



Basic Vibration Analysis

With Common Causes and their Signatures

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Objectives

- Re-Introduce the concept of Vibration in machines
- Present a Business Case for Vibration Analysis
- Present the concepts of:
 - how Vibration is measured
 - how measured values are interpreted
 - common causes of vibration & their signatures
- Arouse the interest of Mechanical Maintenance Engineers

Introduction

- Vibration is simply the oscillating motion of an object or dynamic system about its position of rest.
- Can be desirable: for hearing, Pacemakers, etc.
- Or Undesirable: in structures and machines
- In this context, 'Vibration' refers to the excess of it – the undesirable

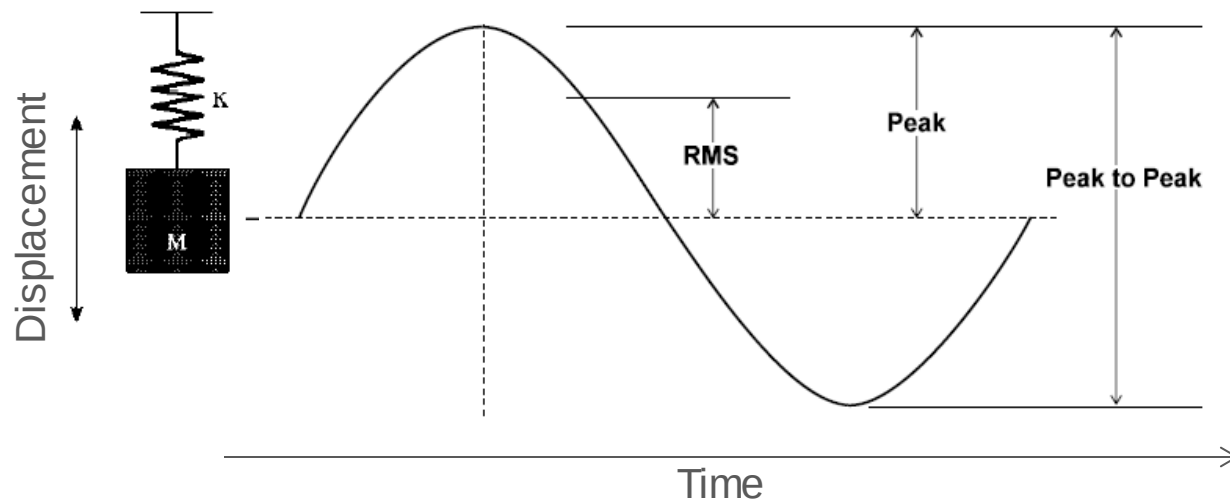
Business Case (Why Bother?)

- Growing concern for more efficient use of Machines, Materials and Money
- Improving emphasis on Condition Based Maintenance (which):
 - Reduces Maintenance Costs
 - Improves Plant Reliability
 - Optimizes use of resources
- Vibration Analysis is at the heart of Condition Based Maintenance

	Temp. Analysis	Pressure	Flow Analysis	Oil Analysis	Vib. Analysis
Unbalance					
Misalignment					
Roller Bearing Damage					
Gear Damage					
Mechanical Looseness					
Noise					
Cracking					

Basic Model

- All Machines can be broken down to Mass and Stiffness
- Mass is represented by an object that can move about its neutral position
- Stiffness is represented by a Spring that constrains that movement

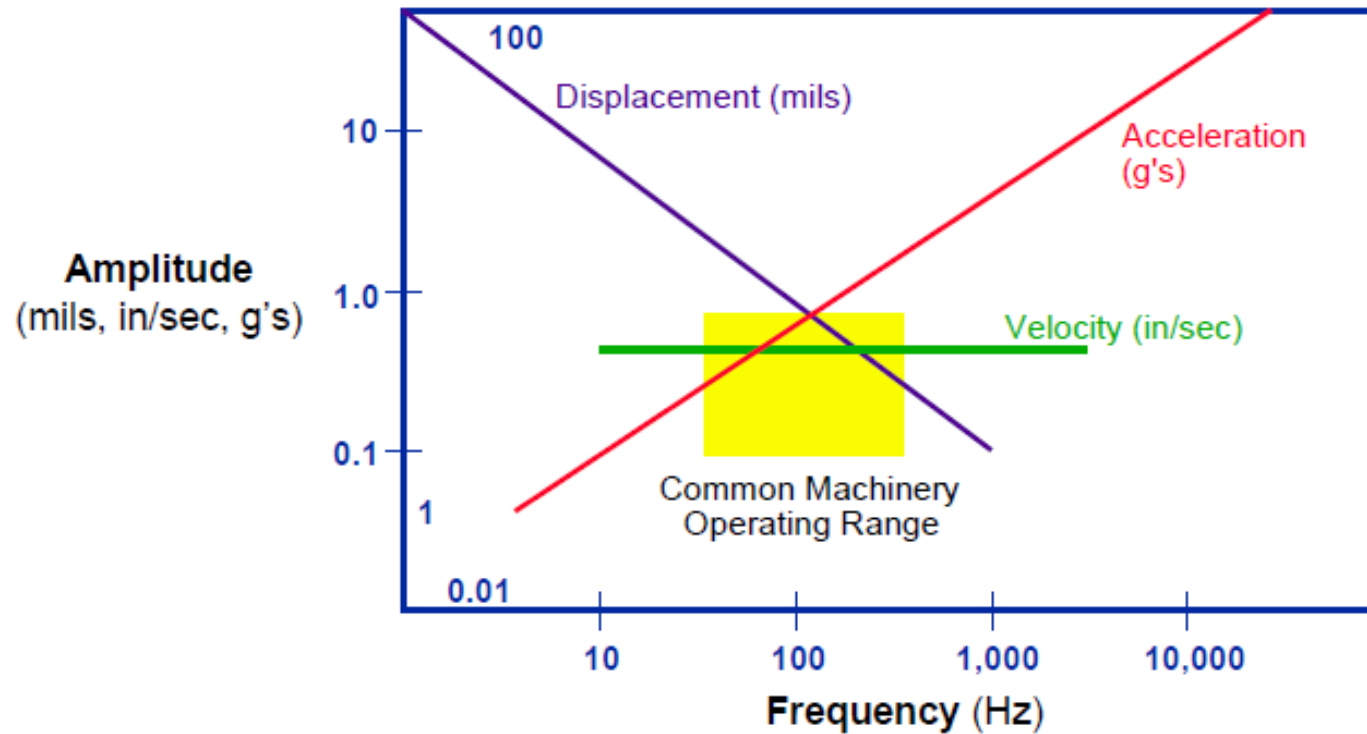


- A Vibrating body moves about its reference position at the frequency of its exciting force

Vibration Measurement

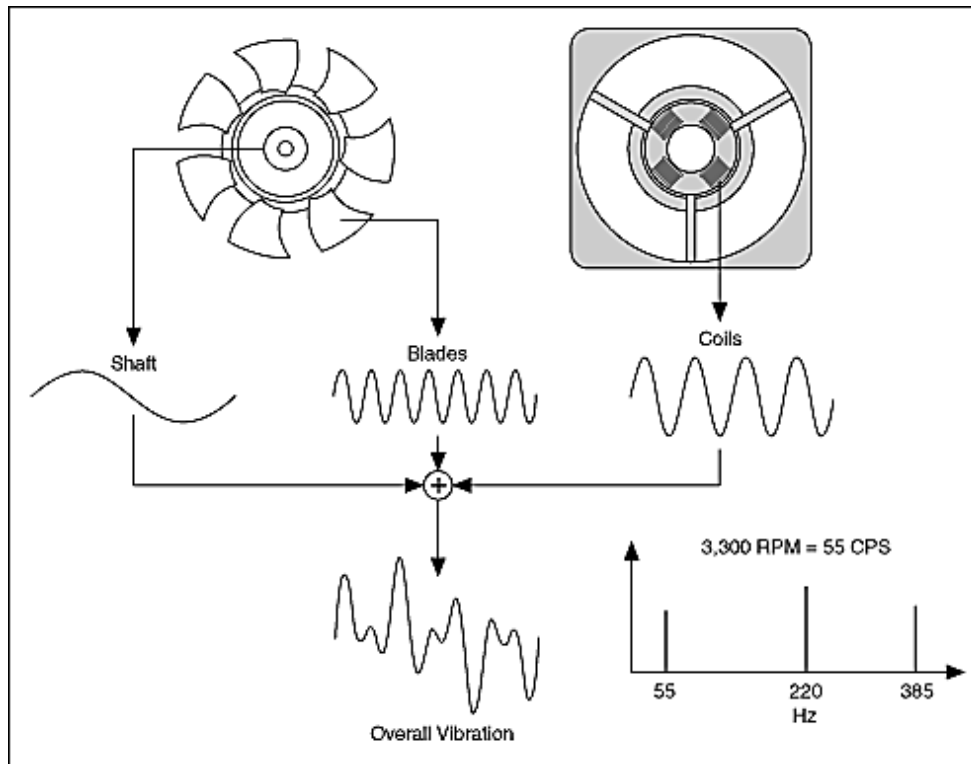
- To determine the level of Vibration of a body, you can measure the:
 - **Displacement** of the body from its rest position (mils or micrometer).
Commonly used for low frequency phenomena
 - **Velocity**: the rate of change of Displacement – the 'speed' of the Vibration (in/sec or mm/sec). Used for vibration in the range of 10 – 10000Hz
 - **Acceleration**: rate of change of the Velocity – change in Vibration 'speed' (G or in/sec² or mm/sec²). Commonly used for high frequency vibration phenomena e.g. Gear Mesh
 - Others: **Enveloped Acceleration, Spike Energy, etc.**

Sensor Relationships



- Velocity has a uniform response over a wide range of machine frequencies and is generally used to measure and evaluate machine integrity in relation to balance, tightness, alignment and the like.

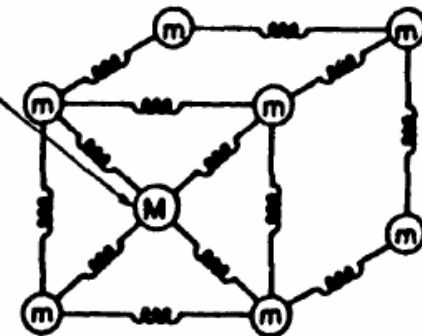
Overall Vibration



Machine components vibrate at different frequencies

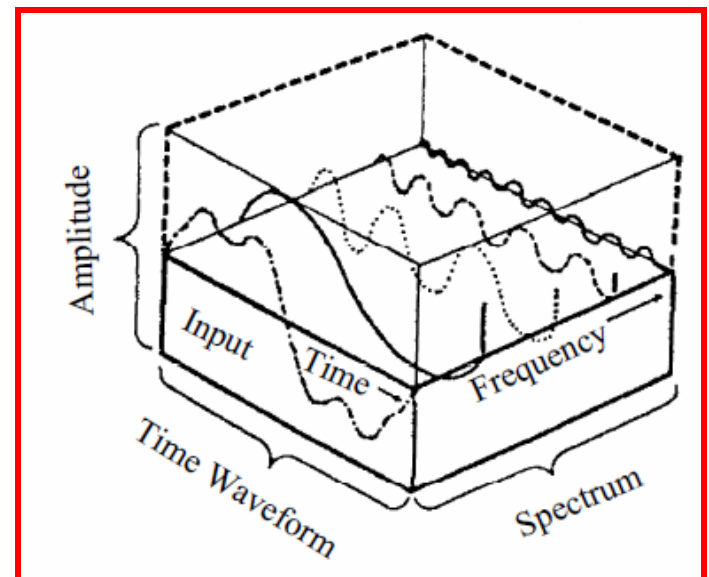
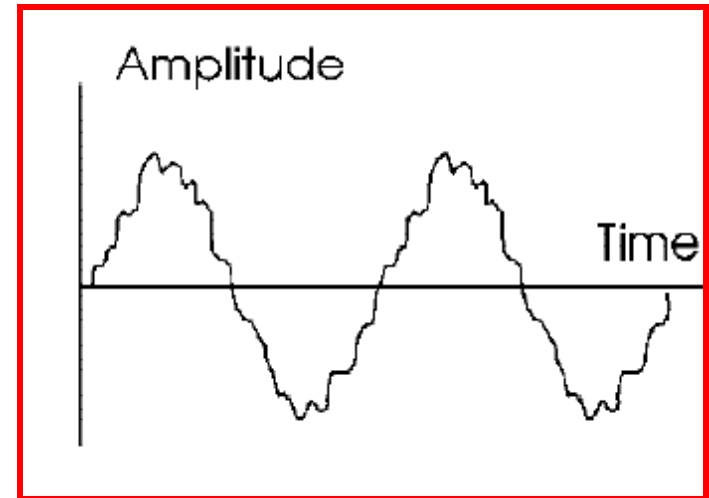
Individual Vibration signals combine to form a complex time waveform showing overall Vibration

A model of a Real Machine comprises a complex network of 'Mass' – 'Spring' connections



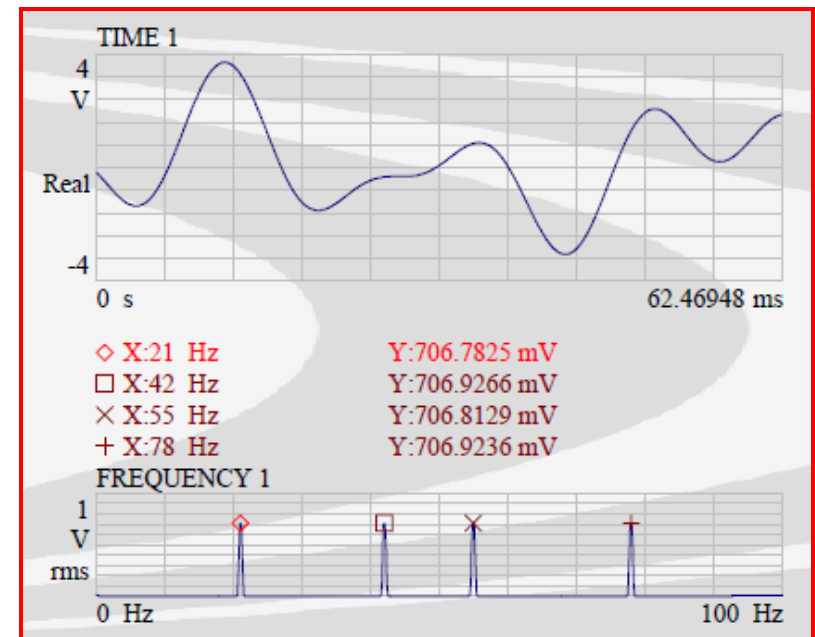
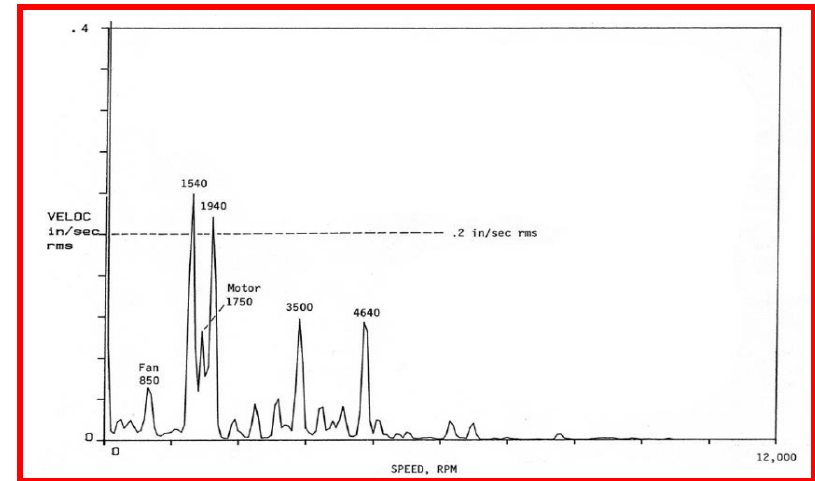
Time Domain Plot

- Typically derived from the signal from an accelerometer or velocity probe
- Displays a short time sample of the 'raw' vibration
- Includes a combination of all Vibration signals within the probe's frequency range
- Gives a clue but not as useful as other analysis formats

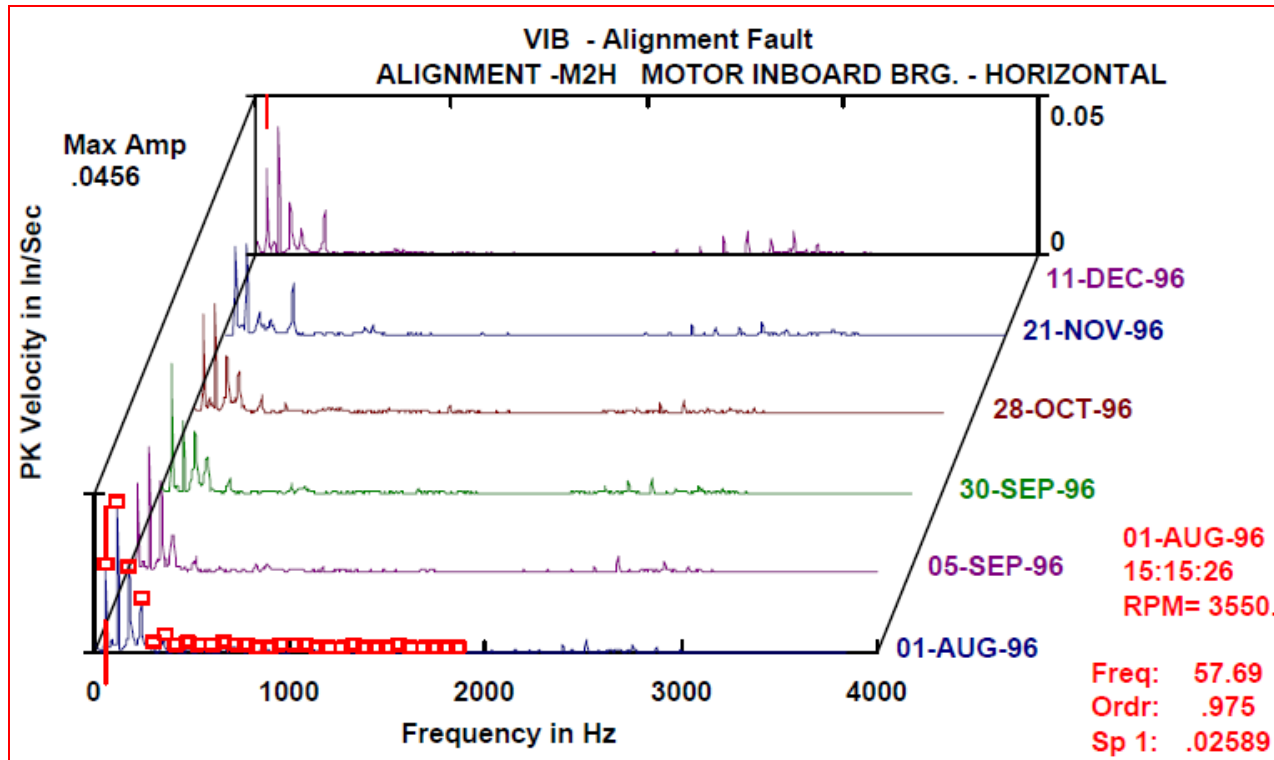


Frequency Spectrum

- Data is converted from the Time Domain to the Frequency Domain using a Fast Fourier Transform
- The Amplitude indicates the severity (of the problem)
- The Frequency indicates the source (of the problem)



Water Fall Plots



- A 3D Plot of the Vibration Spectra against a Third Variable such as Speed, Time, etc.

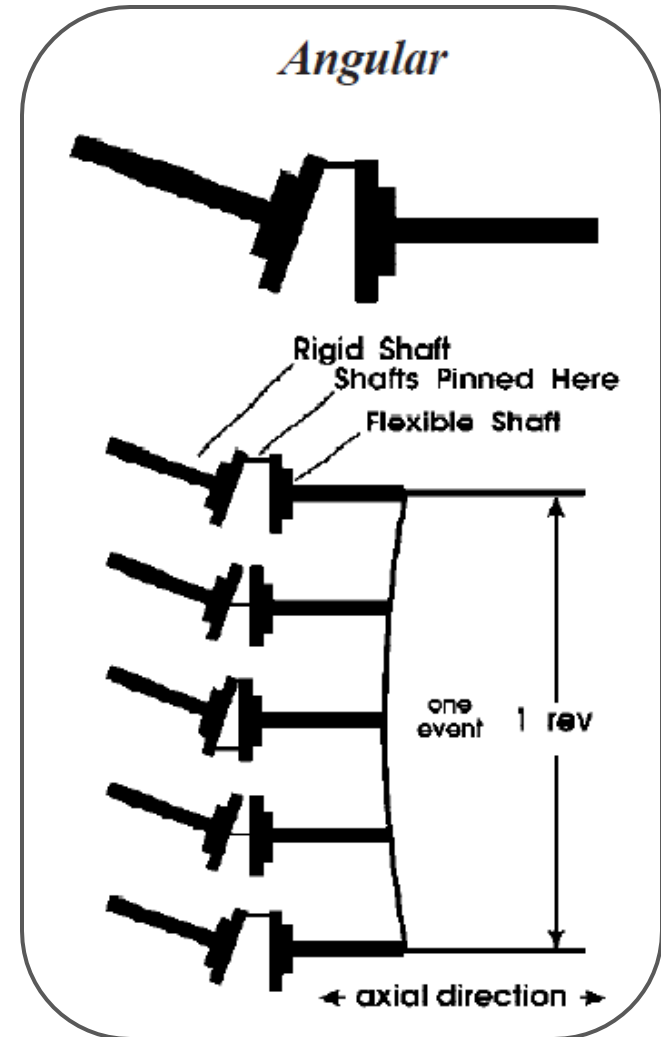
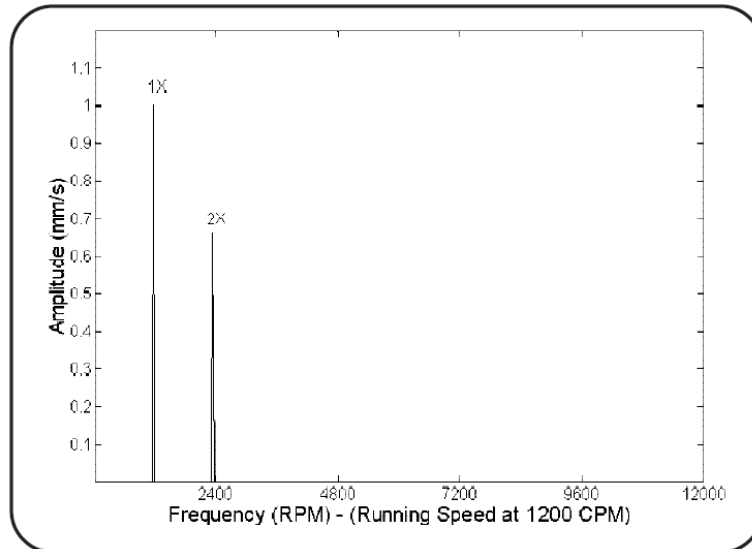
Common Terms

- **1x:** the running speed of the machine. The fundamental frequency.
- **Critical Speed:** rotating speed associated with high vibration amplitude.
Often the speeds corresponding to the natural freq.
- **CPM:** cycles per minute. $60\text{cpm} = 1\text{ cycle per second (cps)} = 1\text{ Hz}$.
- **FFT:** Fast Fourier Transform for converting a time waveform to a spectrum
- **Harmonics:** integer multiple of the fundamental frequency. E.g. 2x, 3x, 4x.
- **Sidebands:** evenly spaced peaks centered around a major peak.
- **Spectrum:** a display of evenly spaced frequencies and their amplitudes
- **Spectrum (baseline):** reference spectrum, taken on a good machine

Common Causes & Signatures

Angular Misalignment

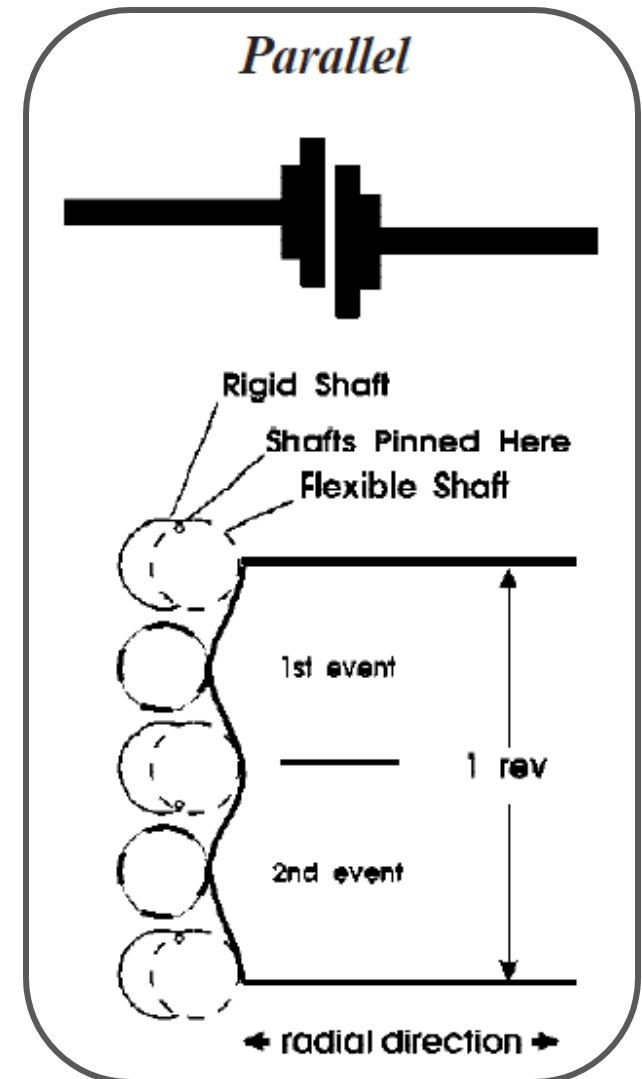
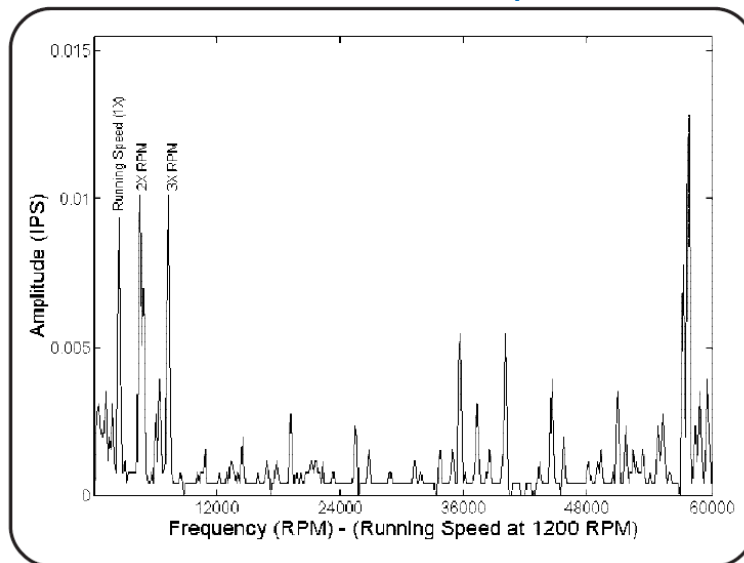
- Indicated as axial vibration at the running speed frequency (1x)
- Causes fatigue failure of the bearing by loading it above design limits
- Overall Vibration, FFT & Phase Measurement used to diagnose misalignment problems



Common Causes & Signatures

Parallel Misalignment

- Indicated as radial vibration at twice the running speed frequency (2x)
- Most misalignment is a combination of angular and offset
- Misalignment forces are seldom the same in both horizontal and vertical positions

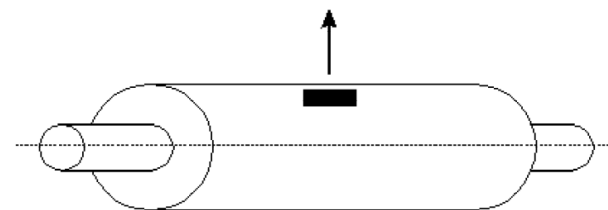


Common Causes & Signatures

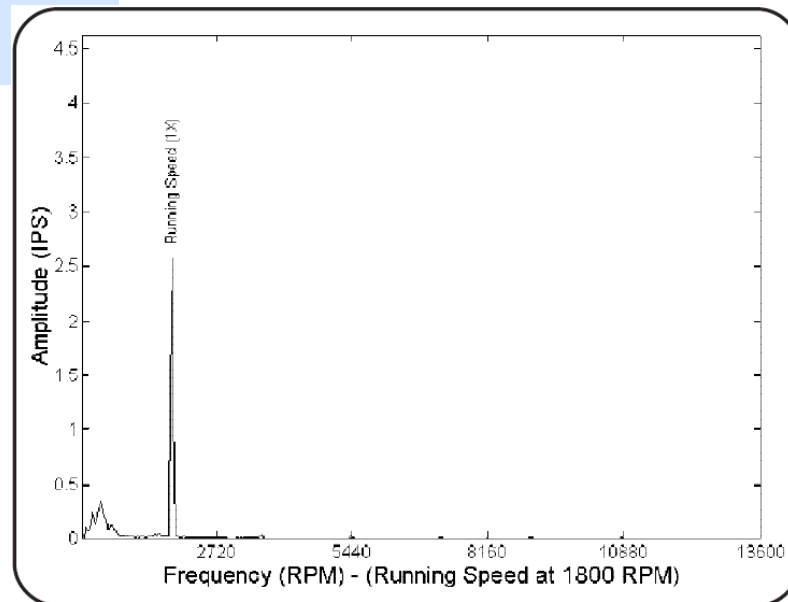
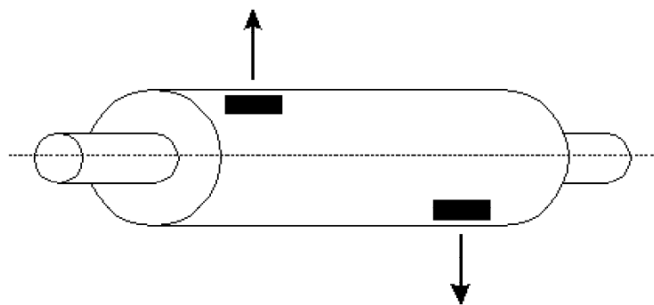
Imbalance

- Single Frequency Vibration whose amplitude is the same in all Radial directions
- Occurs at 1x the running speed and generally does not contain harmonics of 1x running speed
- Amplitude increases with speed up to the first critical speed of the machine

STATIC IMBALANCE



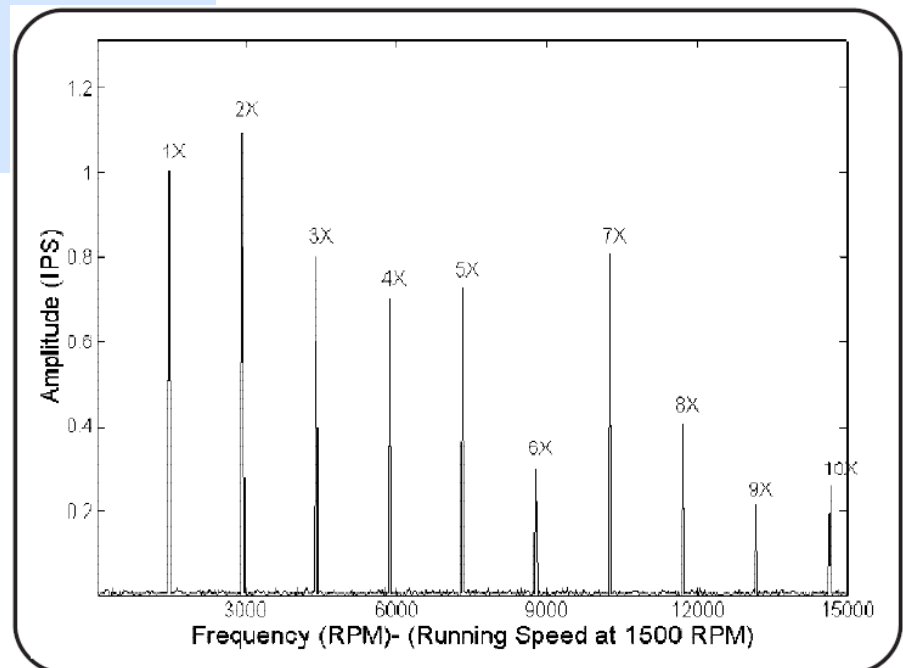
COUPLE IMBALANCE



Common Causes & Signatures

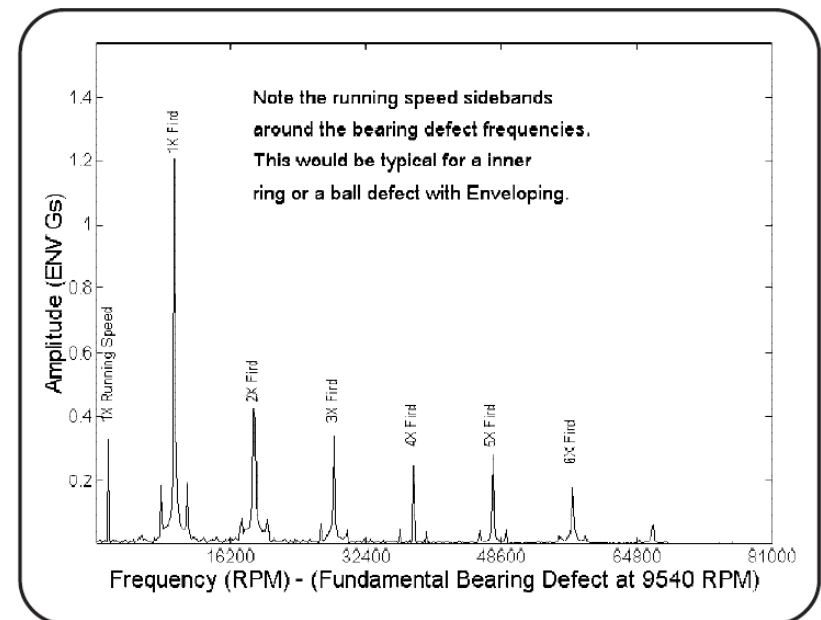
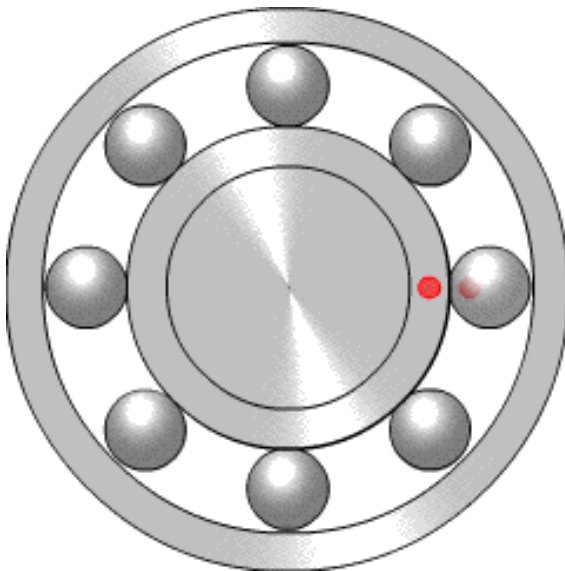
Looseness

- Abnormally high running speed (1x) amplitude
- Long string of peaks at rotating frequency harmonics or $\frac{1}{2}$ rotating frequency harmonics (range 2x to 10x) with amplitude greater than 20% of 1x amplitude



Enveloping

- Enveloping filters out low frequency noise
- Aids in analysis of high frequency Vibration phenomena like gear mesh or repetitive ball bearing signals



Example of an Enveloped Spectrum (Inner Race) for Radial Loaded Bearings!

Standards for Vibration Measurement

ISO 7919 Series	Mechanical vibration of non-reciprocating machines - Measurement on rotating shafts and evaluation criteria
7919-1:1996	Part 1: General Guidelines
7919-2: 2001	Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min
7919-3: 1996	Part 3: Coupled industrial machines
7919-4: 1996	Part 4: Gas turbine sets
7919-5: 1997	Part 5: Machines set in hydraulic power generating and pumping plants
ISO 10816 Series	Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts
10816-1: 1995	Part 1: General Guidelines
10816-2: 2001	Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min
10816-3: 1998	Part 3: Industrial machines with normal power above 15kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ
10816-4: 1998	Part 4: Gas turbine sets excluding aircraft derivatives
10816-5: 2000	Part 5: Machines set in hydraulic power generating and pumping plants
10816-6: 1995	Part 6: Reciprocating machines with power ratings above 100 kW
10816-7 [†]	Part 7: Rotodynamic pumps for industrial application

Others

- ISO 13373-1:2001 – Condition Monitoring and Diagnostics of Machines: General Procedures
- ISO 17359:2003 – Condition Monitoring and Diagnostics of Machines: General Guidelines
- ISO 18436-2:2003 – Condition Monitoring and Diagnostics of Machines: Requirements for Training and certification of personnel
- American Petroleum Institute Standards:

Equipment Type	API Standard	Acceptance Test	Other Requirements
Pumps	610 (9 TH edition March '03)	Shaft Relative + Casing	Vertical Pump (0.20 ips pk)
Fans	673 (2 ND edition November '01)	Casing (0.1 ips pk)	
Steam Turbines	612 (4 TH edition June '95)	Shaft Relative (mil pk-pk)	4 hour run in test required
Gears	613 (5 TH edition March '03)	Casing (0.15 ips pk)	Unbalance 4 W/N oz-in
Centrifugal Compressors	617 (7 TH edition July '02)	Shaft Relative (mil pk-pk)	4 hour run in test required
Screw Compressors	619 (3 RD edition June '97)	Shaft Relative (mil pk-pk)	Unbalance 4 W/N oz-in
Induction Motors ($\geq$ 250 hp)	541 (4 TH edition March '03)		Unbalance 4 W/N oz-in

