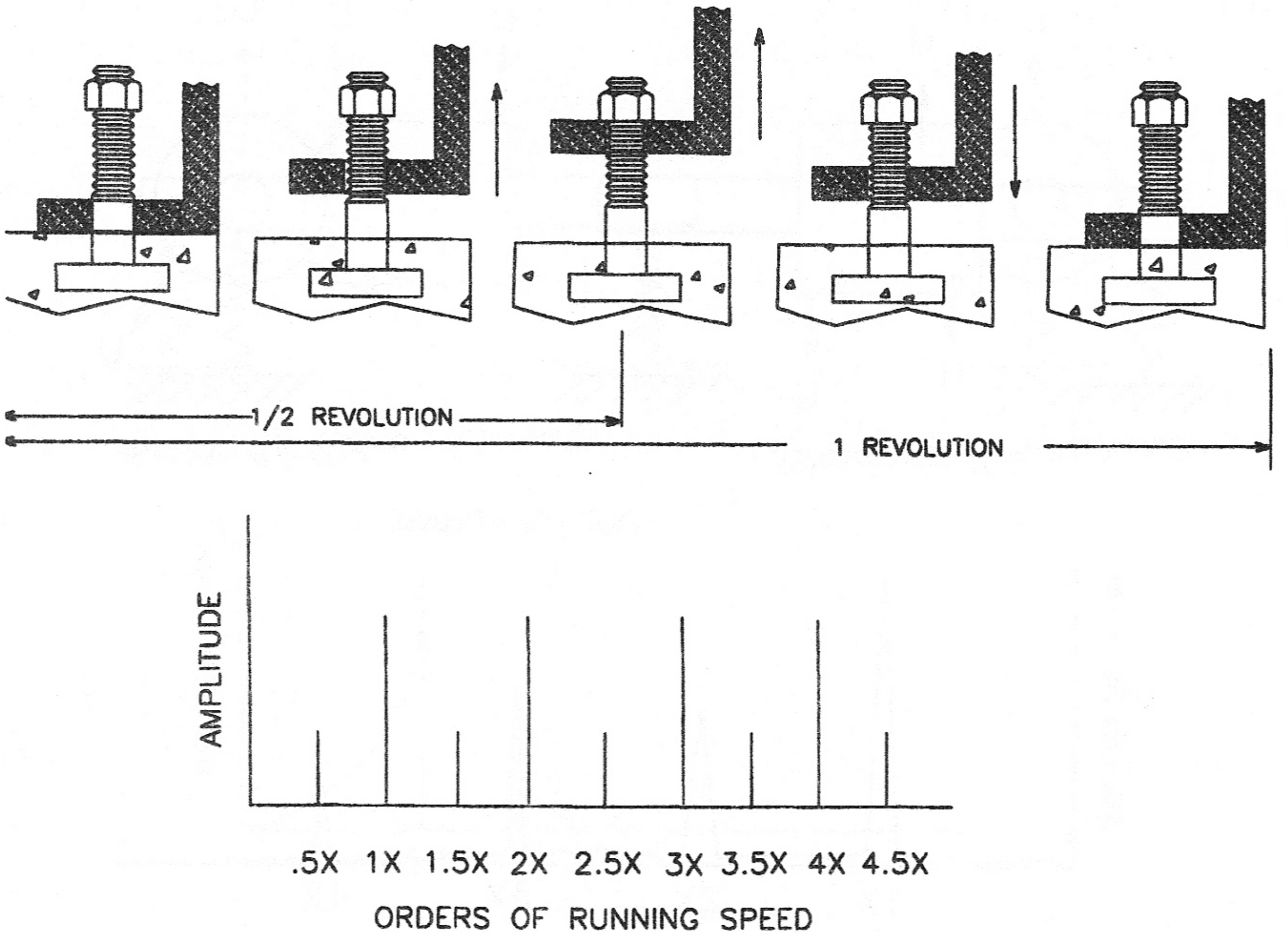
LOOSENESS

Types of Looseness

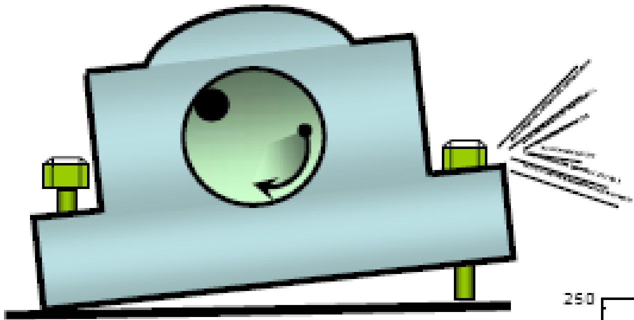
Bearing loose on shaft

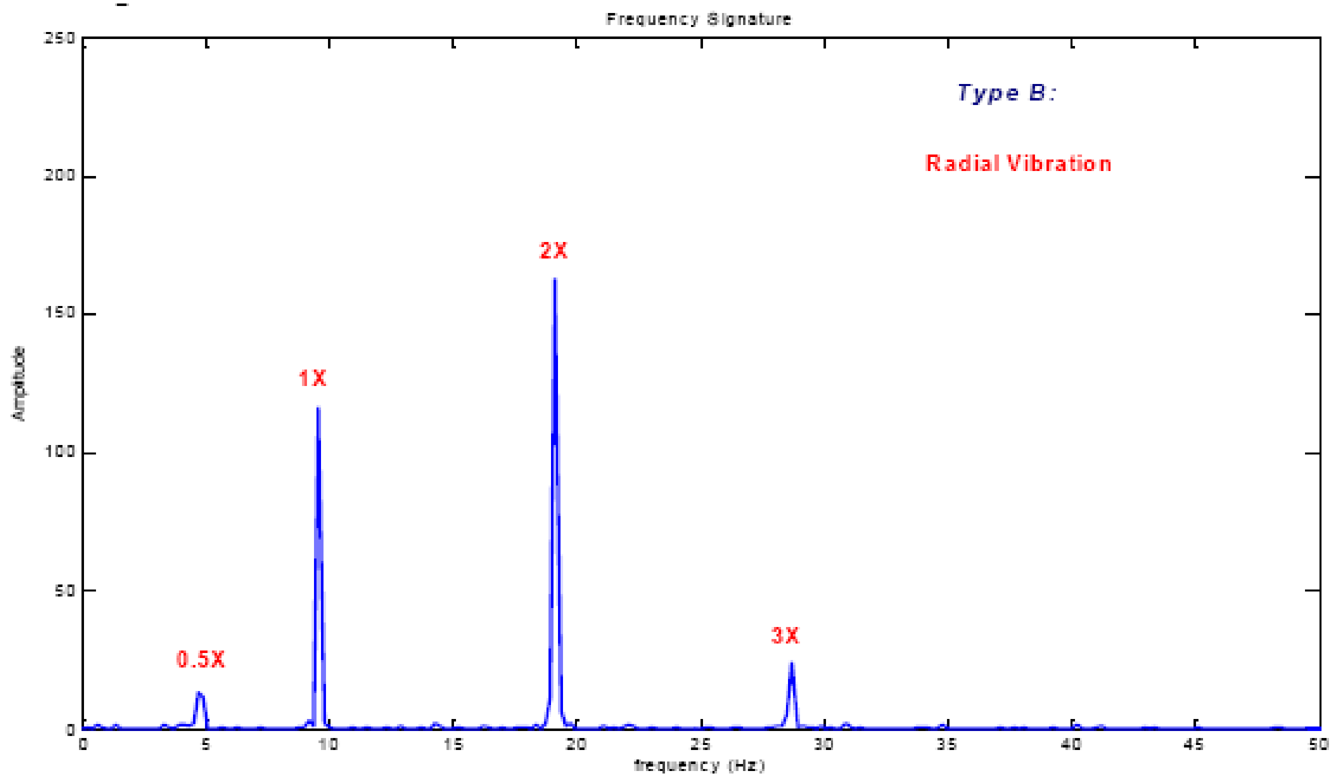
- modulated time waveform
- harmonics (many)
- varying time period of modulation
- truncated time signal (clipped)

Looseness


1/2 REVOLUTION
1 REVOLUTION
AMPLITUDE
.5X 1X 1.5X 2X 2.5X 3X 3.5X 4X 4.5X
ORDERS OF RUNNING SPEED

Machinery Vibration Forcing Functions





Machinery Vibration Forcing Functions

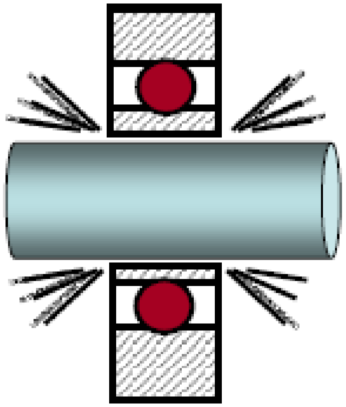
Bearing loose in housing

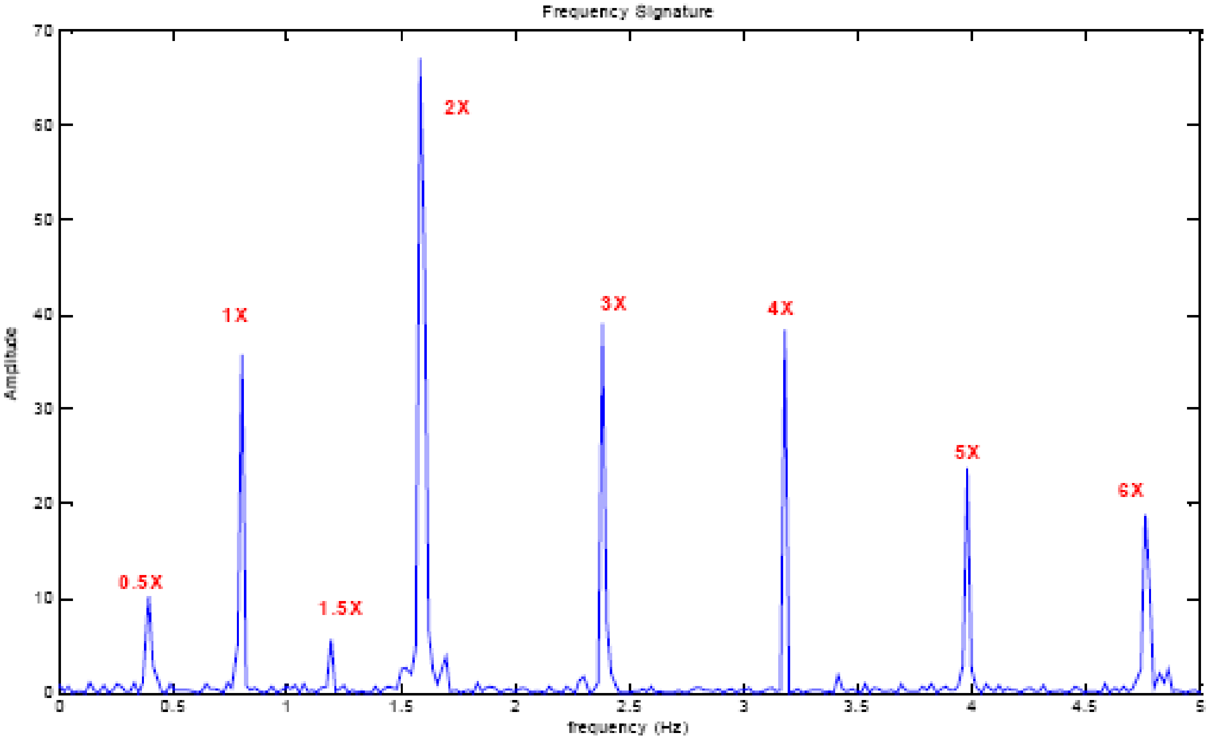
- fourth harmonic distinctive
- beware of 4 blade fans (blade pass frequency will mask looseness signal)
- may also look like rolling element bearing characteristic frequencies
- wideband noise
- further deterioration results in fractional harmonics (½, ⅓, 1½, 2½) increasing in amplitude

Machinery Vibration Forcing Functions

Bearing loose in housing

- Phase is often unstable and may vary widely from one measurement to the next particularly if the rotor shifts position on the shaft from one start-up to the next
- Will have many harmonics
- Can be caused by a loose bearing liner, excessive bearing clearance or a loose impeller on a shaft





Machinery Vibration Forcing Functions

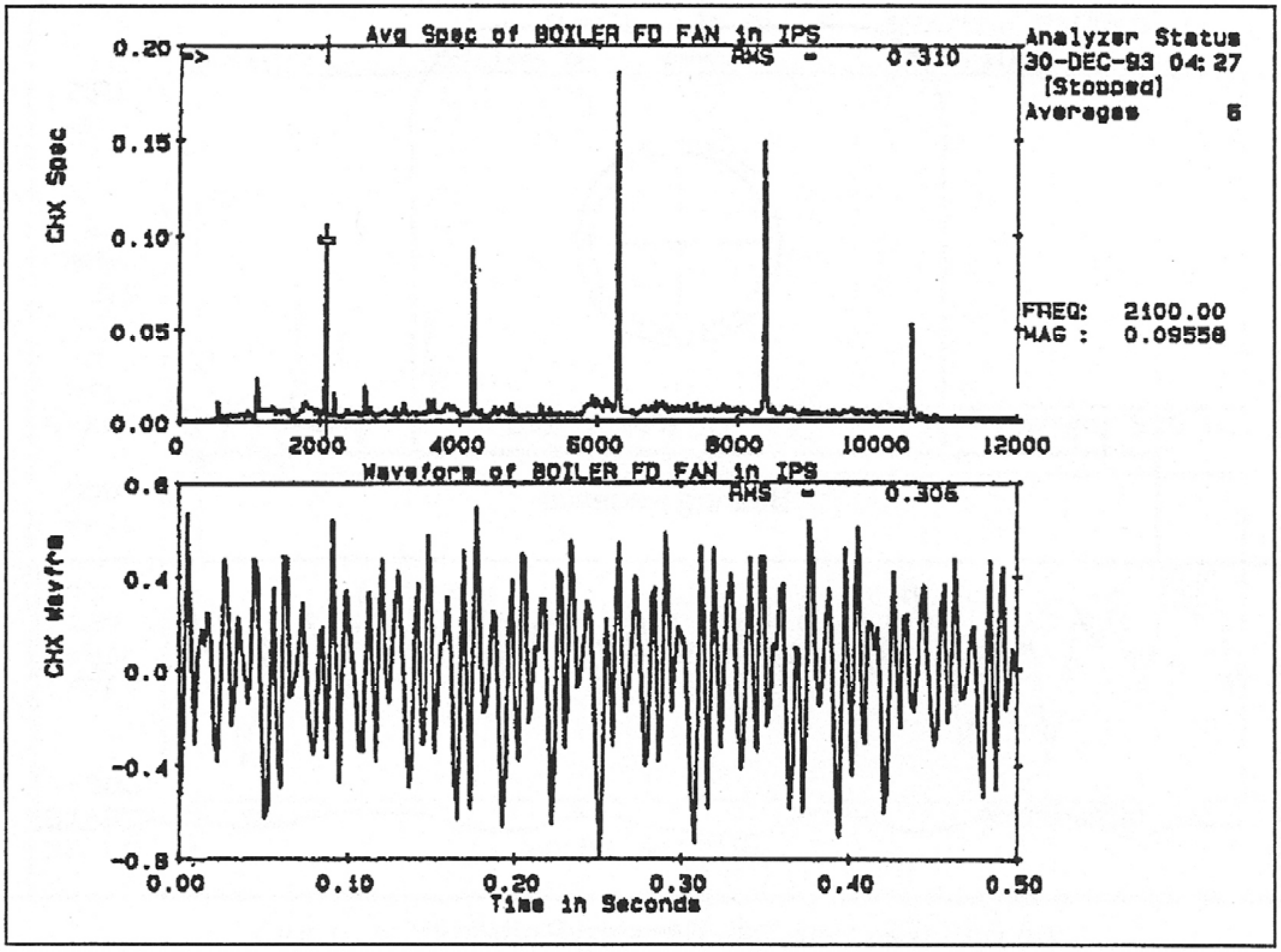


Figure 4.33. Boiler FD Fan Vibration Due to Excessive Bearing Clearance

Machinery Vibration Forcing Functions

Summary of identification and corrections

Fault	Frequency	Spectrum Time Waveform Orbit Shape	Correction
critical speed	1X, 2X, 3X, etc.	amplified vibration due to proximity of operating speed to natural frequency	tune natural frequency
mass unbalanced	1X	distinct 1X with much lower values of 2X, 3X, etc.; elliptical and circular orbits; constant phase	field or shop balancing
misalignment	1X, 2X, occasionally 3X	distinct 1X with equal or higher values of 2X, 3X; 1X axial	perform hot and/or cold alignment
shaft bow	1X	dropout of vibration around critical speed in Bodé plot	heat or peening to straighten rotor (allow rotor to float axially)
fluid film bearing wear and excessive clearance	1X, subharmonics, orders	high 1X, high 1/2X, sometimes 1-1/2 or orders; cannot be balanced	replace bearing

Machinery Vibration Forcing Functions

Summary of identification and corrections

Faults	Frequency	Spectrum Time Waveform Orbit Shape	Correction
resonance	1X, 2X, 3X, etc.	high balance sensitivity high amplitude vibration at order of operating speed	change structural natural frequency
looseness	1X plus large number of orders, 1/2X may show up	high 1X with lower-level orders, large 1/2 order, low axial vibration	shim and tighten bolts to obtain rigidity
eccentricity	1X	high 1X	machine journal for concentricity
thermal variability	1X	1X has varying phases angles and amplitude with load	compromise balance or remove problem
distortion	1X and orders	1X from preload of bearings, 2X line frequency, air gap on motor	relieve soft foot

Machinery Vibration Forcing Functions

RUBS

- caused by excessive mechanical looseness or oil whirl
- moving parts come into contact with stationary ones
- vibration signal similar to looseness
- high levels of wide-band noise (caused by impacts)
- if impacts are repetitive, there may be strong spectral responses at the striking frequency

Machinery Vibration Forcing Functions

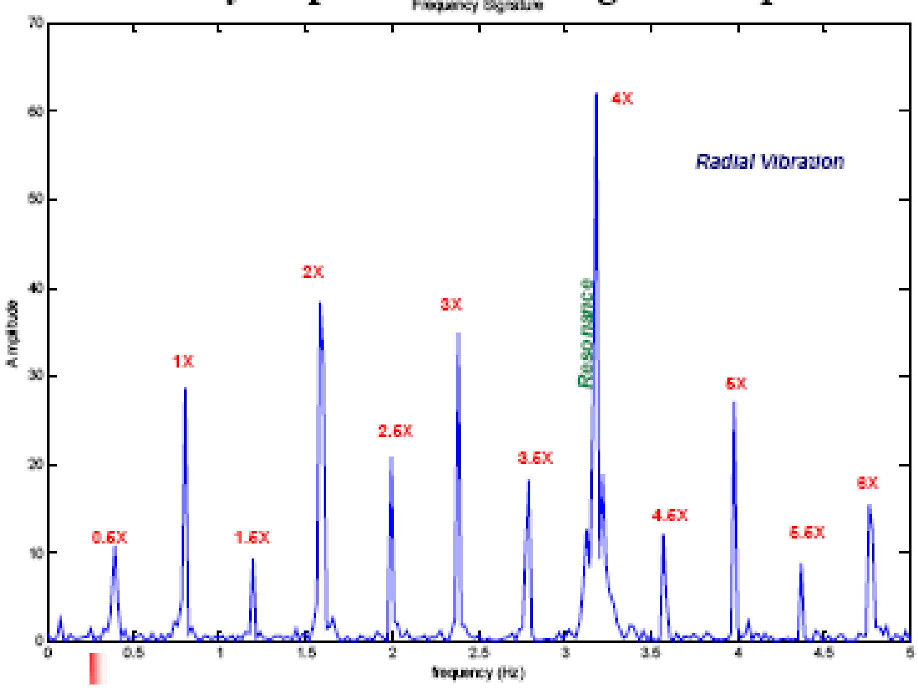
RUBS

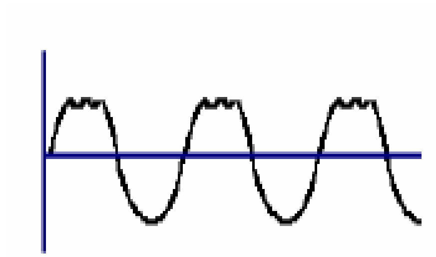
- if rotor presses too hard against a seal - the rotor will heat up unsymmetrically and develop a bowed shape
- vibration signal shows unbalance
- to diagnose - note that the unbalance is absent until the machine comes up to normal operating temperature

Machinery Vibration Forcing Functions

RUBS

- Similar spectrum to mechanical looseness
- Usually generates a series of frequencies which may excite natural frequencies
- Subharmonic frequencies may be present depending on location of rotor natural frequencies
- Rub may be partial or through a complete revolution.





Truncated Flattened Waveform

Machinery Vibration Forcing Functions

OIL WHIP & OIL WHIRL

Oil Whirl

- bearing can not exert sufficient force on shaft to maintain a stable operating position
- corrected by using pressure dams or tilt pad designs
- shaft rides on an oil pressure gradient
- rotates within bearing clearance at just less than one half shaft rotational speed (~0.42X)

Machinery Vibration Forcing Functions

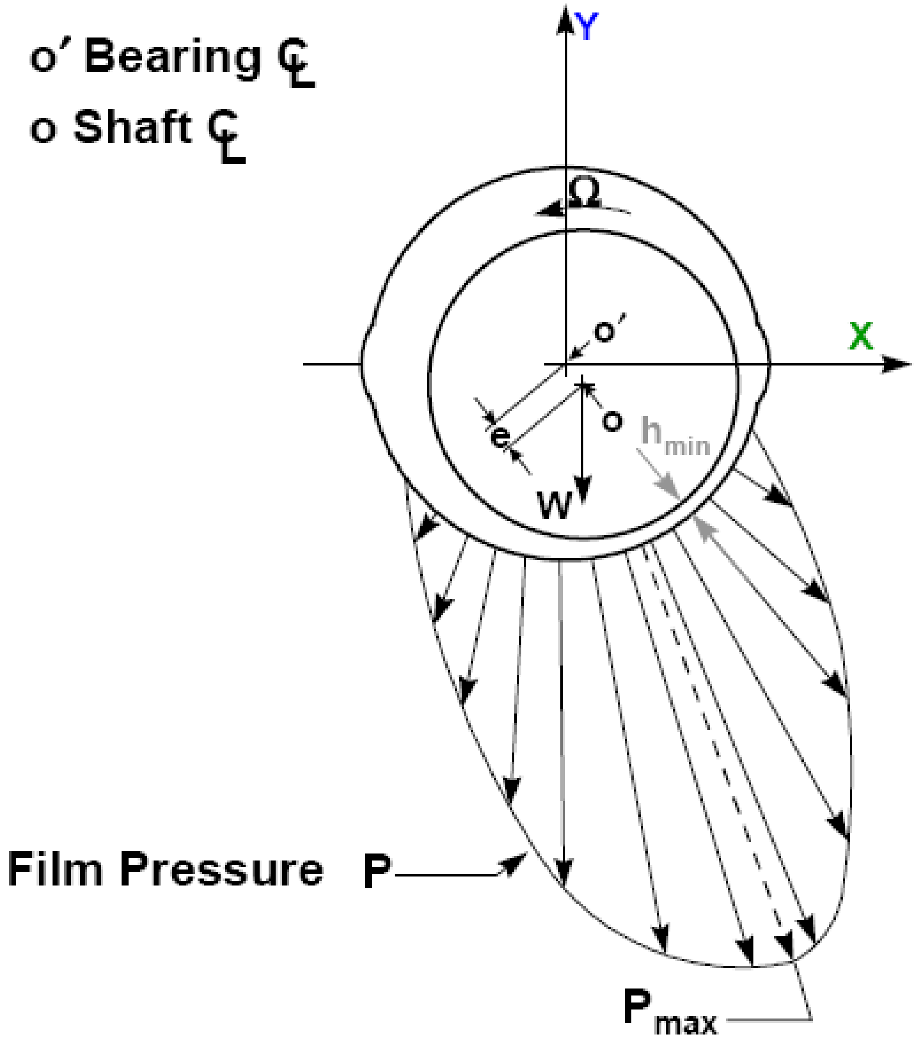
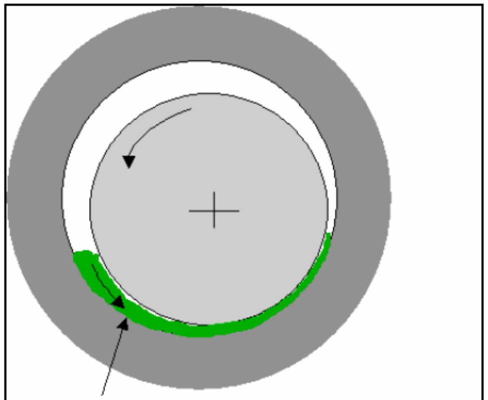
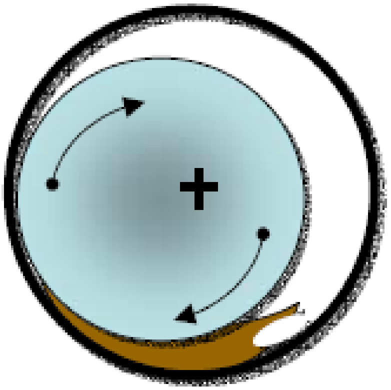


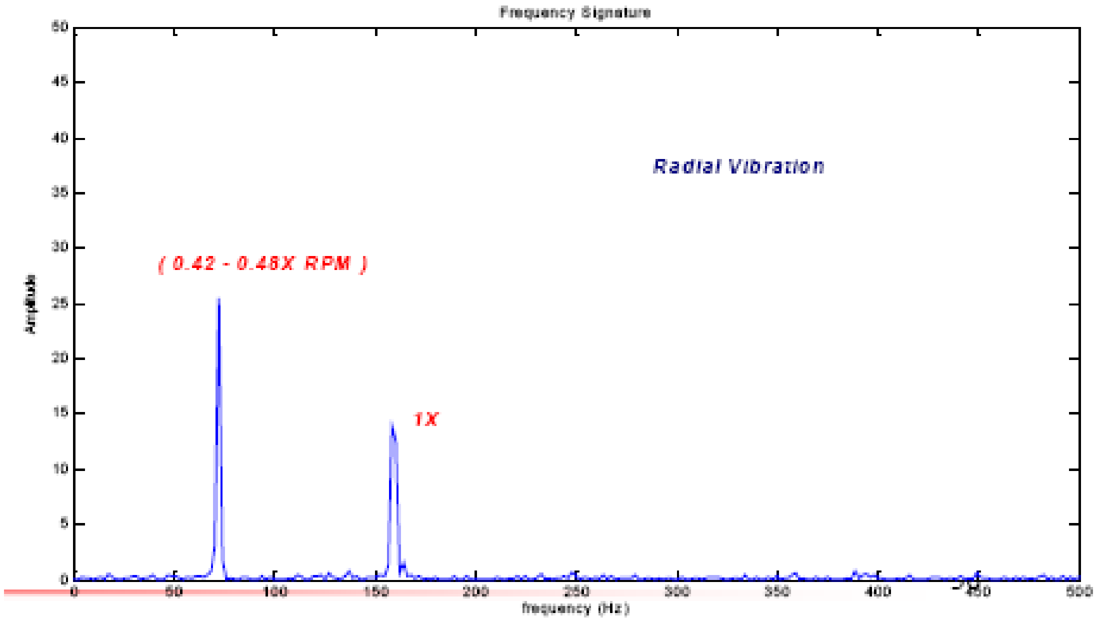
Figure 19. Hydrodynamic Bearing Pressure Profile

Machinery Vibration Forcing Functions



Oil Wedge
Rotational speed of Oil Wedge
= slightly less than ½ RPM





Machinery Vibration Forcing Functions

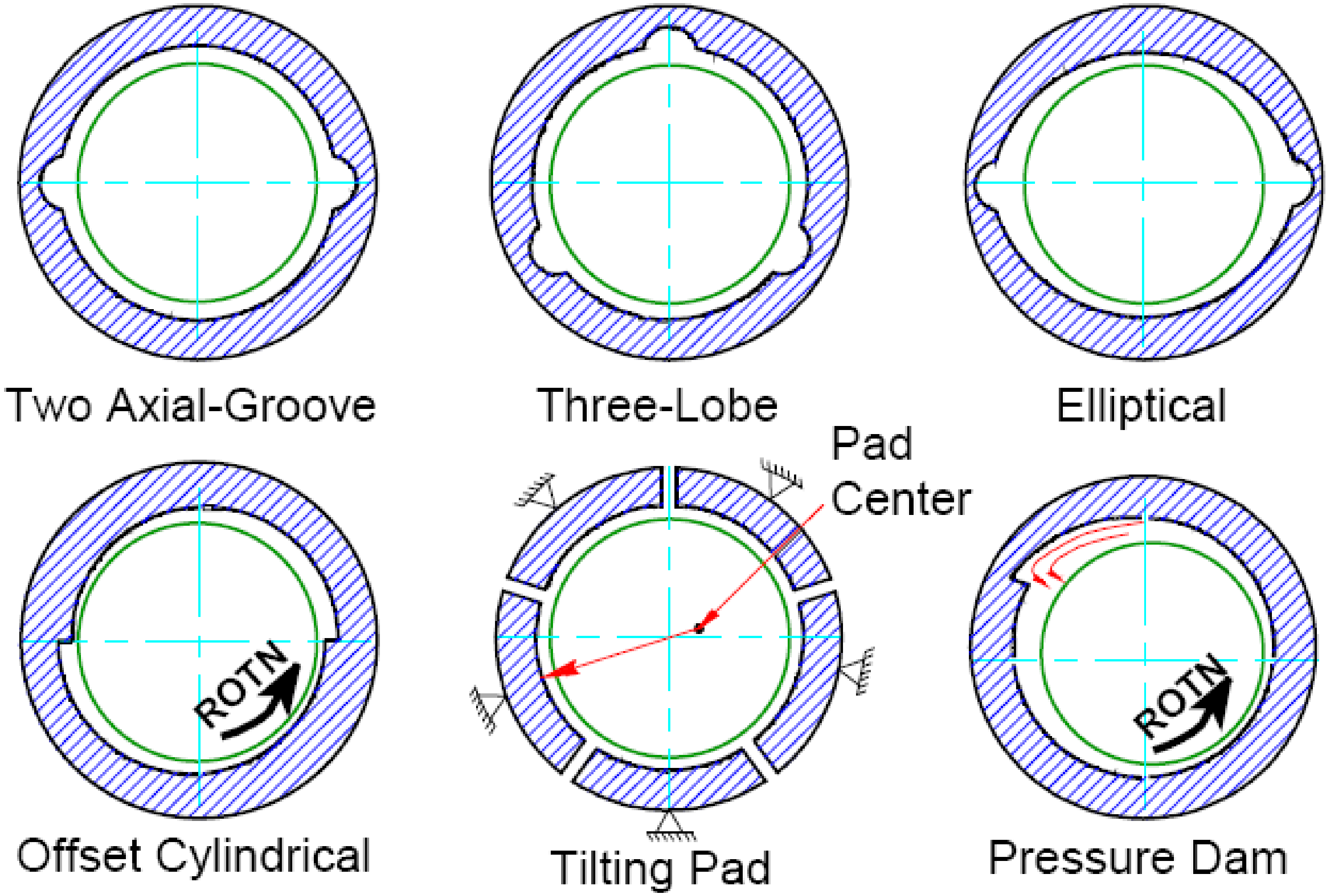


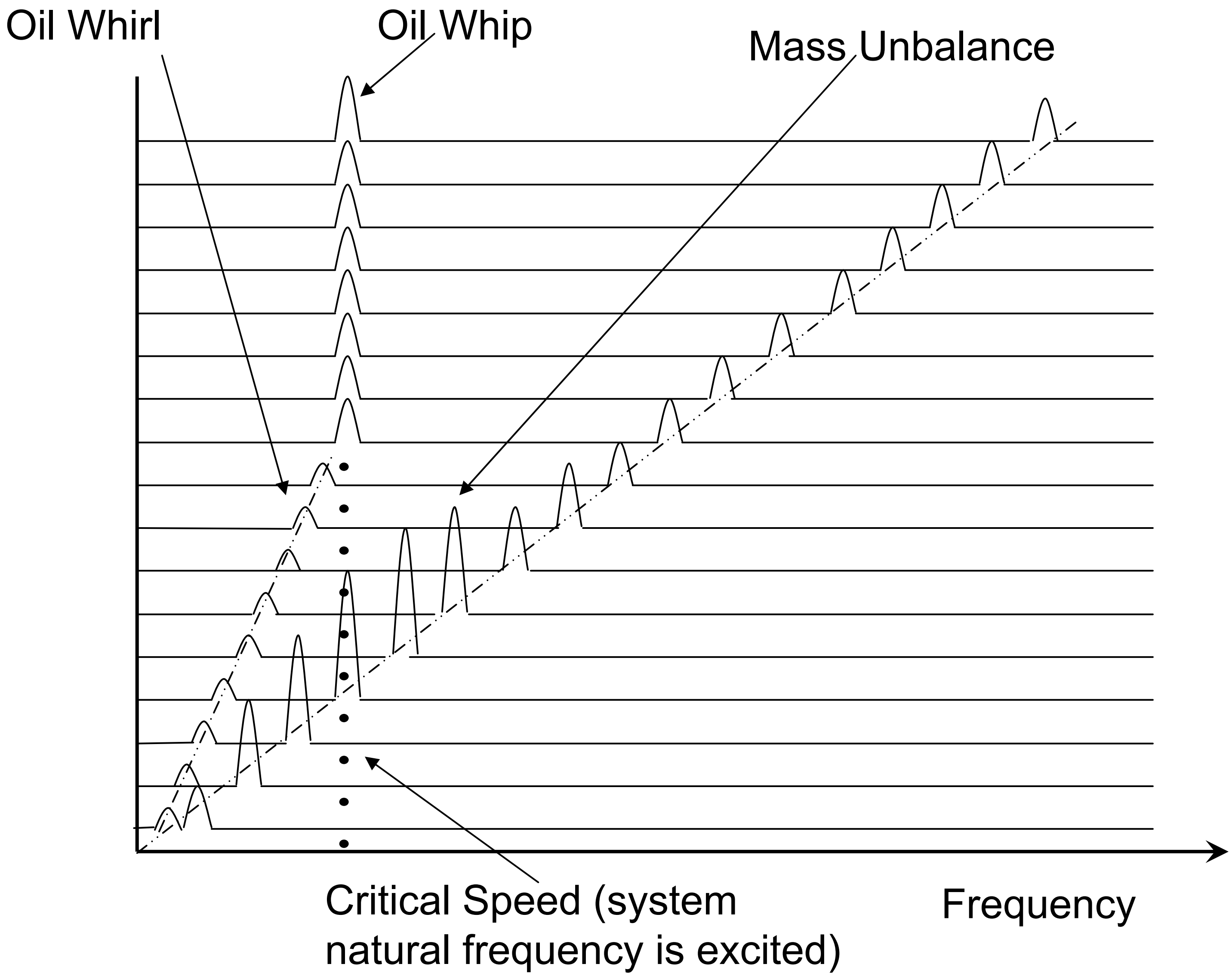
Figure 20. Bearing Designs

Machinery Vibration Forcing Functions

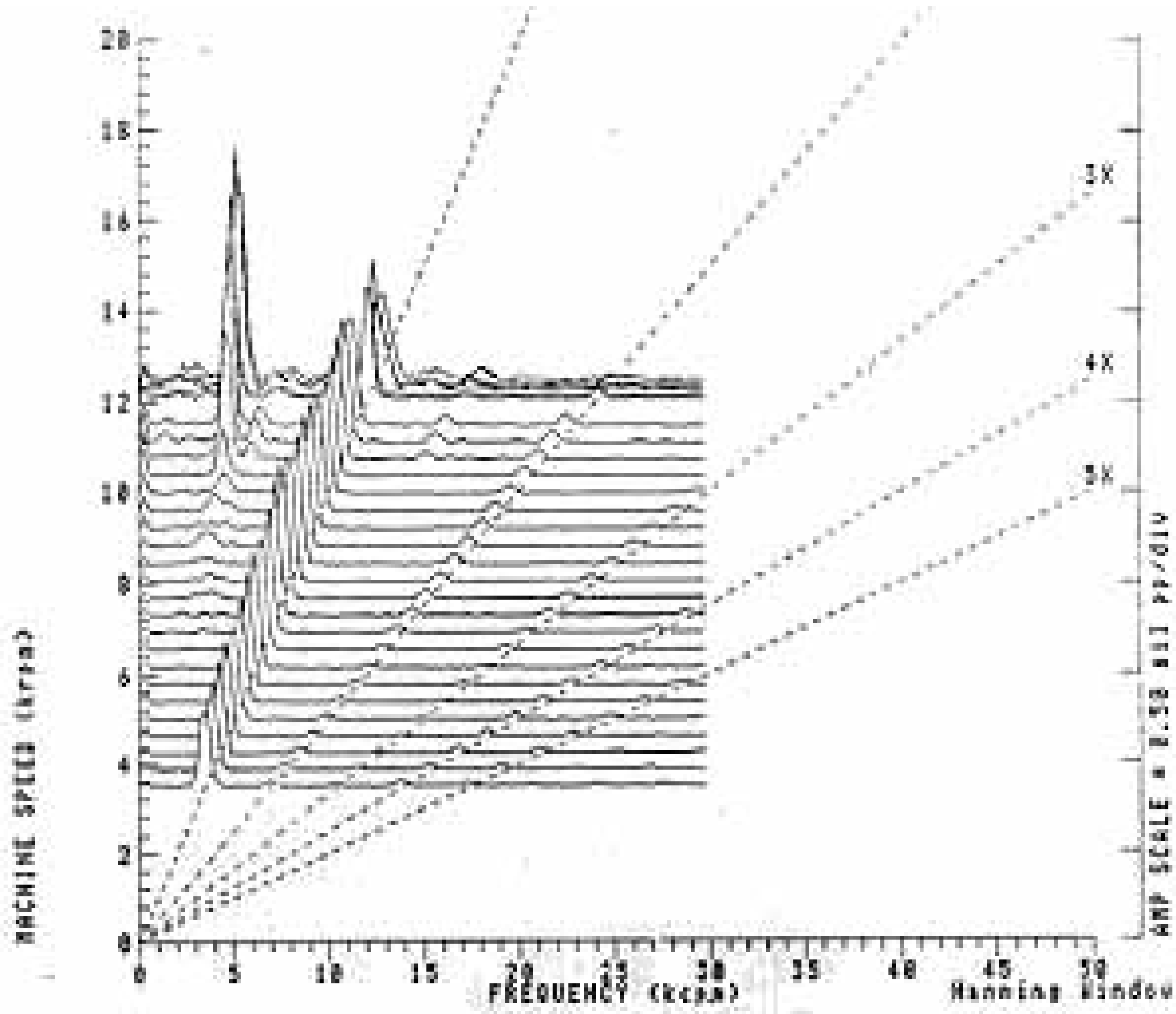
Oil Whip

- occurs when sub synchronous instability (oil whirl) excites a critical speed (resonance)
- excitation remains at a constant frequency regardless of speed changes

Machinery Vibration Forcing Functions



Machinery Vibration Forcing Functions



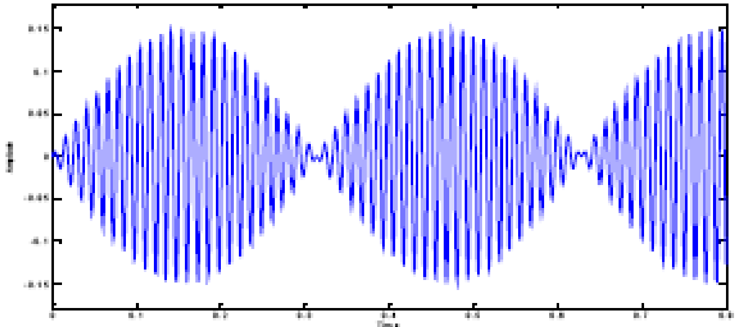
Machinery Vibration Forcing Functions

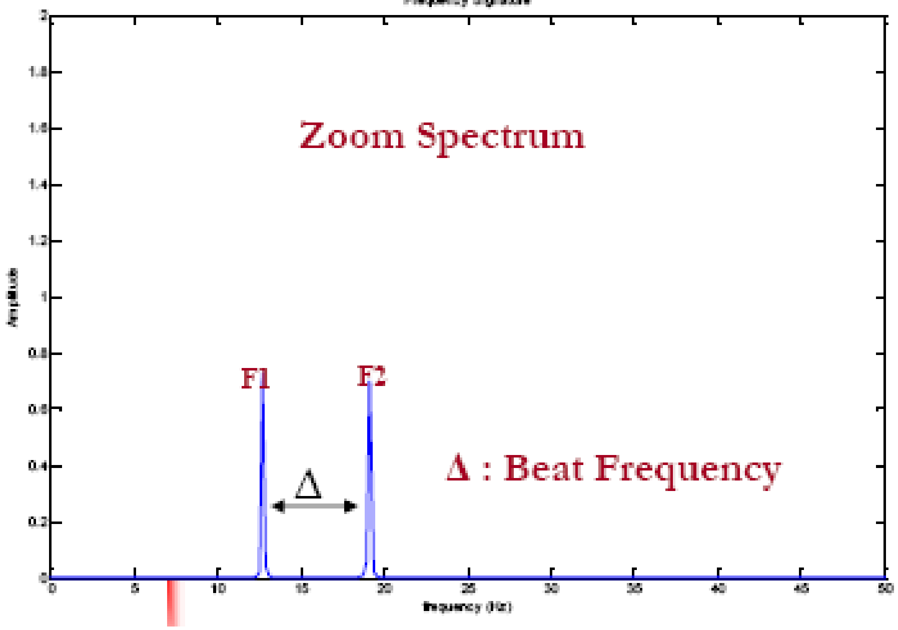
Beating and Amplitude Modulation

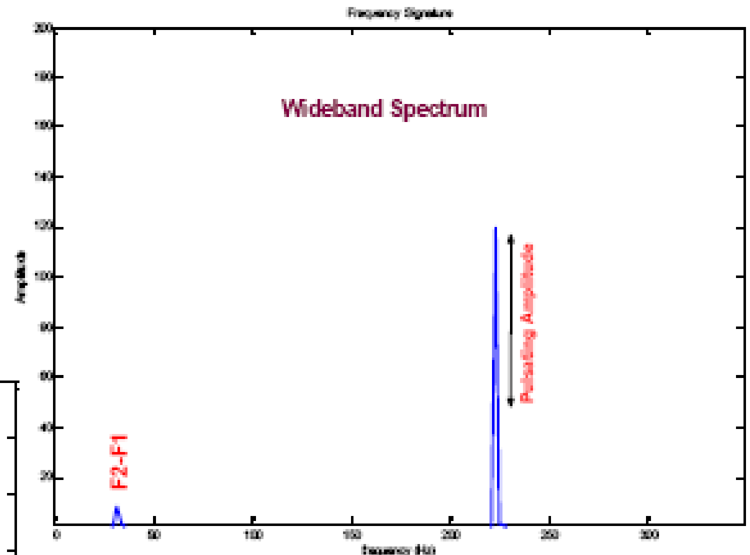
- A beat frequency (or beating) is the result of two closely spaced frequencies going into and out of phase as a function of time
- The wideband spectrum will show one peak pulsating up and down as a function of time
- Zooming in to this peak will show that there are actually two closely spaced individual peaks
- The difference between the peaks is the beat frequency

Machinery Vibration Forcing Functions

Beating







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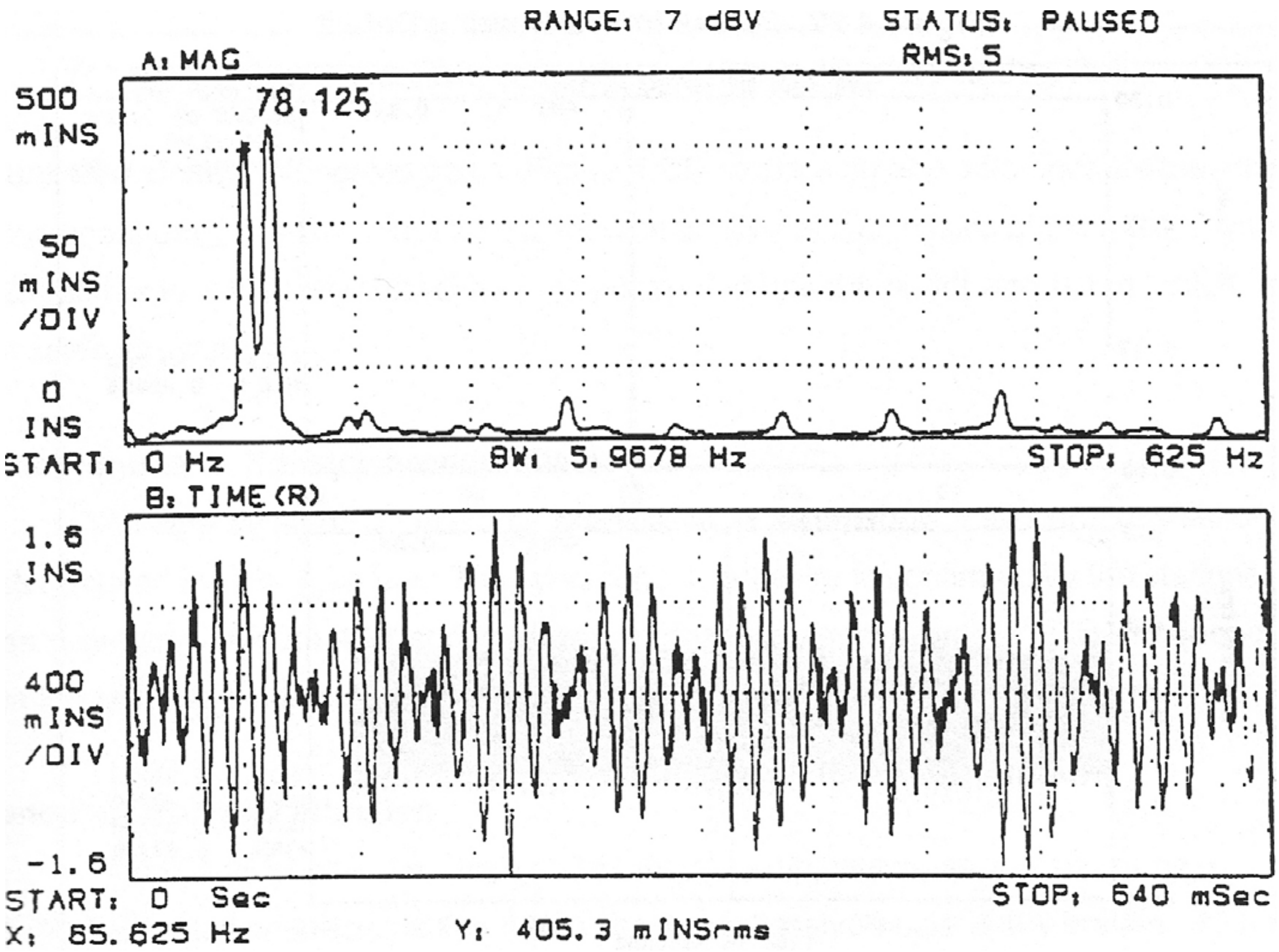
Machinery Vibration Forcing Functions

Beating from two adjacent pumps operating at different speeds



Amplitude Modulation

The frequency of the waveform seems to be constant, but the amplitude is fluctuating up and down at a constant rate.

This type of signal is often produced by defective bearings and gears, and can be easily identified by the sidebands in the spectrum.

The spectrum has a peak at the frequency of the carrier, and two more components on each side. These extra components are the sidebands. Note that there are only two sidebands. The sidebands are spaced away from the carrier at the frequency of the modulating signal.

Machinery Vibration Forcing Functions

Amplitude Modulation

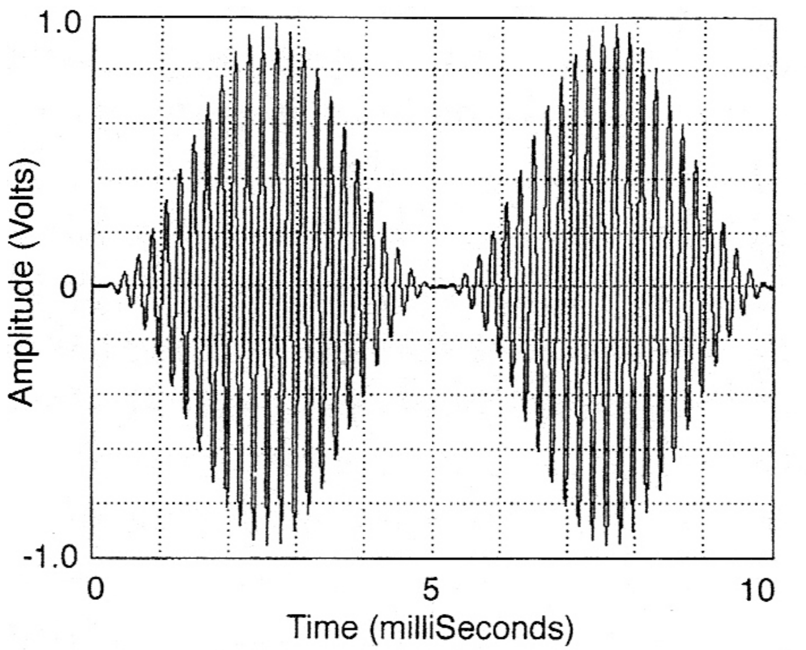


Fig. 7–51 Measured AM Signal With 5,000 Hz Carrier And 200 Hz Modulator

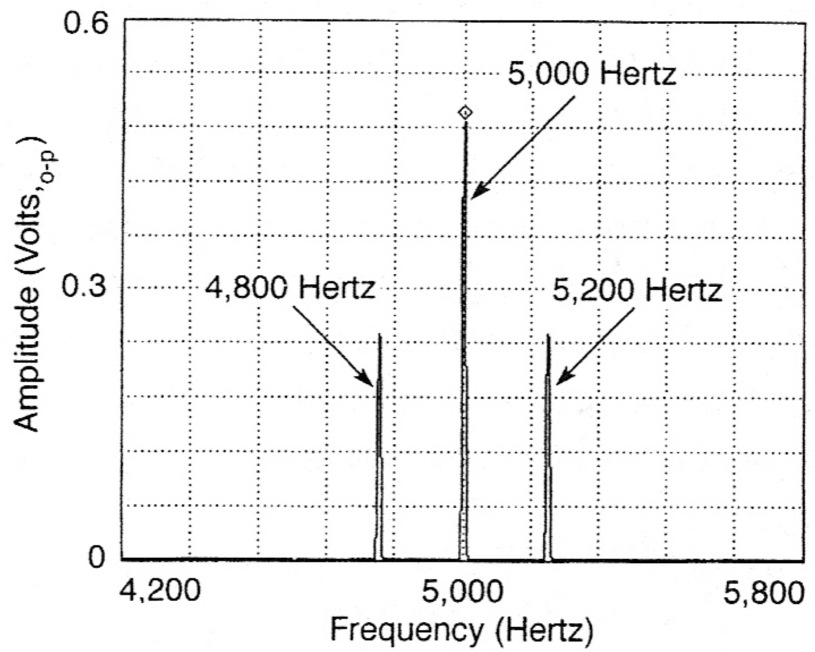


Fig. 7–52 Measured FFT of AM Signal With 5,000 Hz Carrier & 200 Hz Modulator

Amplitude Modulation

In the previous example, the modulating frequency is much lower than the modulated or carrier frequency, but the two frequencies are often close together in practical situations (see next example).

Also these frequencies are sine waves, but in practice, both the modulated and modulating signals are often complex.

A vibration and acoustic signature similar to this is frequently produced by electric motors with rotor bar problems.

Machinery Vibration Forcing Functions

Amplitude Modulation

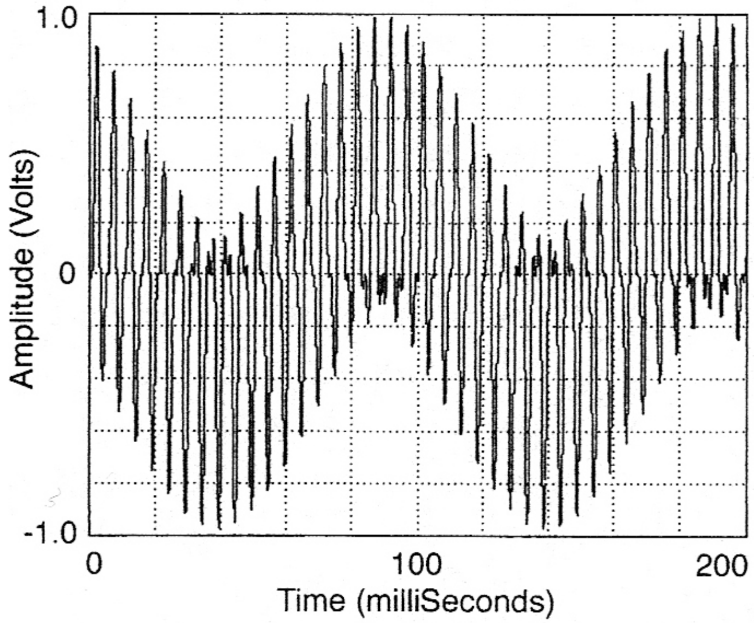


Fig. 7–53 Measured AM Signal With 200 Hz Carrier And 190 Hz Modulator

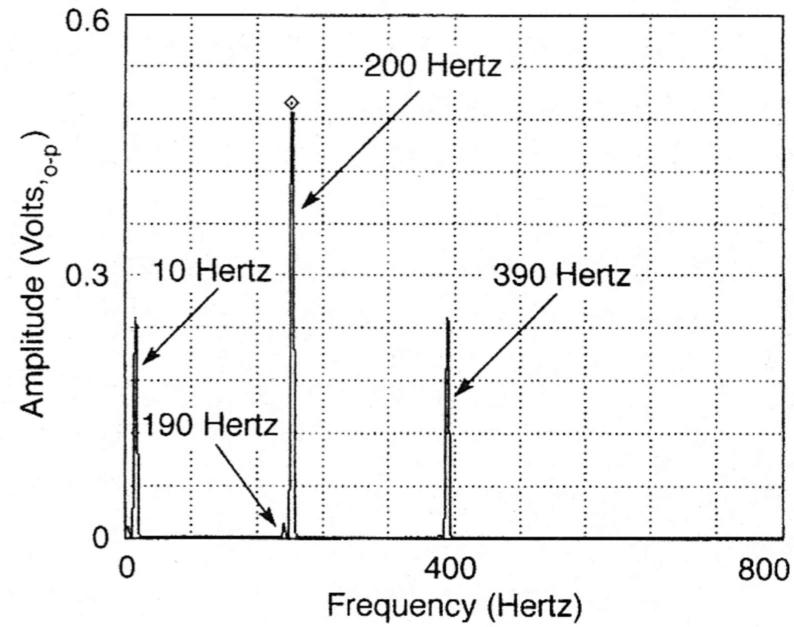
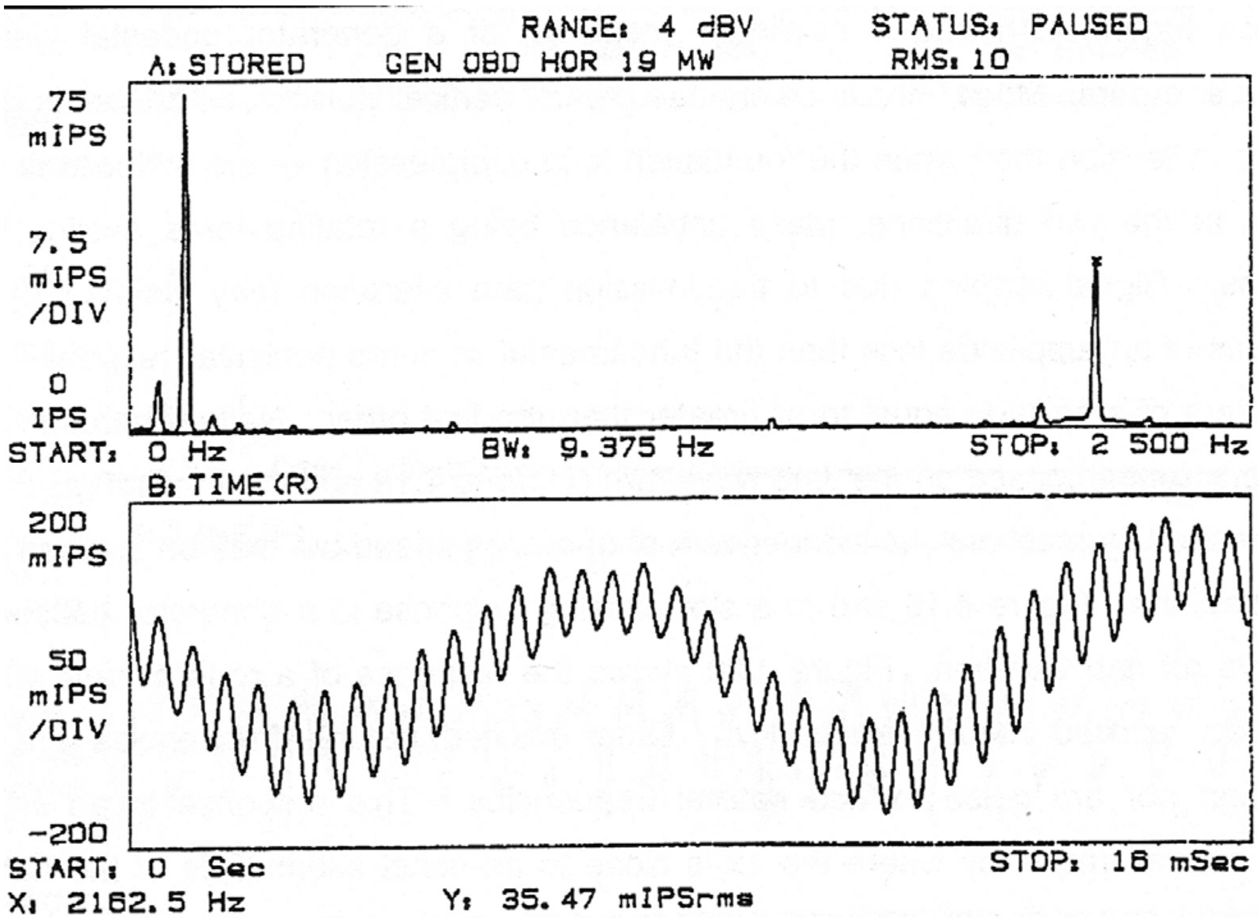


Fig. 7–54 Measured FFT of AM Signal With 200 Hz Carrier And 190 Hz Modulator

Machinery Vibration Forcing Functions

Amplitude Modulation



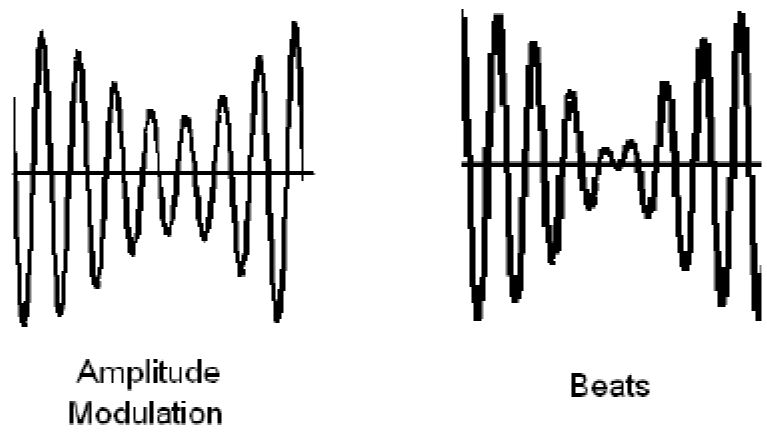
Beating and Amplitude Modulation

It is almost impossible to tell beating from amplitude modulation by looking at the waveform, but they are fundamentally different processes, caused by different phenomena in machines. The spectrum tells the story.

This waveform looks like amplitude modulation, but is actually just two sine wave signals added together to form beats. Because the signals are slightly different in frequency, their relative phase varies from zero to 360 degrees, and this means the combined amplitude varies due to reinforcement and partial cancellation. The spectrum shows the frequency and amplitude of each component, and there are no sidebands present. In this case, the amplitudes of the two beating signals are different, causing incomplete cancellation at the null points between the maxima. Beating is a linear process -- no additional frequency components are created.

Machinery Vibration Forcing Functions

Beating and Amplitude Modulation



Beats vs Amplitude Modulation

Beats and amplitude modulation produce similar waveforms, but there is a subtle difference.

Note that in the case of beats, there is a phase change at the point where cancellation is complete.

Next Time

- Machinery Vibration Testing and Trouble Shooting
- Fault Diagnostics Based on Forcing Functions
- Fault Diagnostics Based on Specific Machine Components
- Fault Diagnostics Based on Specific Machine Types
- Automatic Diagnostics Techniques
- Non-Vibration Based Machine Condition Monitoring and Fault Diagnosis Methods