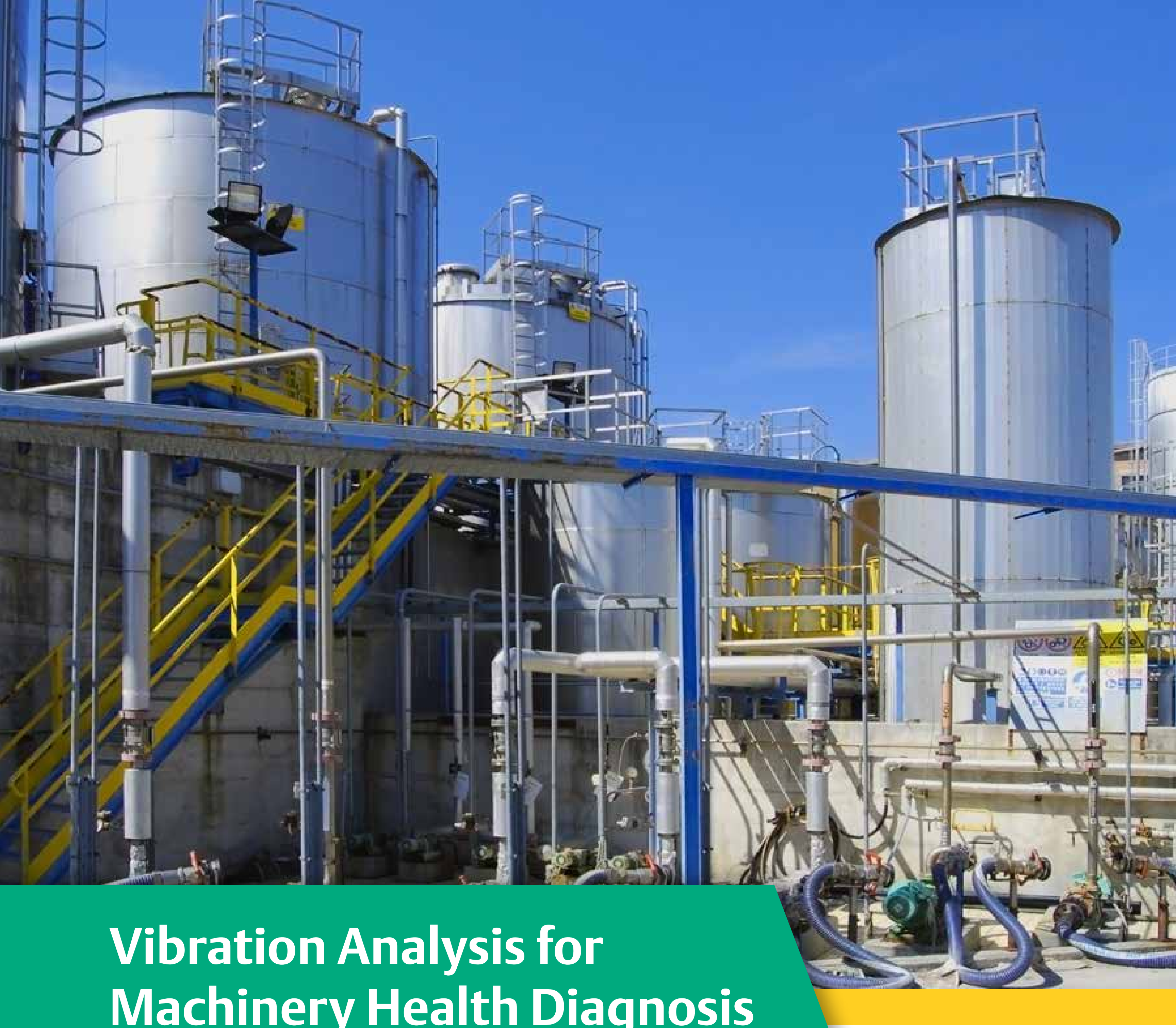


Vibration Analysis for Machinery Health Diagnosis

EMERSON

How Vibration Data is Gathered and Processed for Analysis

Vibration analysis can identify these and other problems:

- Imbalance
- Belt problems
- Resonance
- Oil whirl
- Vane pass
- Cavitation
- Misalignment
- Electrical problems
- Sleeve bearing problems
- Flow problems
- Lubrication problems
- Gear problems looseness
- Rubs
- Oil whip
- Blade Pass
- Pipe strain
- Rolling element bearing defects

Facts About Vibration

- Vibration is movement relative to a reference position, such as the center line of a shaft on rotating equipment
- Vibration is a result of an excitation force or forcing function and may be either random or periodic
- Vibration analysis can often pinpoint a failing element of a rotating machine in time to avoid catastrophic failure and costly replacement of machinery as well as lengthy production interruptions
- Each machine fault generates a specific vibration pattern.
- The frequency of the vibration is determined by the machine geometry and operating speed
- A single vibration measurement provides information about multiple components

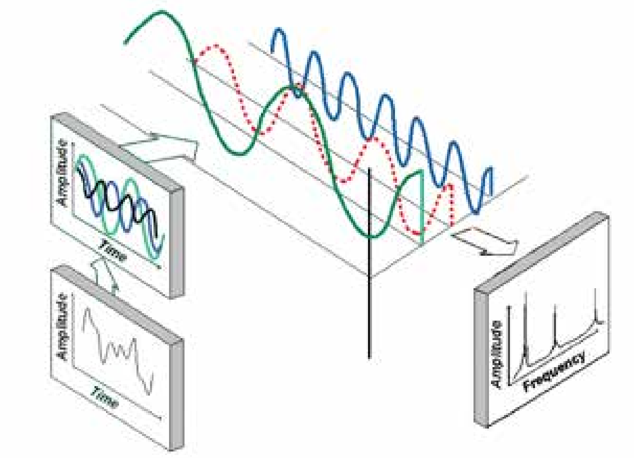
When evaluating any machine's health, the analyst should:

1. Visually inspect each machine for overall condition while onsite collecting data. Look for things such as leaking seals and other damaged or incomplete components, cracked welds, deterioration in the grouting, missing clamps and hold-downs.
2. Ensure that the turning speed (TS) can be identified at the measurement point location before any critical measurement is taken.
3. Once TS is identified, determine TS harmonic relationships.
4. When harmonics of TS are determined, other vibration peaks of interest and other harmonic relationships may be identified for analysis.

Line Frequencies

Line frequency related peaks commonly exist on every AC driven machine and are present to some extent at 2x of line frequency. For more discussion of electric motor issues, see Electric Motor Problems and Diagnostic Techniques.

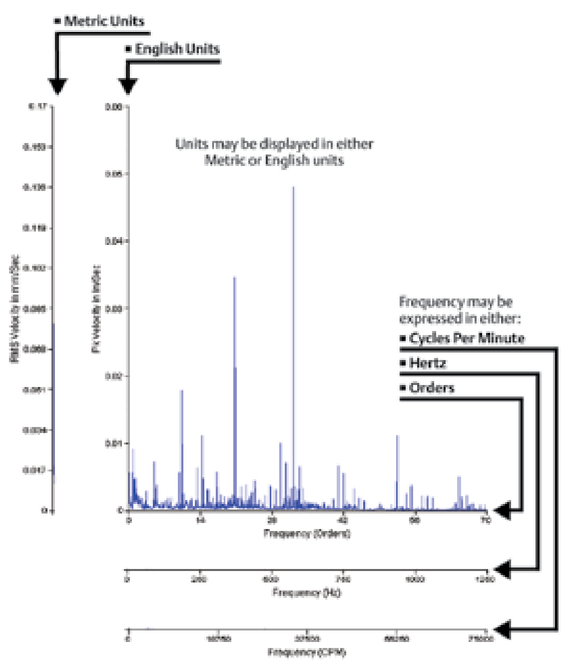
FFT Signal Processing

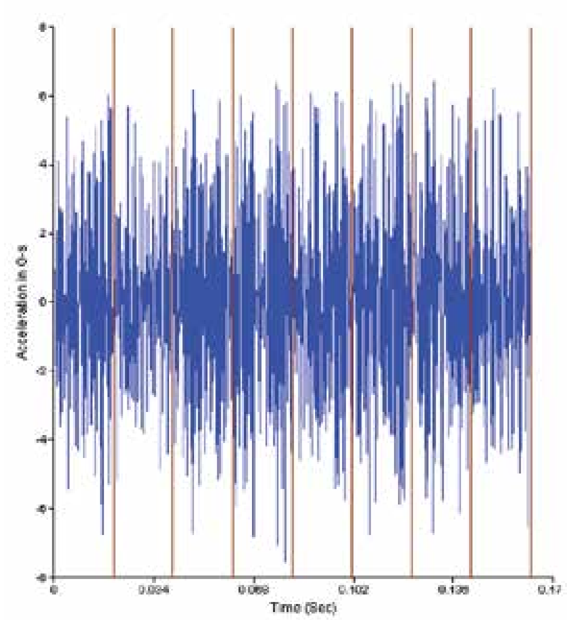


Captured Waveform **Resulting Spectrum**

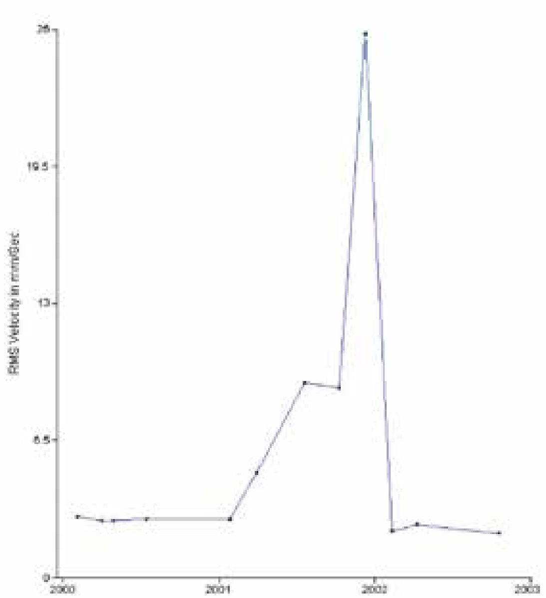
Vibration Plot Types

Both spectrum and waveform provide useful data. Machinery faults often occur at specific frequencies and are most easily identified in the spectrum. Trend plots show changes in a measurement over time.

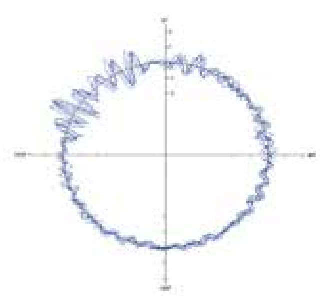




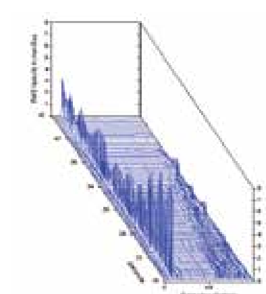
The Time Waveform shows random events, periodic events and imapcting



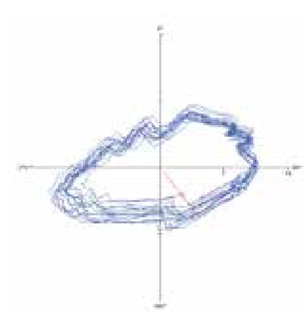
Basic Trend Plot displays growing defect and result of maintenance action



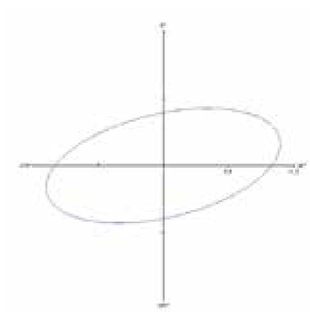
Circle Plot or Roll Profile Plot



Cascade spectrum plot shows resonance over time, such as during a startup



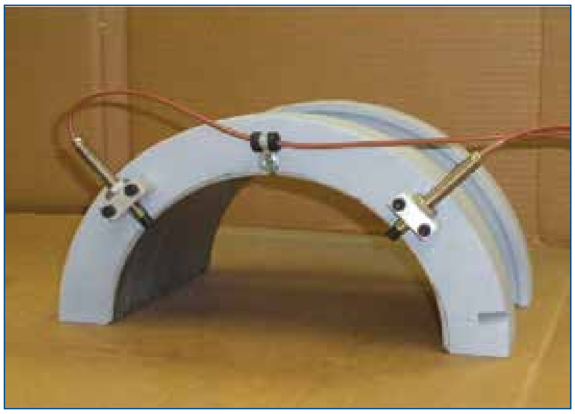
Unfiltered Orbit Plot



1x Filtered Orbit Plot

Transducer Mounting (Vibration Sensors)

- Stud mounting is preferred but common only with inaccessible situations and online systems
- More care is necessary when mounting higher frequency range accelerometers
- Adhesive mounting is second in performance to stud mounting
- Magnetic mounting is most commonly used for route-based monitoring
- Hand-held probes yield poorest performance and are not recommended but are sometimes necessary because of access restrictions or safety concerns



Typical displacement probe mounting on a large sleeve bearing

Resonance

Every machine will vibrate when excited by a forcing function. Each machine has one or more natural or resonant frequencies. When any forcing function is near the natural frequency, the resulting vibration will be significantly amplified and could cause premature failure.

A critical speed occurs when the rotating element is turning at a speed which excites resonance in the machine. Many times a forcing function (such as from a rotating shaft) excites a resonance frequency in another part of the same or nearby machine. This resonance frequency may be identified by an impact test, typically when the machine is ff; the machine structure may be "rung" like a bell. Changing a structure's stiffness, mass, damping, operating speed and/or reduction of the forcing function will affect the resonance issue and may help solve the problem. Resonance is becoming more of a problem in industry because:

- New equipment is often built lighter
- More variable speed machinery is being used in industry
- Machines are now often run at higher speeds without properly considering natural or resonant frequency of equipment

Typical magnetic mounting of accelerometer

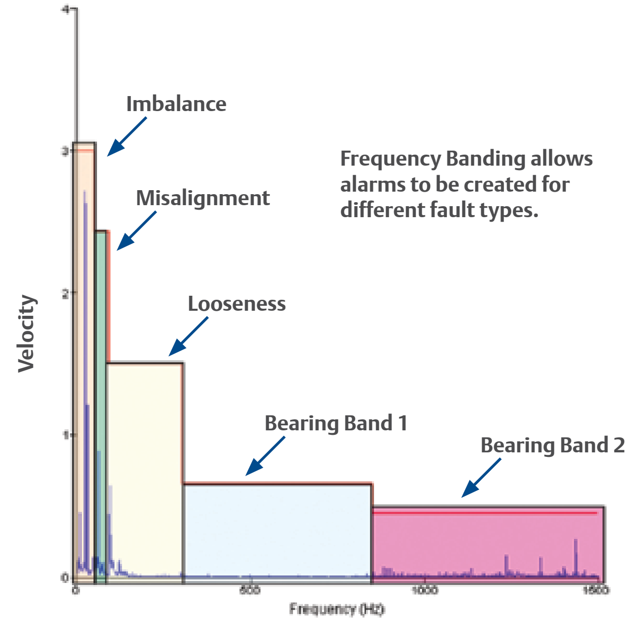
Analysis of the vibration spectrum can be divided into 3 areas:

Sub-synchronous is less than 1x turning speed (TS) of the shaft and can identify problems with: belts, oil whirl/whip, rubs, loose roller bearing in housing, cage or train frequency of antifriction bearing, primary belt frequency, defective tooth-to-tooth repeat frequency, surge, ignition or fuel problem on reciprocating source.

Synchronous is a 1x turning speed (TS) of the shaft and exact multiple integers of TS (energy is said to be "phase locked" to TS) and can identify problems with: imbalance, misalignment, looseness, bent shaft, vane/blade pass, gear mesh, belt sheave pitch line runout, broken gear tooth, sleeve bearing, resonance.

Non-synchronous is not equal to any multiple of TS of the shaft and can identify problems with: rolling element defects, electrical, other components in the machine, one or more system resonances, belts, noise, cavitation, other unusual sources, background vibration, pipe, strain lubrication fault.

Electrical faults occur as a multiple of the frequency of the supply/current.



Typical Sensors, Sensor Units and Applications for Vibration Analysis

	Probe Type	Units*		Frequency Range and Typical Application	Display Units for Plotting
		Metric	English		
Displacement	Non-contact eddy current probe (requires signal converter)	µ Pk-Pk	Mils Pk-Pk	0-1kHz. Permanently or semi-permanently mounted. Measures shaft vibration relative to machine casing. Commonly used on turbo machinery	Displacement enhances low frequency and is ma measure of motion expressed in thousandths of an inch (1 mil – 0.001") or in metric units
Velocity	Spring-loaded mass, sensitive to heat and humidity (no power required)	Mm/s (RMS)	In/s (Peak)	10Hz-1kHz. Accuracy dependent on temperature, humidity and position. Displays low and high frequency data equally	Velocity displays low and high frequency data equally and is a measure of speed expressed I inches per second or metric units per second
Acceleration	Piezoelectric crystal, extremely robust (requires external power)	Peak g's	Peak g's	0.5Hz-60kHz depending on design and mounting. 10Hz-3kHz typical. Very robust design. Ideal for monitoring rolling element bearings and gear boxes	Acceleration enhances high frequency data and is a measure of the rate of change of speed (1g- 386 in/sec squared or metric units/ second squared)

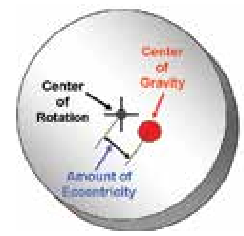
** These are typically accepted units, but may be user defined.*

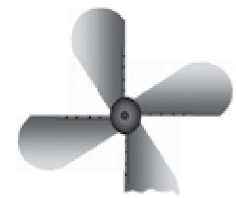
Imbalance and Misalignment

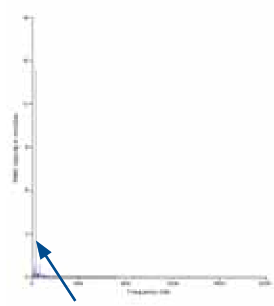
Imbalance is the condition of a rotating component where the center of rotation is not the same as the center of mass.

Common causes of imbalance:

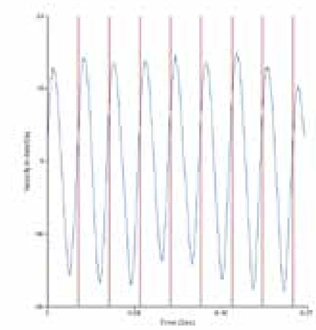
- Material buildup
- Wear
- Broken or missing parts
- Improper assembly or poor design
- Thermal distortions
- Turning speed peak amplitude increases with increase in speed
- Little axial energy except with overhung machines
- Little or no turning speed harmonics
- Simple, sinusoidal, periodic waveform
- One event per shaft revolution
- Little or no impacting
- Presence of significant turning speed harmonics suggests other or additional defects (looseness, etc.)



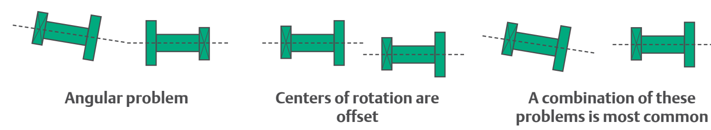




Imbalance vibration is always 1 x TS

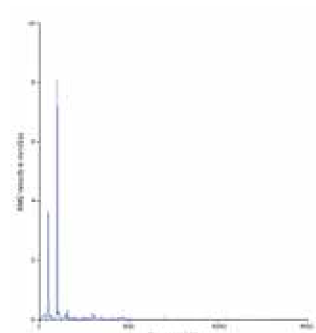


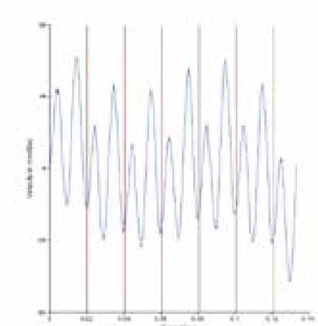
Misalignment is when rotational center lines of coupled shafts are not collinear.



High 2xTS peak characterizes offset misalignment; a high 1xTS signifies angular misalignment, though both frequently combine to cause1xTS and 3xTS in the spectrum. Highest amplitudes typically occur in the radial direction for horizontally mounted equipment; overhung motors may exhibit higher amplitudes in the axial plane.

Velocity waveform for misalignment is very periodic and repetitive with one or two peaks (events) per revolution. Offset amplitudes typically appear higher in the radial plane; angular misalignment amplitudes typically appear higher in the axial plane.



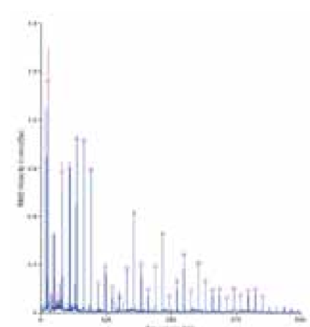


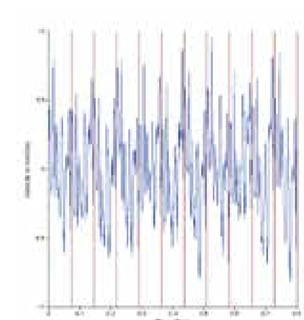
Mechanical Looseness

Looseness is characterized by harmonics of TS with raised noise floor. Waveform displays random impacting which may be in a non-repetitive irregular pattern. Highest amplitudes typically occur in the radial direction, specifically the vertical plane for horizontally mounted equipment.

The number of turning speed harmonics and their amplitudes increase with the severity of the problem. Unstable phase characterizes looseness.

Fractional harmonics (1/4, 1/3, ½, ¾) may appear due to looseness.

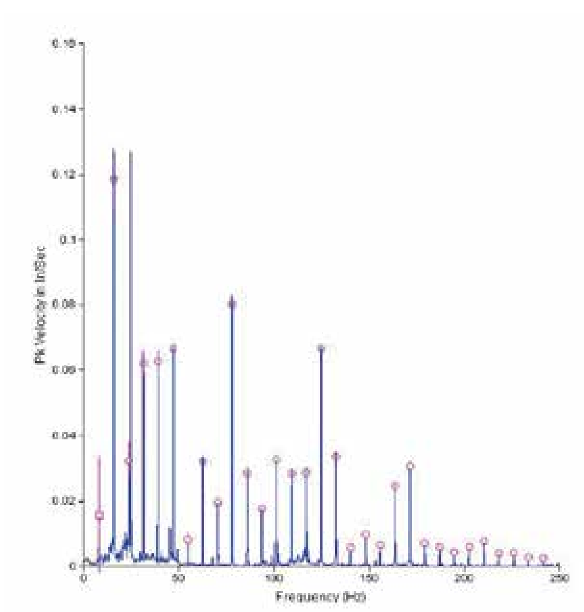


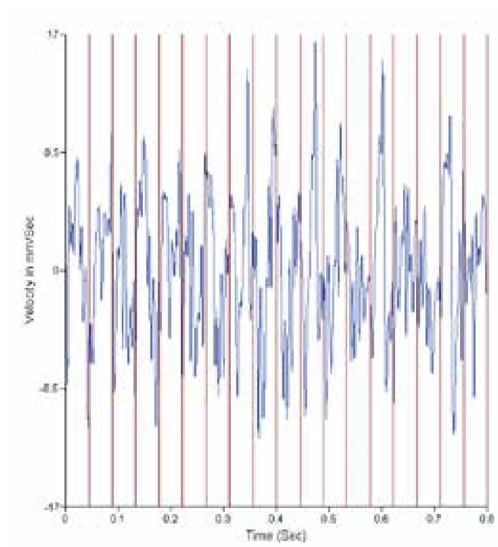


Belt Defects

Worn or mismatched belts produce sub-synchronous and sometimes non-synchronous peaks and harmonics. The 2x belt frequency typically dominates, and multiples of the 2x appear throughout the spectrum, because the defective belt passes over 2 sheaves. The highest amplitudes typically occur in the radial direction, specifically in line with the belts.

- To resolve belt frequency in the spectra, it is necessary that the time block of data includes at least 6 revolutions of the belt (further references are available in The Simplified Handbook of Vibration Analysis by Art Crawford
- An eccentric sheave produces radial vibration at 1xTS of the sheave
- Misaligned sheaves create axial vibration at 1xTS of the sheave





Antifriction Bearing Faults

An imperfection in one or more of the contact surfaces of an antifriction or rolling element bearing is called a defect. The problem may be invisible even under a microscope, and may be more complex than a simple imperfection.

Antifriction bearing problems are a major source of failure in industrial machinery.

Some common causes of bearing defects or premature failure:

- Excessive or inadequate lubrication
- Improper mounting methods
- Improper application
- Excessive vibration before and/or after installation
- Excessive load
- Age of bearing
- Improper storage & handling
- Manufacturing defects

Bearing defect frequencies will usually appear in this order (highest to lowest):

- BPFI (Ball Pass Frequency Inner)
- BPFO (Ball Pass Frequency Outer)
- BSF (Ball Spin Frequency)
- FTF (Fundamental Train Frequency)

View the spectrum in acceleration to see the high frequency peaks. High frequency vibration analysis can detect lack of lubrication.

The following frequencies can be approximated with the following formulae:

- BPFO = # of rollers x shaft TS x 0.4 (approx.)
- BPFI = # of rollers x shaft TS x 0.6 (approx.)

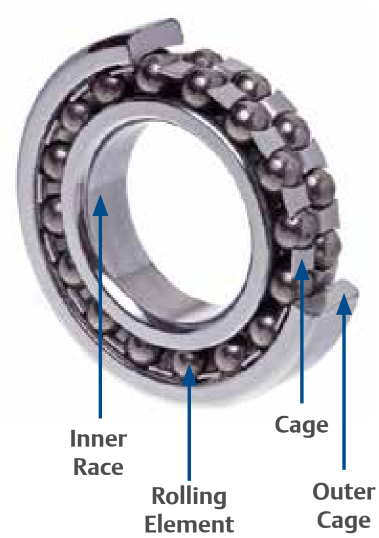
Typical waveform characteristics:

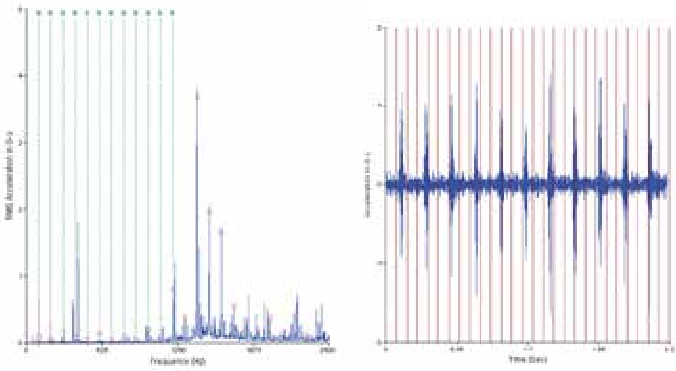
- Periodic but non-sinusoidal impacting
- Excessive "g swing" with sharp impacting spikes often resembling an angle fish pattern
- Periodic characteristic diminishes with advanced degradation

Bearing spectrum characteristics:

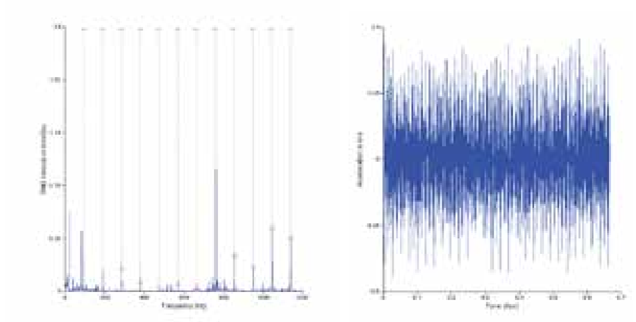
Commonly first appear as high-frequency/low-amplitude non-synchronous peaks. Harmonics of the non-synchronous peaks often show turning speed sidebands appearing around the race defect frequency.

Broad energy "mounds" or "grass" indicate advanced degradation.

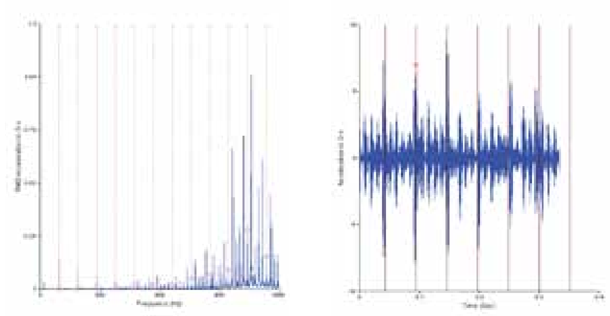




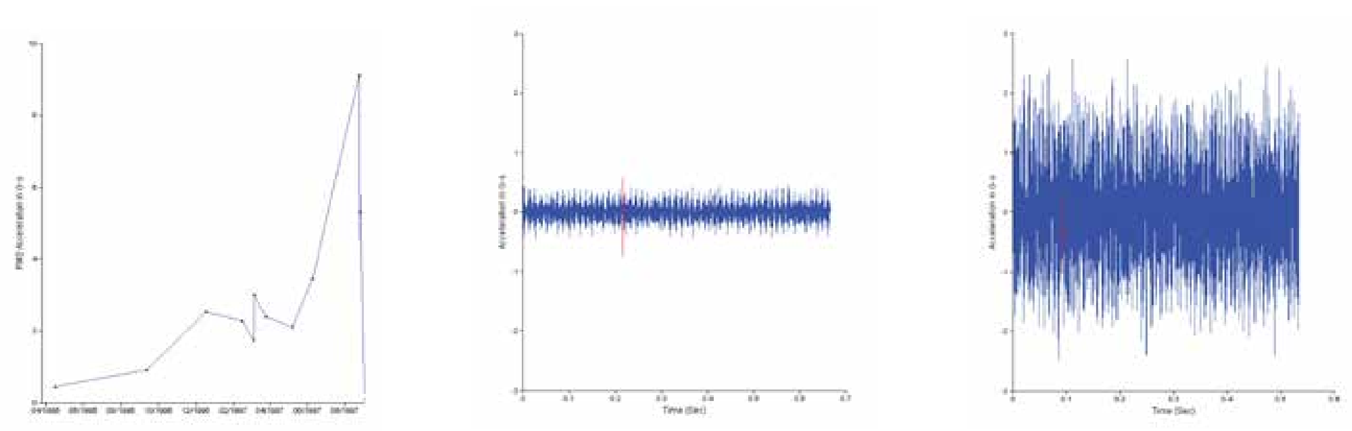
For rolling element defects, cage frequency sidebands are typically displayed in a spectrum centered around 1 or 2 times BSF fault frequency as illustrated in the plots above. These sidebands are caused by the defect passing in and out of the load zone at the TS of the cage. The associated waveform displays modulation at the cage TS which appears as sidebands in the spectrum.



An outer race defect normally shows little or no modulation in the waveform, thus no sidebanding about the BPFO frquencies in the spectrum.



Running speed sidebands are typically displayed in an inner race defect spectrum about BPFI frquencies as illustrated in the plot. These sidebands are caused by the defect passing in and out of the load zone at the shaft. The associated waveform displays modulation which appears as sidebands in the spectrum.



These plots demonstrate an advancing fault. The trend shows a deteriorating bearing defect. As it advances, increased high-frequency broadband energy indicates rapid deterioration exhibited in the waveforms.

Bearing ID Interpretation

Bearings are built to world standards, ensuring consistent availability worldwide. Because most motor bearings are listed on motors tags as AFBMA or ABMA numbers, you may be able to calculate the common bearing number from the equipment nameplate. Identification resources are available from:

Interchange, Inc.
PO Box 234
Champlin MN 55316-0234
800.669.6208
Fax 800.729.0395 or 763.694.7117
Sales@Interchangeinc.com
www.interchangeinc.com

Gear Boxes and Defects

Gears rotating together at a common tangent create gear mesh. Data collection on gear boxes can be challenging. Defects may include misalignment, chipped or broken teeth, looseness, stress fractures, and worn gears or bearings.

Gear box waveform characteristics:

- Gear mesh will appear (impacting indicates a problem). Since gear boxes are naturally energetic due to the gears meshing, trending is very helpful
- Very busy waveform
- Pulses appear once per revolution with cracked or broken tooth

Gear Mesh Frequency (GMF) = Rotation Speed (in Hz) X # of Gear Teeth

For example, a gear is rotating at 10 Hz with 72 teeth. GMF = 10Hz X 72 = 720 Hz

Causes of premature gear box failure include:

- Improper lubrication
- Wrong application
- Bearing failure
- Water intrusion
- Overheating
- Poor design or manufacture
- Seal failure

Gear box spectrum characteristics:

- GMF will commonly exist and appears as high frequency synchronous peaks
- Defects can display harmonics of GMF and/or turning speed sidebands
- Sideband amplitudes will normally increase as condition deteriorates

Gear Monitoring Tips

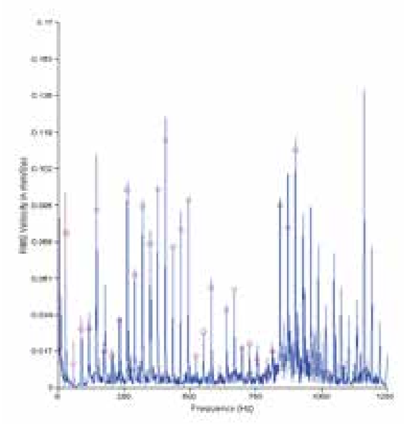
- Gear mesh energy normally appears regardless of gear conditions; amount of energy depends on gear configuration and load
- Increase of gear mesh harmonics are an indication of normal uniform wear
- Eccentric wear generates sidebands; frequency of the sidebands are related to the problem gear
- An increase in amplitudes of gear mesh sidebands indicates problems
- Spacing between sideband peaks can indicate which gear is bad
- Gear natural resonance can be excited by gear defects; an increase in amplitude is a good indicator of potential problems
- Gear misalignment often appear as as 2xGMF in the spectrum
- To analyze gear problems, set Fmax at 3.4xGMF to allow room for sidebands
- Use at least 1600 lines of resolution if the Fmax is <2000Hz; use at least 3200 if the Fmax is >2000Hz. The objective is to resolved the slowest shaft speed in mesh
- Mark gears to be reinstalled to allow same mesh.
- Best to replace gears in sets
- Additional significant harmonics (3 and up) can indicate looseness.

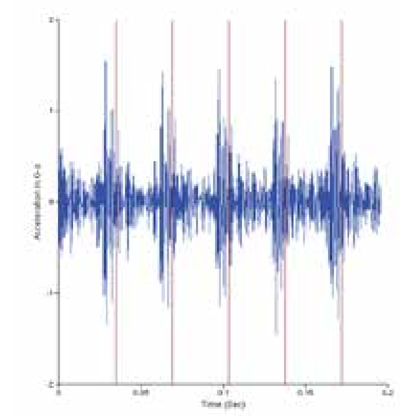
Gear Ratio Calculation

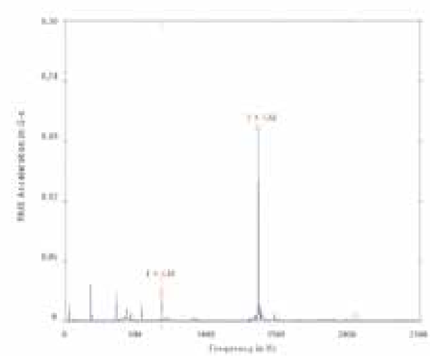
Knowing the ratio of th einput to output gears can be very helpful in determining the turning speed of the output shaft.

Ratio = Number of teeth on output gears can be very helpful in determing the turning speed of the outp shaft.

For example, a gear box with 72 teeth on the input gear and 24 teeth on the output gear would have a ratio of 72/24, or 3:1. If the input is 10Hz, the output would be 30Hz (TSxRatio).



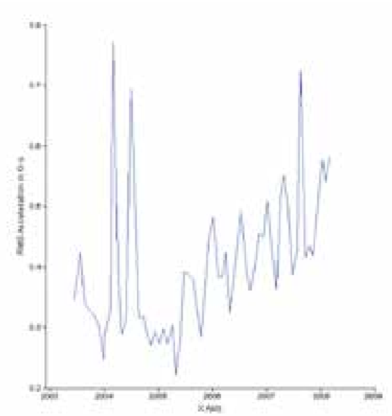


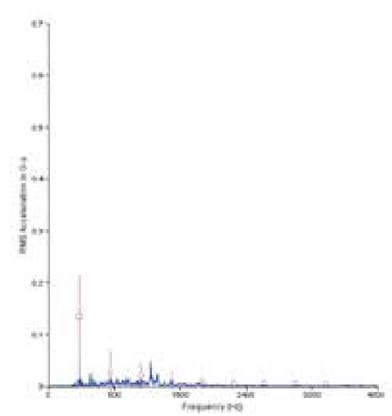


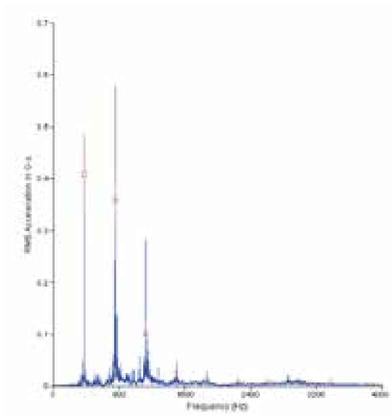
The spectrum (expressed in orders) demonstrates extensive impacting at gear turning speed. Recurring periods of high spiking appear in the waveform each time the cracked tooth passes through engagement.

Other technologies to monitor gear boxes:

- Oil analysis
- Infrared thermography
- Advanced Vibration Diagnostics such as Autocorrelation and PeakVue®







Trend plot clearly shows increasing gear tooth wear over several months, despite readings taken under varying load.

Gears demonstrating wear over time. Note changes in amplitude from early stage wear to more advanced tooth wear and increasing side bands. Cursors denote gear mesh frequency and its multiples.

Vibration Analysis is Used to Improve Profitability in Every Major Industry in the World		
Photo – power	Photo – offshore	Photo – paper
Photo – O&G	Photo – Steel	Photo – food or bev
Photo – Mining	Photo – Petrochem	Photo - manufacturing

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