Basic Vibration

Introduction:

'What is Vibration?'

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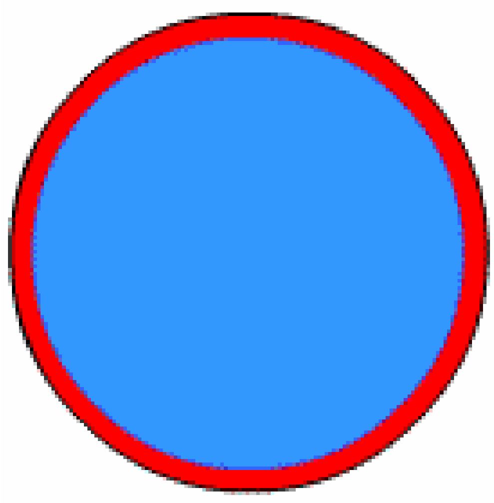
Objectives

- To understand:
  - What vibration is.
  - How it travels.
  - Relationship between a waveform and a spectrum.
  - Different units of measurement
  - Three different forms of energy
  - Understanding of Lines of Resolution

What is Vibration?

Question - What is Vibration?

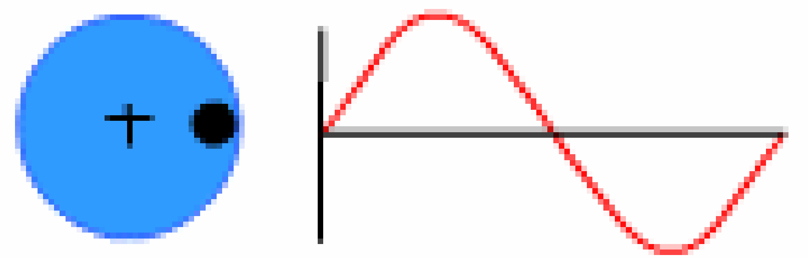
- In simple terms vibration is :-
- *‘A response to some form of excitation’*
- The free movement of the shaft in a journal bearing will cause it to vibrate when a ‘forcing function’ is applied



How Does Vibration Travel

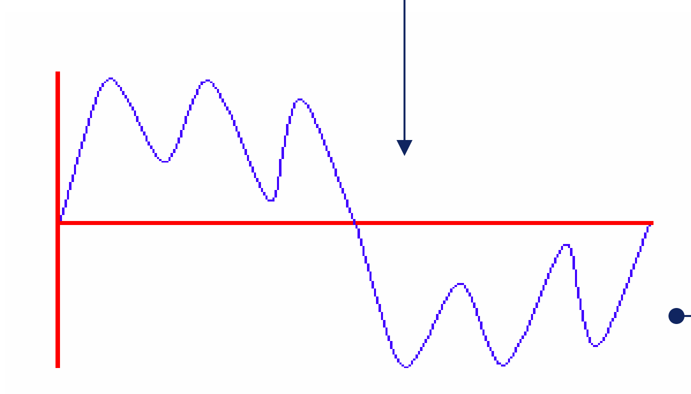
- Vibration transmits as a sine wave.
- We can measure this sine wave in an Amplitude versus Time domain
- This is called a Time Waveform

- Example
  - We have a disc with some kind of forcing function
- If we were to plot this imbalance over one revolution, how would it look?

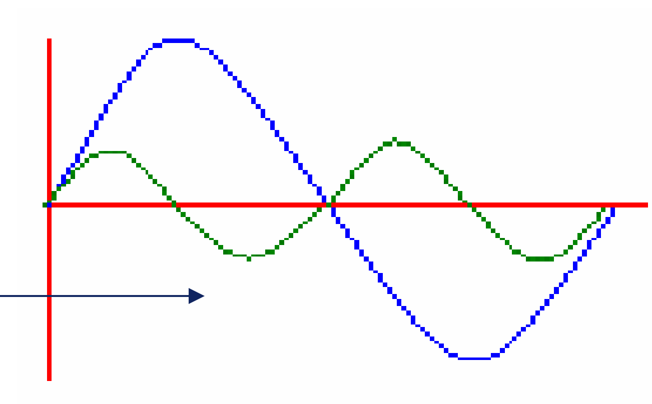


How Does Vibration Travel

- Unfortunately there can be multiple sine waves emitting from a machine, So our wave form becomes complex



- We call this a complex sine waveform
- Analysis is very difficult on this type of waveform.
- Fortunately we have what's called an 'FFT' which converts the complex waveform back into several simple waveforms



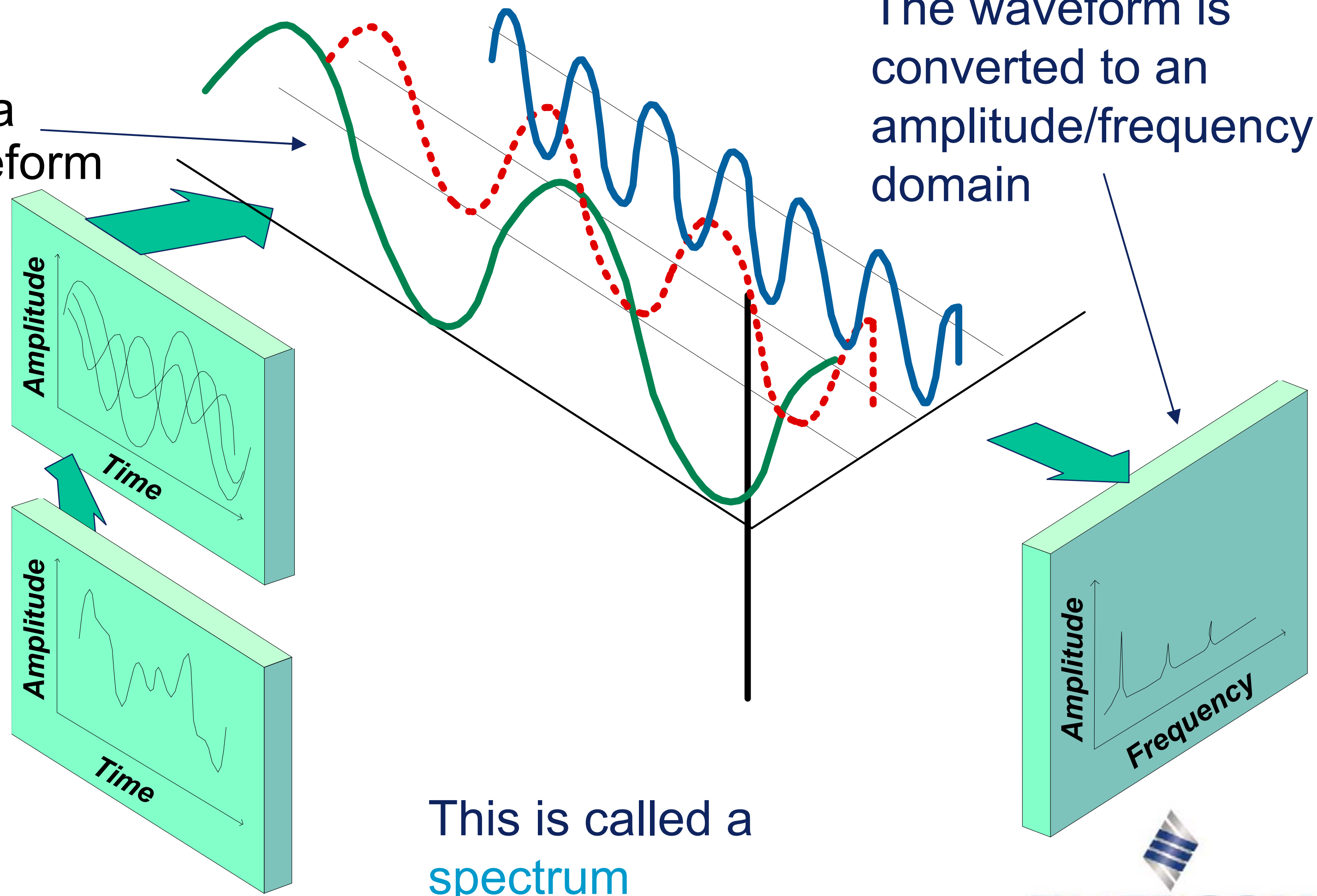
FFT

- The term ‘FFT’ stands for ‘Fast Fourier Transform’
- It is named after an 18th century mathematician called Jean Baptiste Joseph Fourier.
- He established:
- Any periodic signal could be represented as a series of sines and cosines. Meaning if you take a time waveform and mathematically calculate the vibration frequency along with their amplitudes, we can convert this in to a more familiar frequency format.
- Fortunately for us, the analyzer does it for us!

FFT (Fast Fourier Transform)

- Complex waveform changes to a simple waveform

The waveform is converted to an amplitude/frequency domain



This is called a [spectrum]

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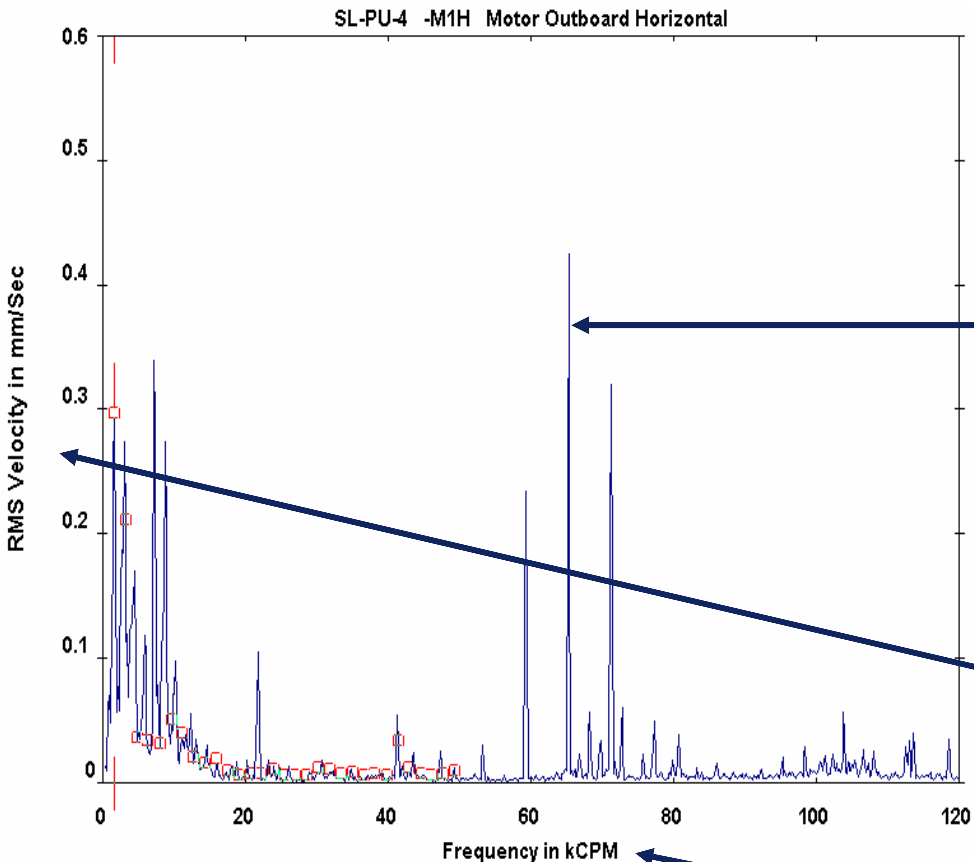
Spectrums

Spectrums



- Before we learn how to diagnose potential faults within a spectrum, we need to understand the units of measurement.
- The vibration data that is converted from the waveform by the FFT process can be seen very clearly
- However there are a few considerations we need to take into account first.
- The amplitude scale and the amplitude units are important
- As well as the frequency scale and units

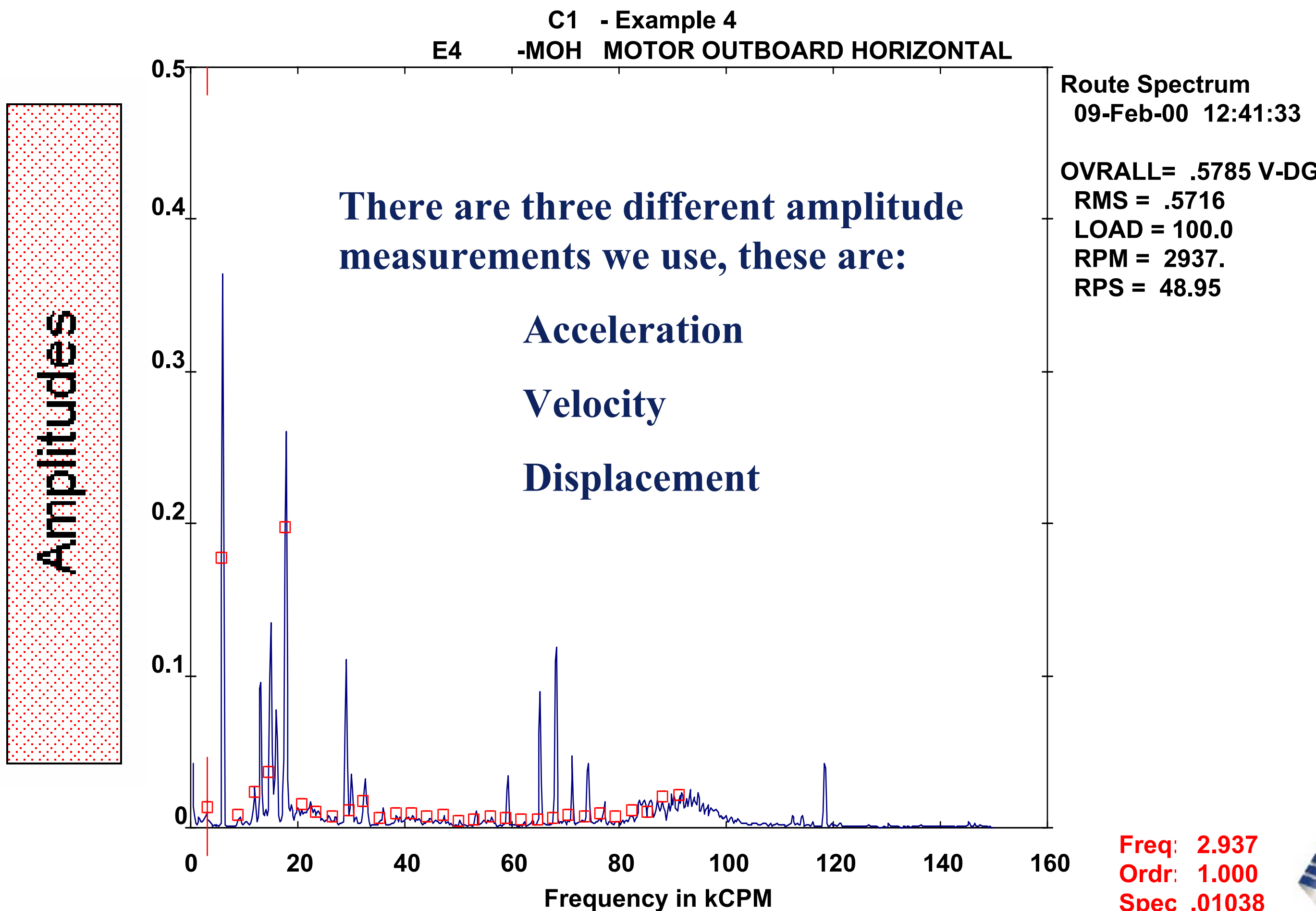
Amplitude Units

There are three different amplitude measurements we use, these are:

Acceleration

Velocity

Displacement



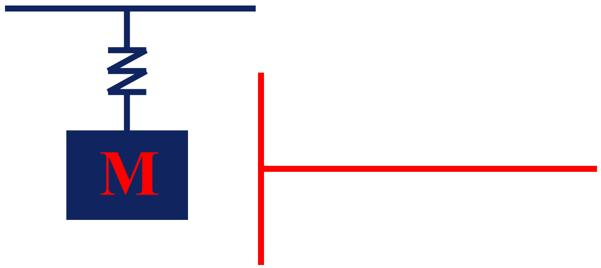
Amplitude Units

- **Acceleration**
  - Measures the change in velocity over a period of time
- **Velocity**
  - Rate of movement
- **Displacement**
  - Measures total movement in relation to a reference point

- A good way of remembering this is to think of a car:
  - From rest to 60mph is your acceleration (change in velocity over time)
  - Drive at 60mph for x-time (this is your velocity)
  - From start to finish is the total distance traveled (Displacement)

Displacement - Velocity - Acceleration

- The relationship between Displacement / Velocity and Acceleration can be determined by a simple spring mechanism.



- Displacement
  - If we are to plot the actual movement of the weight (M) over time. During one cycle we will determine the displacement

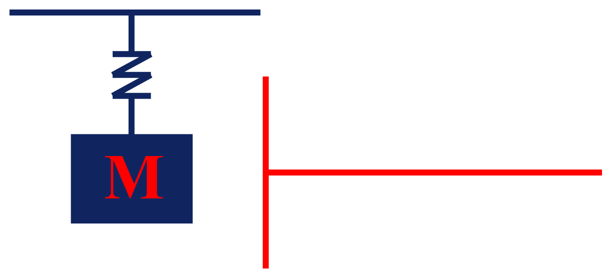
    Displacement

    Click for Animation

  - As the weight reaches the top of its travel this is it's maximum movement (Pk+) as it travels down to the bottom, this is the maximum movement (Pk-) before coming to rest
  - Therefore plotting the Pk-Pk value

Displacement - Velocity - Acceleration

- Using the same mechanism as used to display displacement, velocity can also be determined



- Velocity
  - If we are to plot the velocity movement of the weight (M) over time. During one cycle we will determine the relationship between velocity and displacement

    Velocity

    Click for Animation

  - As the weight reaches the top of its travel this is it's minimum velocity as it travels down to the start position it is now at maximum velocity. Upon reaching the bottom it will now be at minimum velocity again.
  - Therefore Velocity leads displacement by 90 degrees

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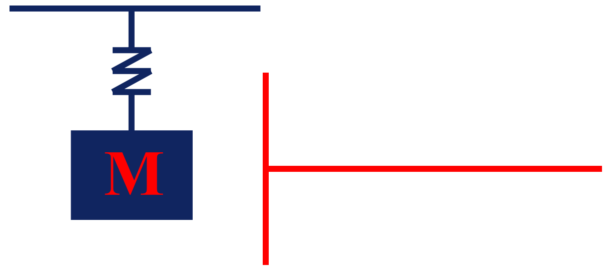
Displacement - Velocity - Acceleration

- Using the same mechanism as used to display displacement and velocity. Acceleration can also be determined



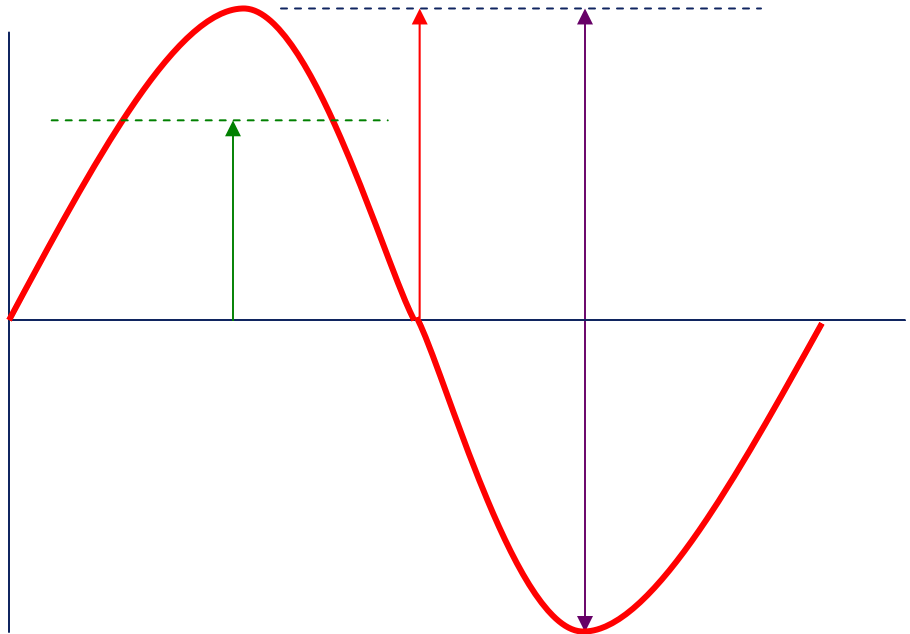
- Acceleration
  - If we are to plot the rate of acceleration over time. During one cycle we will determine the relationship between velocity, displacement and acceleration

Acceleration

Click for Animation

  - As the weight reaches the top of its travel this is it's maximum acceleration (Pk-) as acceleration opposes displacement. Upon reaching the bottom it will now be at minimum acceleration again (Pk+).
  - Therefore acceleration leads velocity by 90 degrees and displacement by 180 degrees

Amplitude Units



- **Acceleration - G-s**
- Value from the base line to the peak amplitude
- Looks a force generated in our machine (High frequency domain)
- **Velocity RMS - MM/Sec**
- RMS - root mean square, appears at 0.707 the value of the amplitude
- Gives a good overall picture, of the vibration in our machine
- **Displacement - microns**
- Total movement, value is from Peak to Peak
- Ignores all high frequencies and looks at the low frequency

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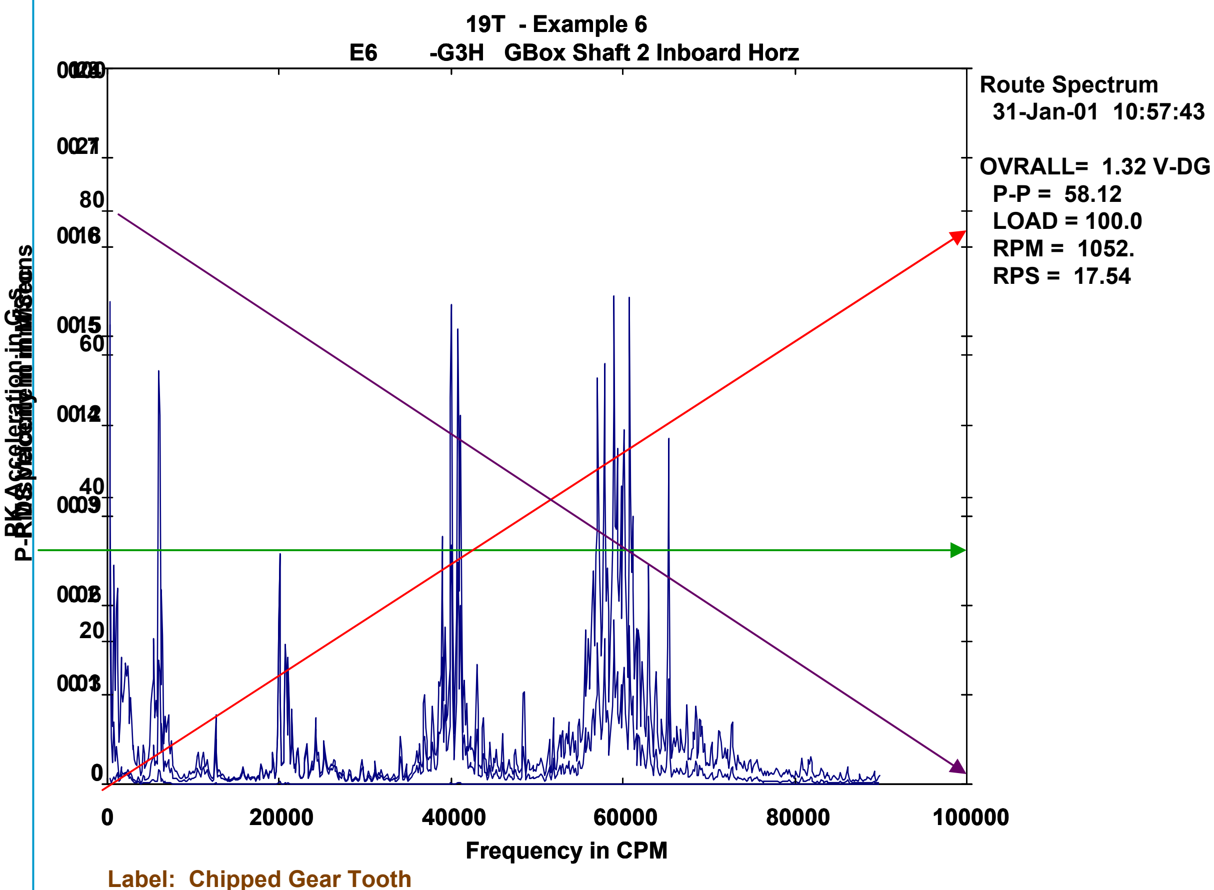
What Effect Do These Have In Our Spectrum



- Velocity RMS
- Good overall value
- Acceleration G-s
- Accentuates the high frequencies (good for Bearings)
- Displacement - microns
- Accentuates the low frequencies

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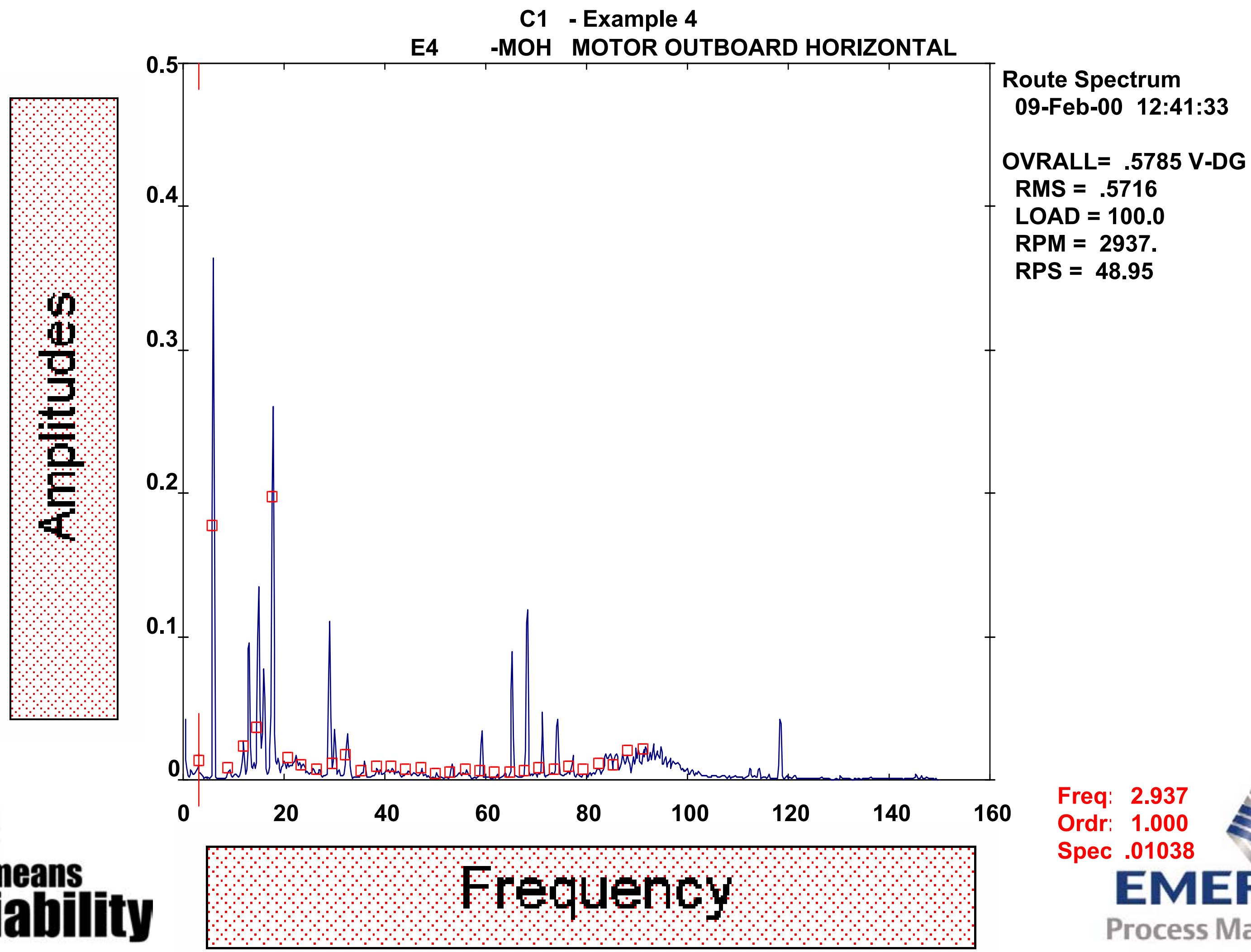
Energy in the Spectrum



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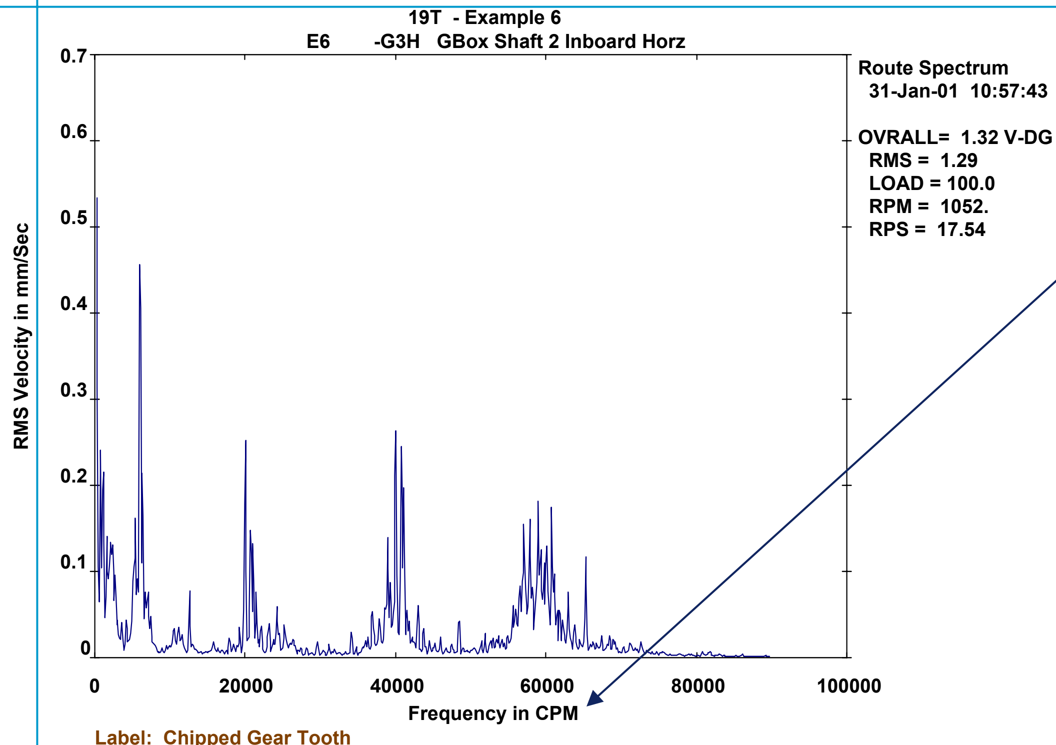
Frequency Units



- There are three different units we can use, these are:
- 1) CPM (cycles per minute)
- 2) Orders (NxRPM, is integer of 1)
- 3) Hz (cycles per second)
- All three are related to each other, and have no direct effect on the spectrum peaks.

- If a motor Runs at 1500RPM
- 1 RPM = 1 CPM ∴ 1500RPM = 1500CPM or 1 Order (1x1500)
- 1500CPM ÷ 60 (minutes to seconds) = 25 Hz (CPS)
- All interchangeable to users preference.

Non- Synchronous Energy

Synchronous Energy

Sub-Synchronous Energy

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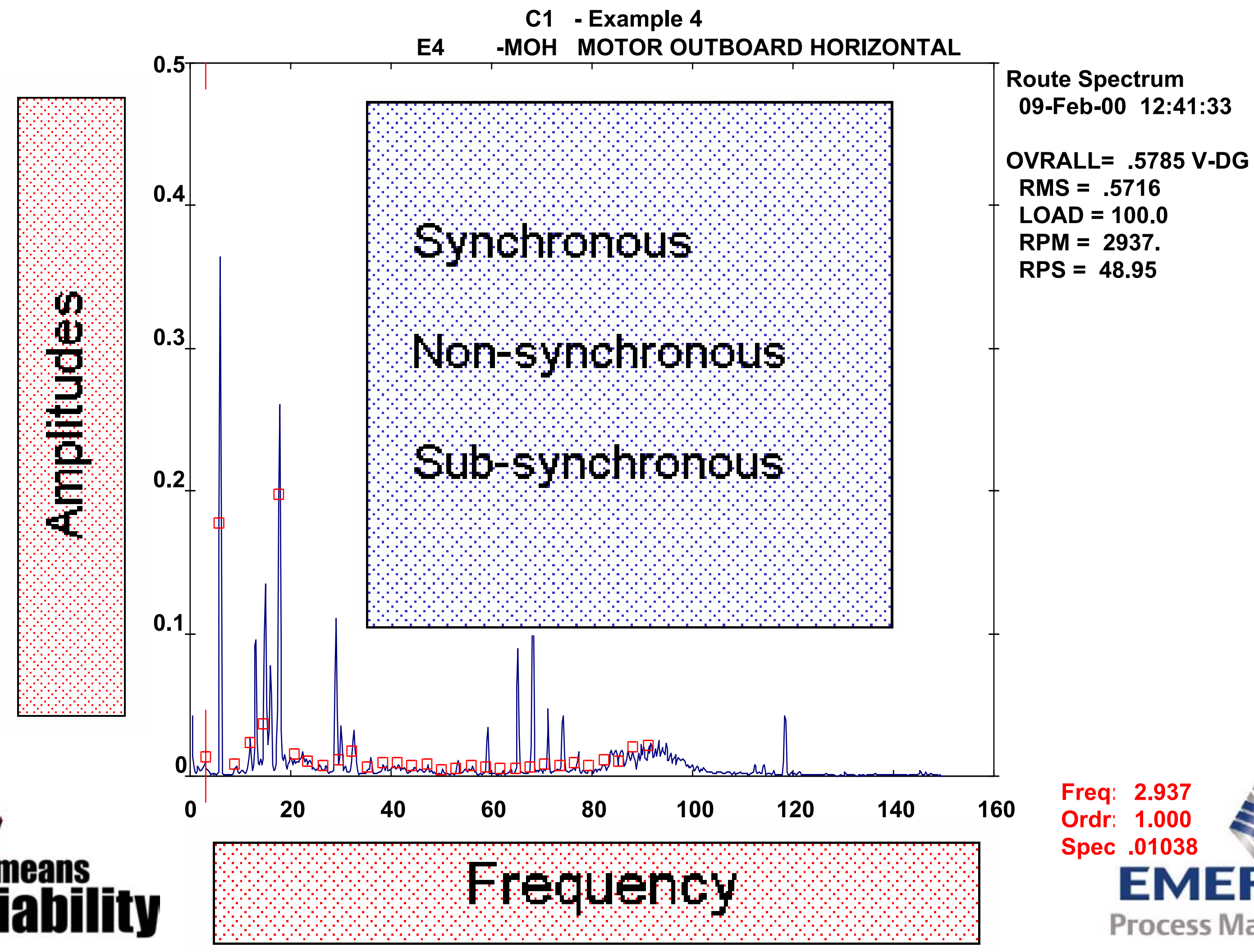
Energy in the Spectrum



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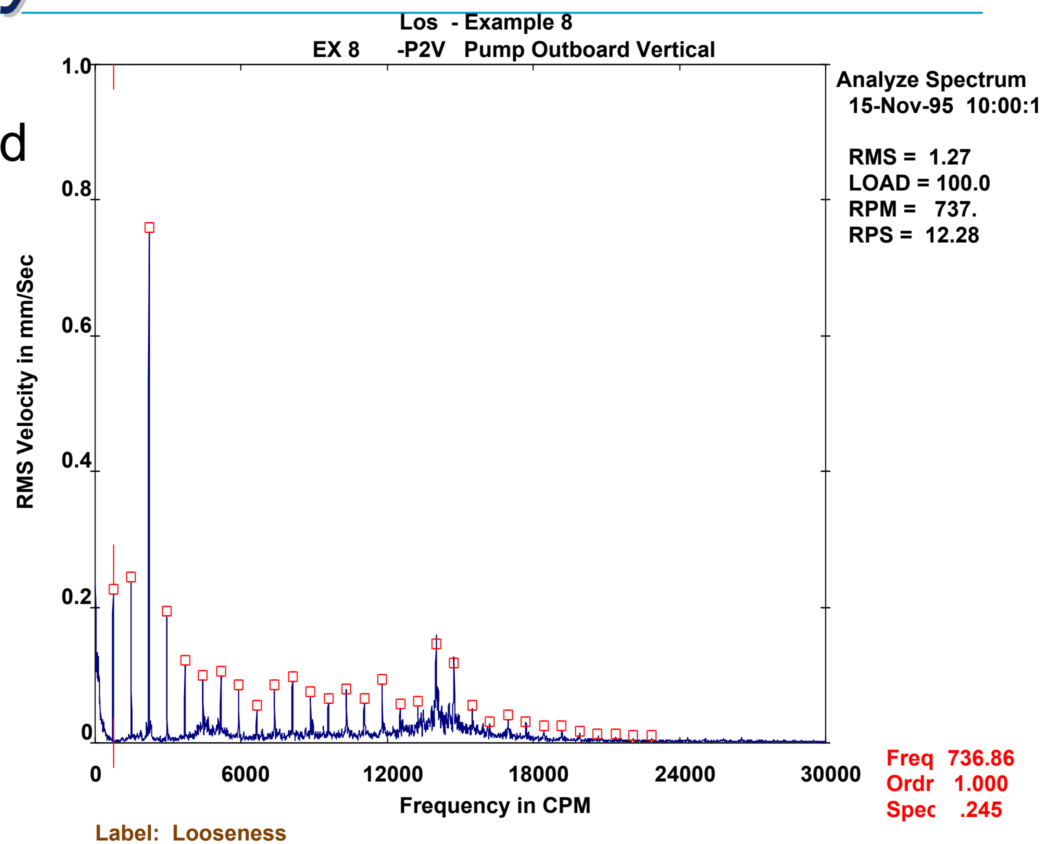
Synchronous Energy

- Synchronous energy - related to turning speed.
- We can see from the spectrum that the first peak is at 1 Orders (which means it is 1 x turning speed)
- All the other peaks are harmonics off, which means they are related to the first peak



Examples of synchronous energy:

1) Imbalance 2) Misalignment 3) Gearmesh

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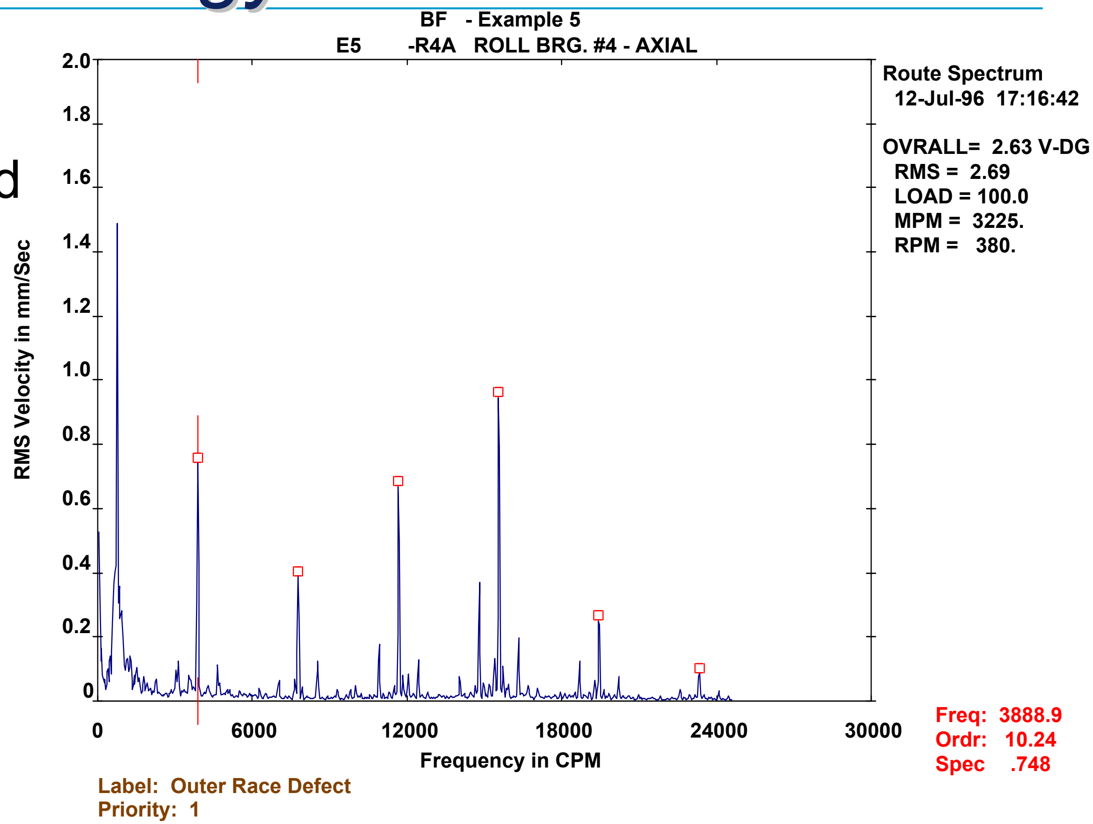
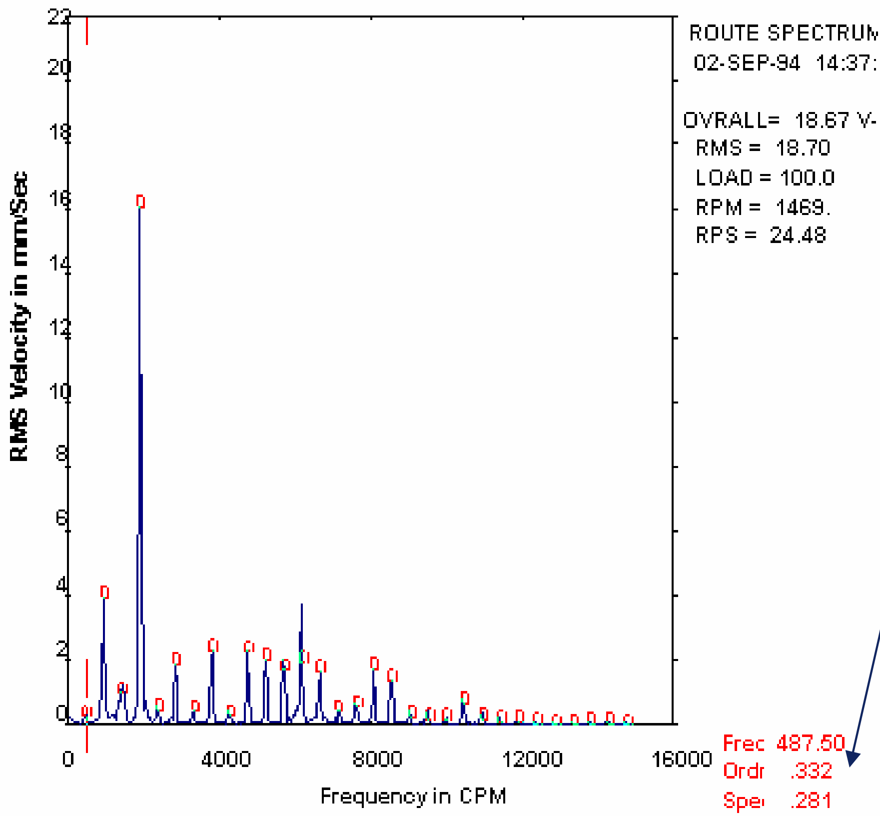
Non-Synchronous Energy

- Non-synchronous energy - not related to turning speed
- We can see from the spectrum that the first peak is at 10.24 Orders. This is not related to turning speed.



- Examples of non-synchronous energy:
- Bearings Multiples of belt frequency Other Machine Speeds

Sub-Synchronous Energy



- Sub-synchronous energy - Less than turning speed
- The spectrum shows the first impacting peak below 1 Order. This is sub-synchronous energy
- Examples of sub-synchronous energy are:
- Belt Frequencies
- Other Machine Speeds
- Cage Frequencies

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Lines of Resolution

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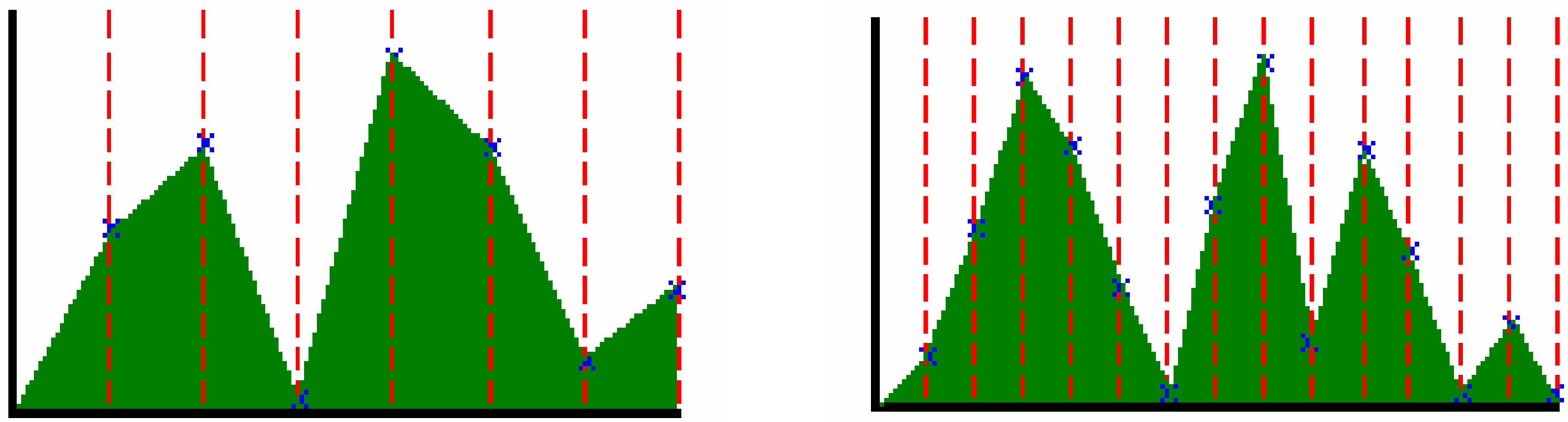
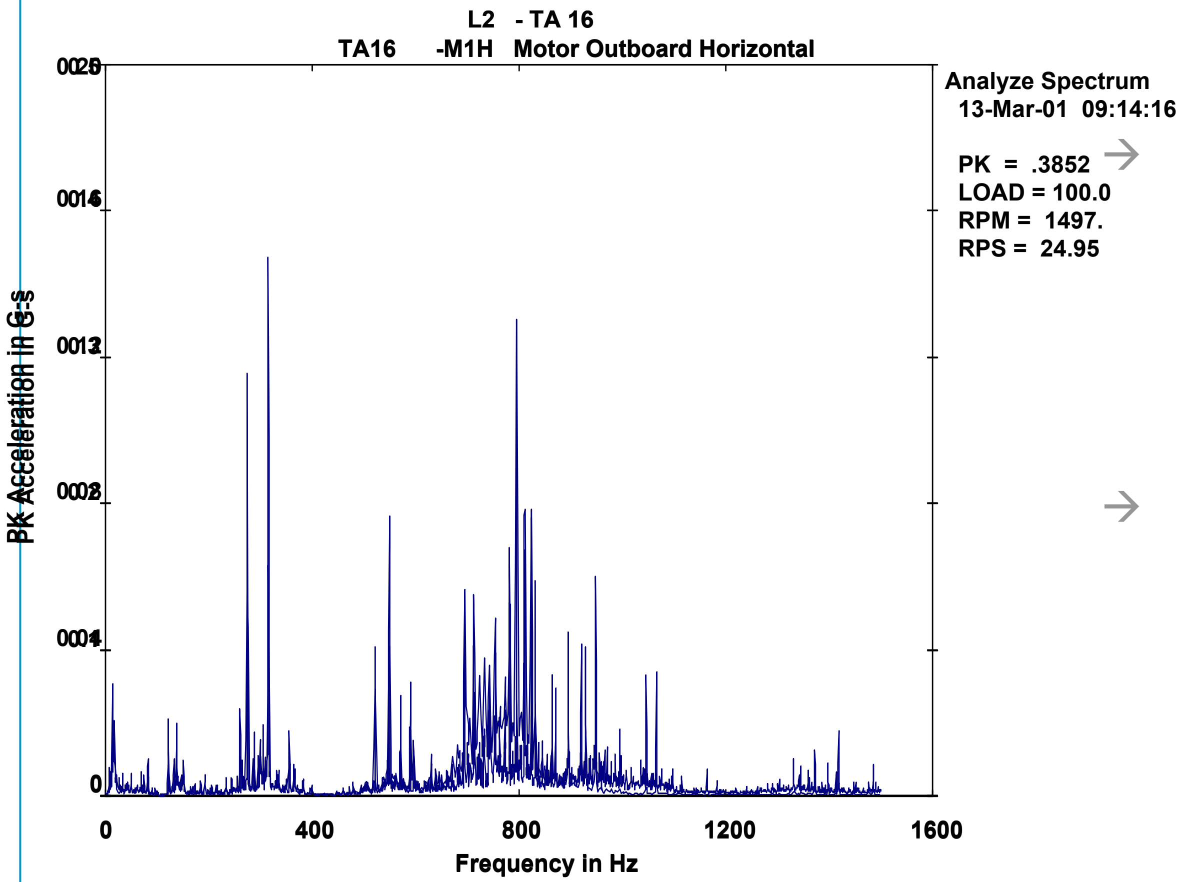
Lines of Resolution

- Lines of Resolution (LOR) determine how clear the peaks(data) are defined within our spectrum.
- The more lines we have over the same F-max (Maximum frequency scale). The more accurate our data will be
- Example.
  - The diagram below shows data that has been collected using 400 LOR. Notice how the top of the peaks are capped. When the LOR are increased the data becomes more accurate.



Lines of Resolution



- The spectrum shown displays data at 800 L.O.R with an Fmax of 1600 Hz
- The second spectrum displays the same data but with 3200 L.O.R over the same Fmax

Lines of Resolution

- There are 8 LOR settings we can choose from on the analyzer. These start at 100 Lines and go up to 6400 Lines.

- The average number of LOR is around 800 Lines for a typical motor/pump set up

To change the LOR settings we need to alter our parameter set. This is done in the Database Setup program

Remember. If you double your lines of resolution you double your data collection time.

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Review of Objectives

- To understand:
  - What vibration is.
  - How it travels.
  - Relationship between a waveform and a spectrum.
  - Different units of measurement
  - Three different forms of energy
  - Understanding of Lines of Resolution
- **Ask questions if your not sure?**

Analysis Techniques

Measurement Point Identification

Locating Turning Speed

Measurement Points

Identifying Measurement Points

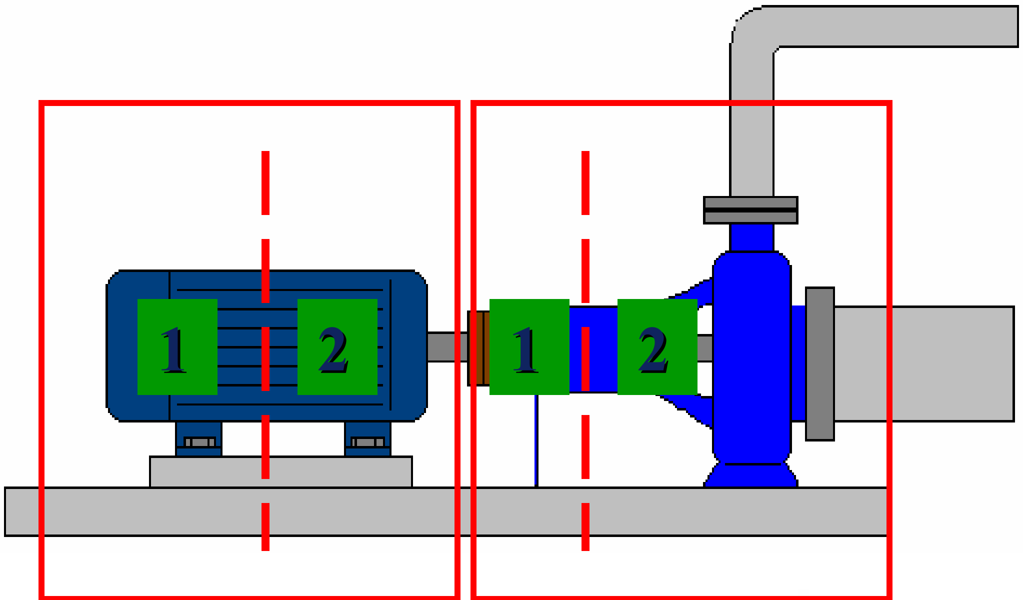
- What is a Measurement Point?
- A measurement point is simply:
  - A reference to a particular place/plain on the machine to be monitored
- Why do we need them?
  - This helps the analyst know what the machine is and where the data was collected.
  - Also helps to ensure the data is collected at the same point on the machine every time to help with repeatability of data
- A measurement point is determined by three characters.
- Each character refers to a particular place on the machine being monitored
  - E.g. M1H is a typical measurement point

Identifying Measurement Points

- What does M1H tell us about the point where the data was collected?
- The first letter refers to the *'Type of Machine'* being monitored
  - M = Motor P = Pump G = Gearbox
- The second letter refers to the *'Measurement Plain'* for the data to be collected
  - H = Horizontal V = Vertical A = Axial P = Peakvue
- ∴ We know the data was collected on a 'motor' in the 'horizontal' direction

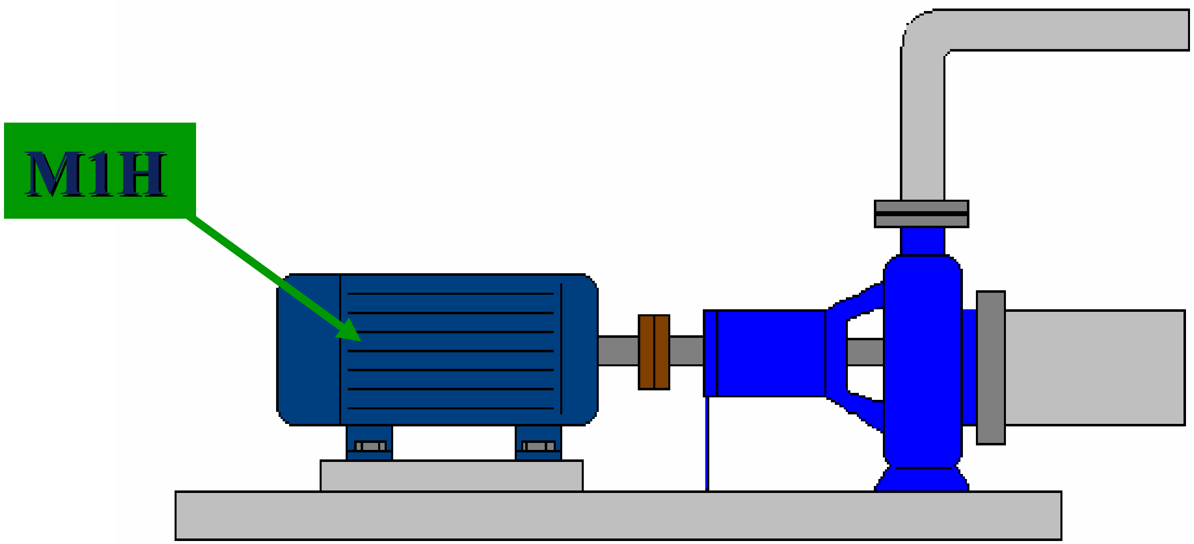
Identifying Measurement Points

- The number refers to *'which side of the machine'* the data was collected
  - Numbers are either 'Inboard'(Drive End) or 'Outboard'(Non-drive End)
- The diagram shows the numbering sequence for a motor/pump unit
  - Taking each machine as a separate unit
- Each shaft is split into two and numbered in numerical order
  - starting at the drive unit (non-drive end) through to the driven unit (non-drive end)



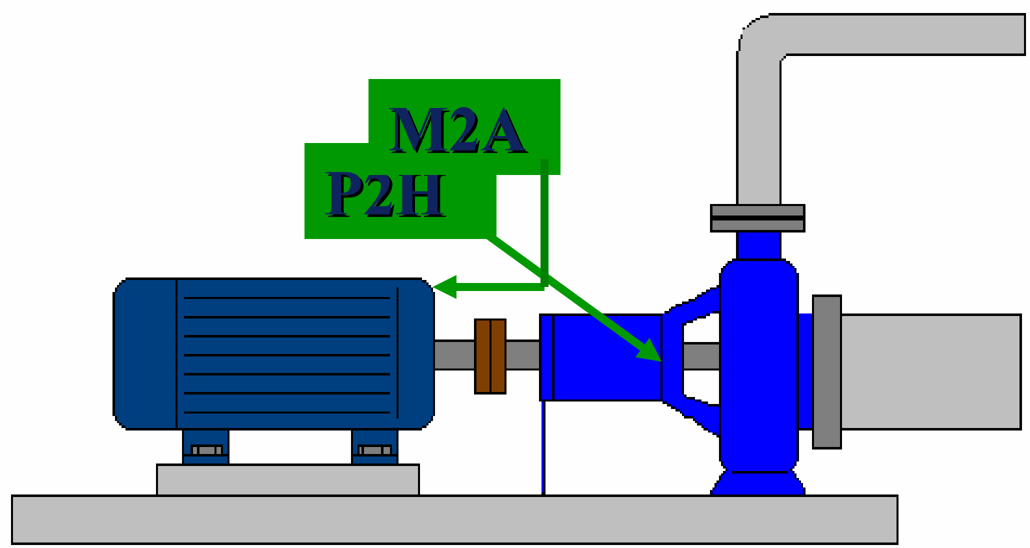
Identifying Measurement Points

- What does the measurement point ‘M1H’ mean?
  - M = Motor 1 = Outboard H = Horizontal
- Where would the point M1H be on the diagram below?



Identifying Measurement Points

- Using the same motor pump unit as previous,
  - Where would the measurement P2H be taken?
  - What does P2H translate to?
- Question 2
  - Where would the measurement point M2A be taken?
  - What does M2A translate to?



Pump Outboard Axial
Motor Inboard Horizontal

Identifying Measurement Points

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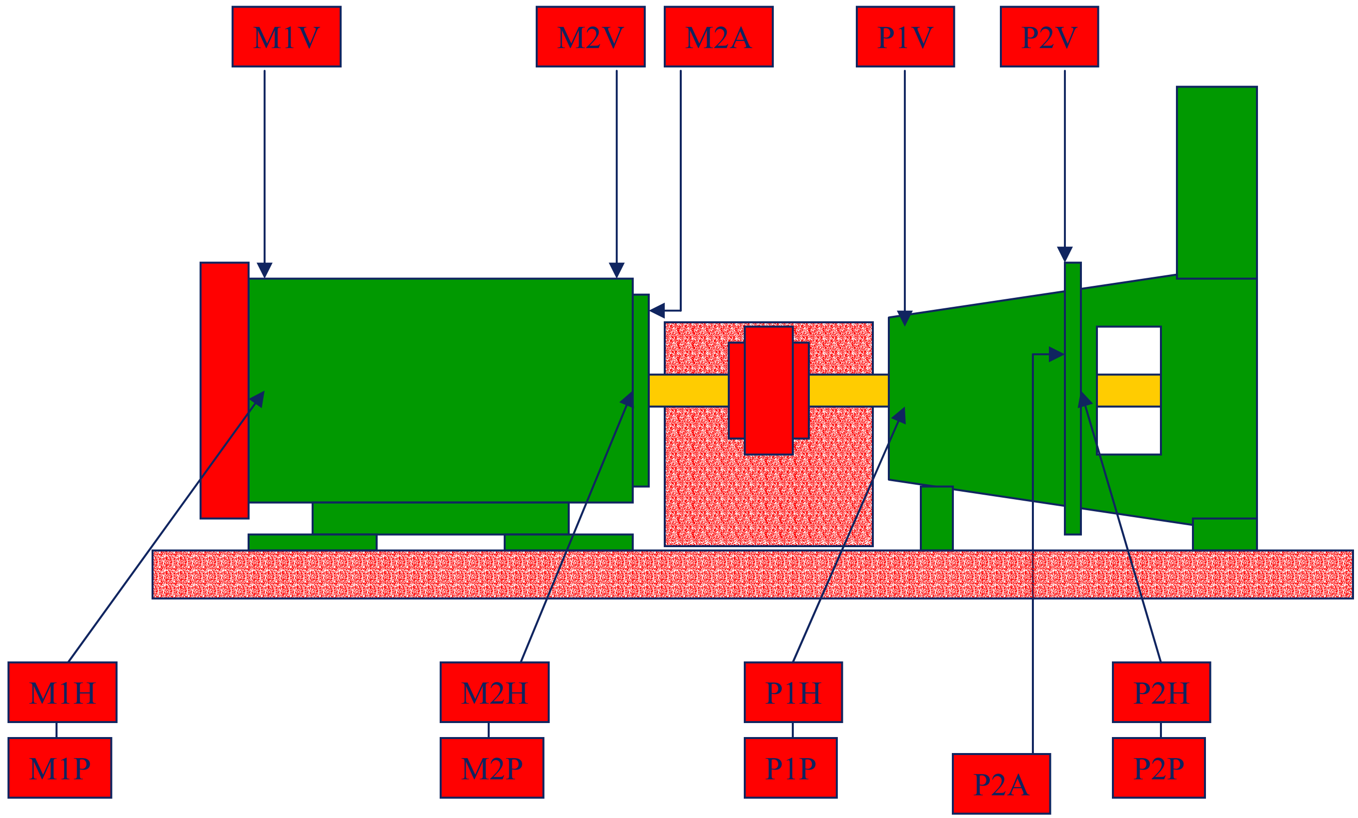
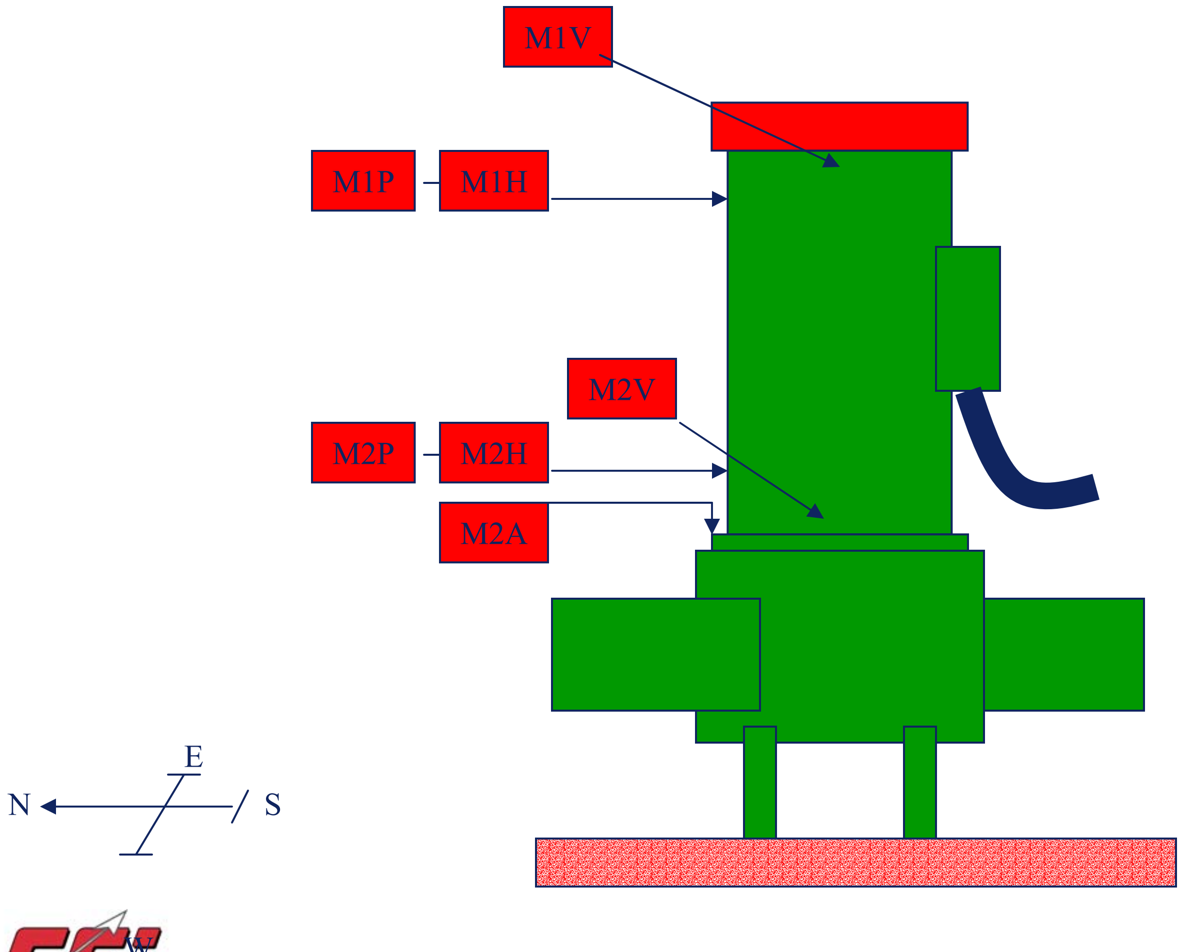
Point Identification Horizontal Mount Pump



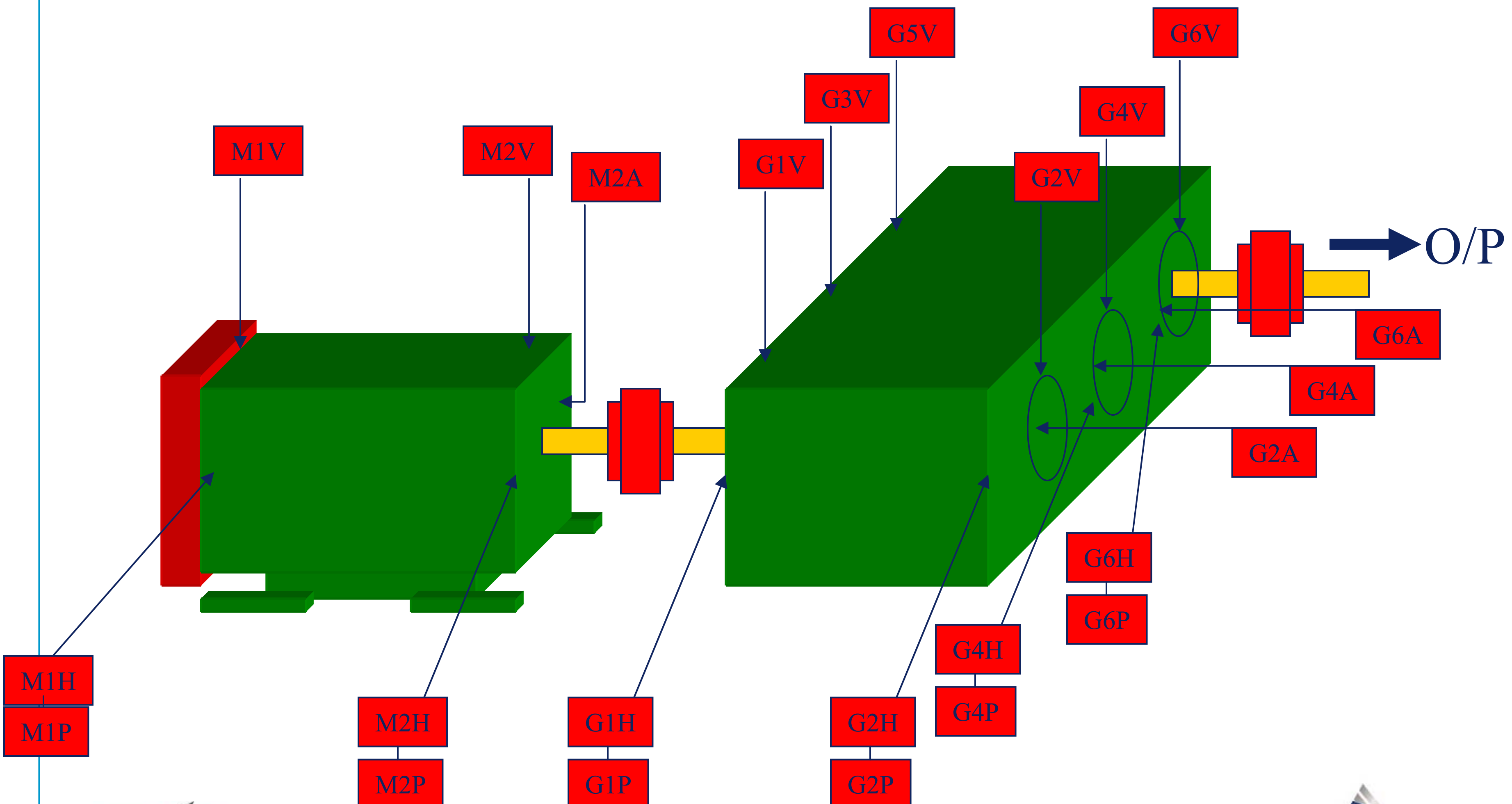
P2A to be taken on first available flange on the pump casing

Point Identification Flange Mounted Extended Shaft



No readings will be taken on the bowl as there is no direct transmission path.

Gearbox Point Identification



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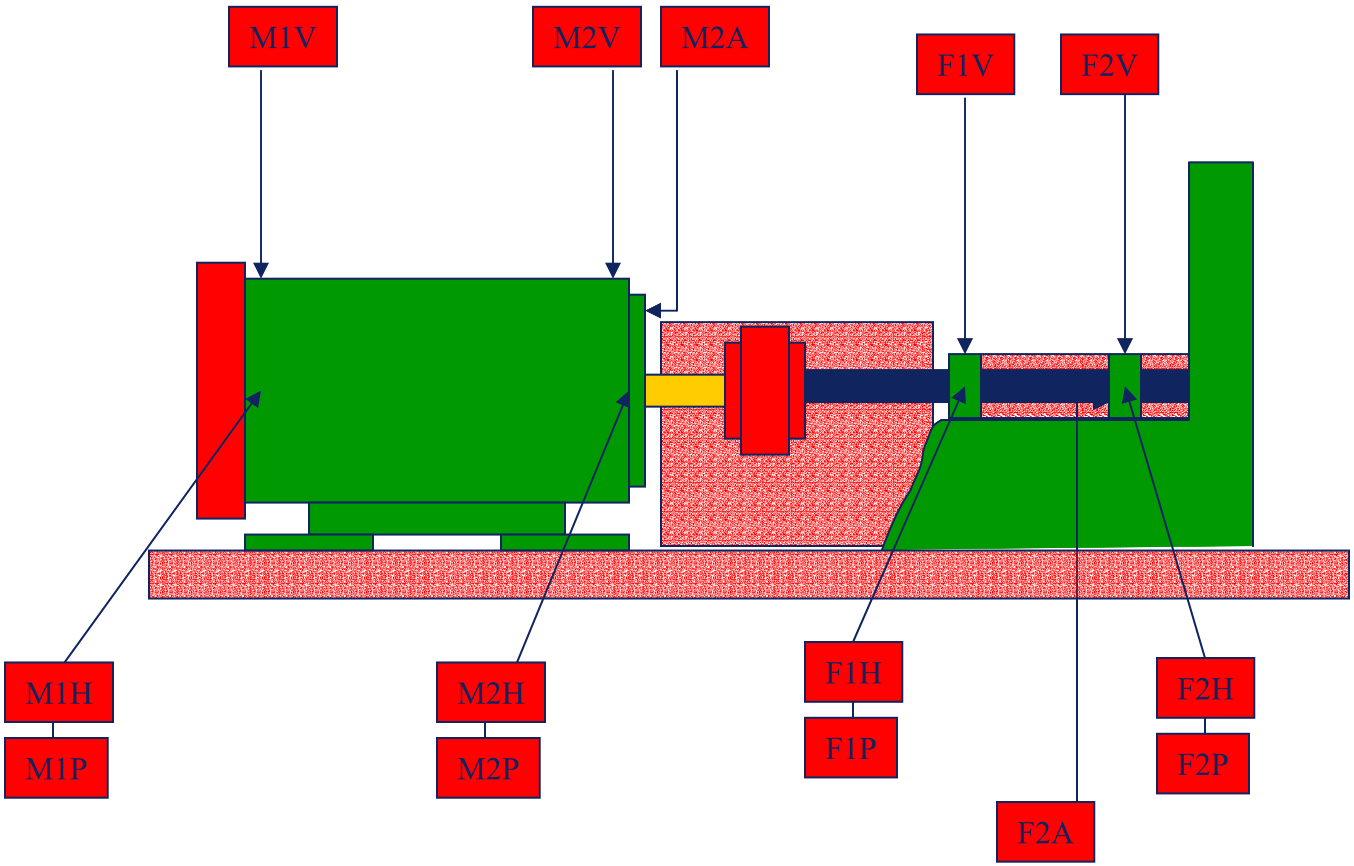
Point Identification Horizontal Mount Fan



F2A to be taken on first available flange on the fan bearing

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Locating Turning Speed

Turning Speed

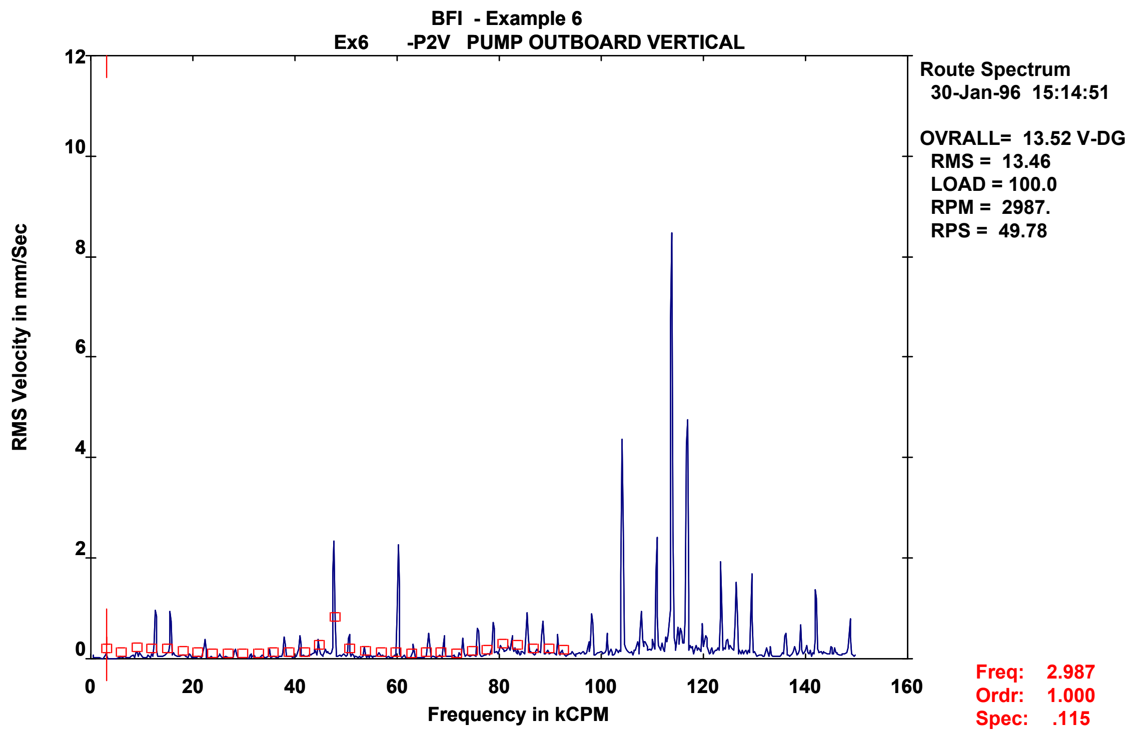
- When performing analysis on spectrums and waveforms, it is of utmost importance to set the turning speed (running speed) correctly

- When the turning speed has been located, the software will re-calculate all the frequencies to this exact speed.

- Once the turning speed has been set, it is now possible to determine what is Synchronous/Non-synchronous and Sub-synchronous energy.

Turning Speed

- The spectrum is showing numerous impacts appearing at different frequencies.
- By locating the turning speed, it is very clear that the impacts are Non-synchronous



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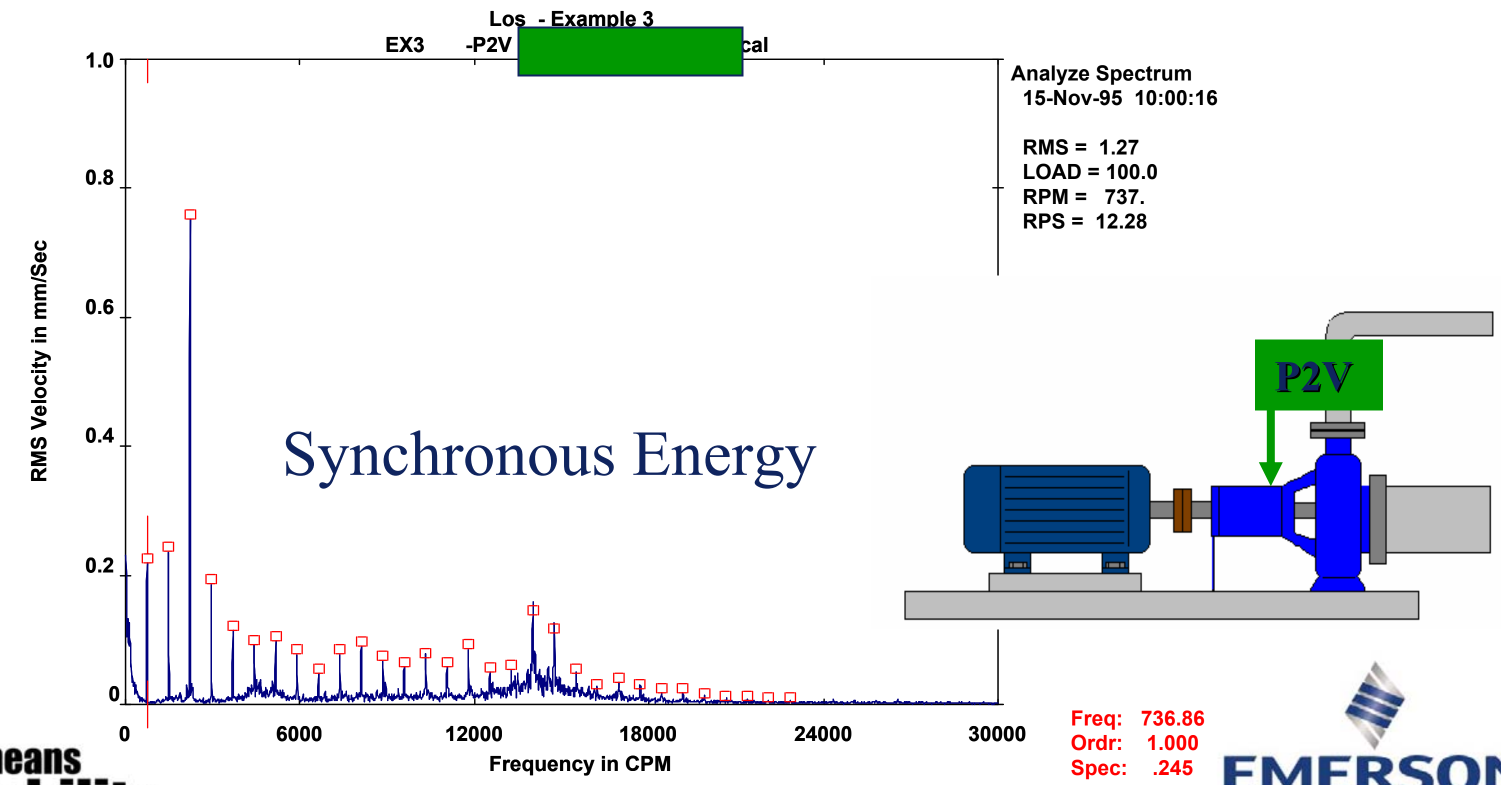
Analysis Techniques Test

- Have a look at the spectrum below.
  - Where was the data taken?
- When the turning speed has been located
  - What type of energy is present?



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Review of Terminology!

- **Acceleration (G-s)**
  - Change in velocity over time
  - Peak Value of the Waveform
  - Accentuates high frequencies within the spectrum
- **Displacement (Microns)**
  - Total amount of movement
  - Peak to Peak value in the waveform
  - Accentuates low frequencies ignores high frequencies
- **Velocity (RMS)**
  - Rate of movement
  - RMS value within the waveform
  - Looks at both high and low frequencies within the spectrum
- **Orders**
  - integer of shaft speed
- **CPM**
  - Cycles per Minute (1CPM = 1RPM)
- **Hz**
  - Cycles per Second (1CPM / 60)

Review of Terminology!

- **Synchronous Energy**
  - Frequencies which are directly related to the shaft turning speed
- **Non-Synchronous Energy**
  - Frequencies which are above the shaft turning speed but are not related to it
- **Sub-Synchronous Energy**
  - Frequencies which appear below the shaft turning speed
- **Measurement Point**
  - A specific place on the machine where data is to be collected
- **Lines of Resolution (LOR)**
  - Number of divisions per spectrum for data collection

Basic Vibration Analysis

Fault Diagnostics

Introduction

- Each type of machine *fault* or *defect* reveals a specific vibration *characteristic* in the spectrum and time waveform domain that distinguish that fault from another.
- Simply by gaining a basic knowledge of these patterns and applying a few *rules of thumb* we can start to analyse machine vibration and prevent machine failure.
- This section concentrates the characteristics / patterns and rules that apply to diagnose machine faults such as:
  - Imbalance Misalignment Looseness Gears
  - Bearings Belts Electrical Resonance

Imbalance

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What is Imbalance?

- Who can give me a definition of ‘imbalance’. What is ‘Imbalance’?

- It is simply the result of a **shafts center of mass not rotating at the center of rotation.**

- If the ‘center of mass’ changes (heavy spot) it produces a centrifugal force that forces the rotor to rotate off center and causes and increase in vibration amplitude

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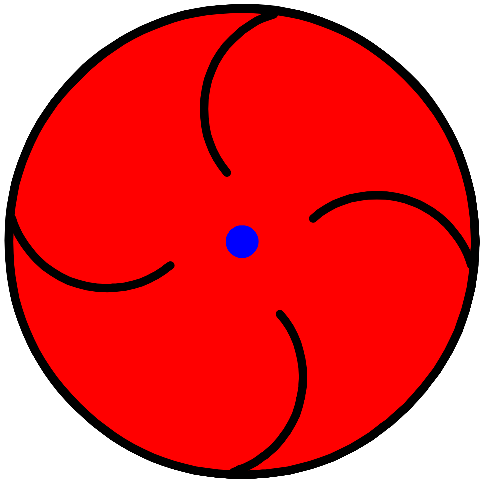
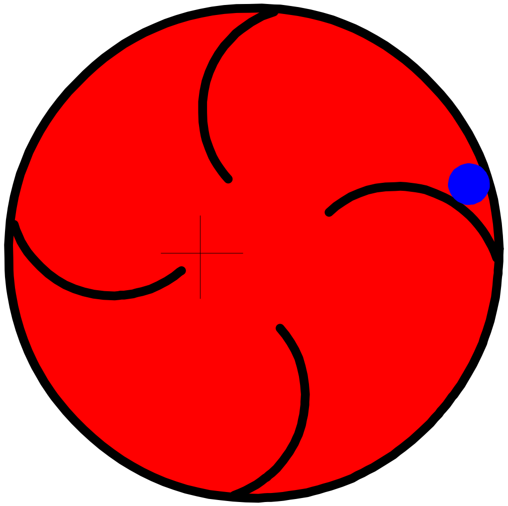
Imbalance

- **System balanced**
  - Centre of mass rotating around the centre of gravity



- **System imbalance**
  - Centre of mass **not** rotating around the centre of gravity



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Characteristics & Causes of Imbalance

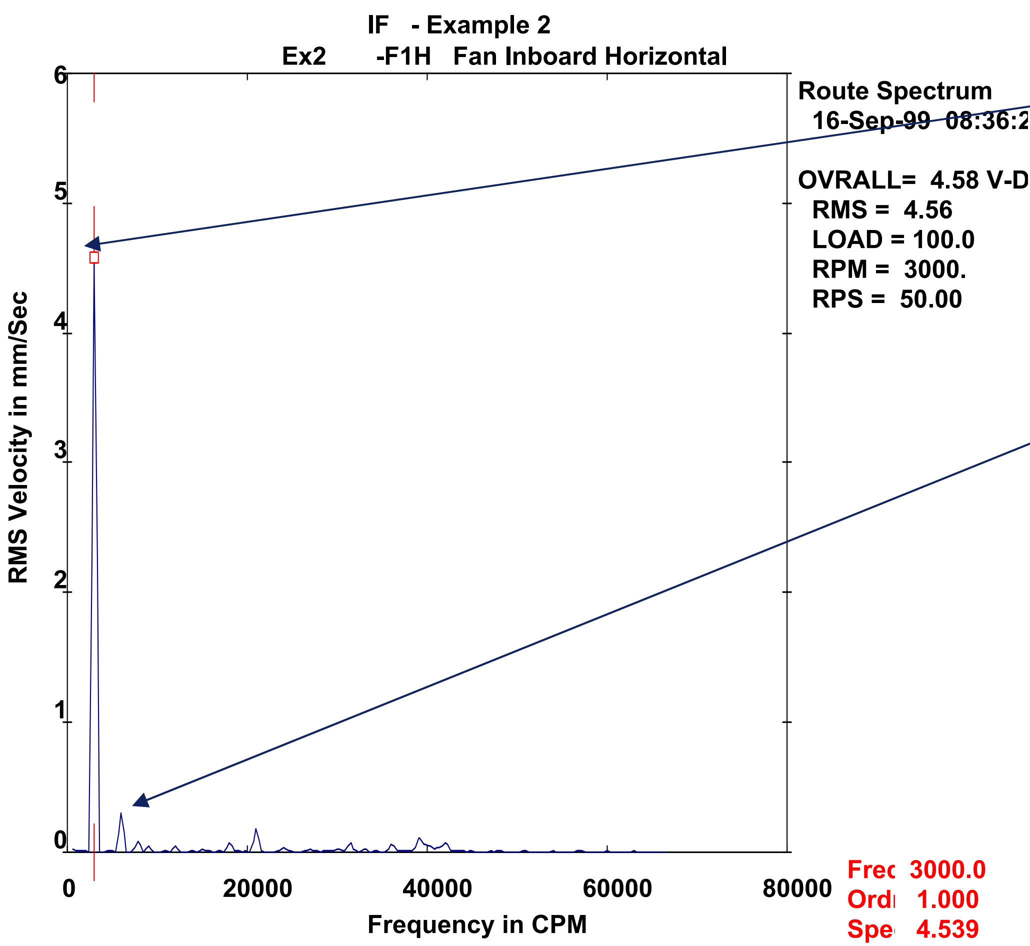
Characteristics

- Periodic simple non-impacting time waveform
- Spectral peak at 1 Order
- Radial in nature
- Very little axial vibration
- Amplitude will increase with speed

Causes

- Build up of material/dirt on blades/impellers (number one cause)
- Wear to parts - blades/impellers
- Improper assembly
- Broken or missing parts

Imbalance in a Spectrum



- High 1 x Ts (turning speed) peak
- Synchronous energy
- 2nd peak is very low (if imbalance is only fault)

Expect to see similar amplitudes between horizontal and vertical plains (usually slightly higher in the horizontal)

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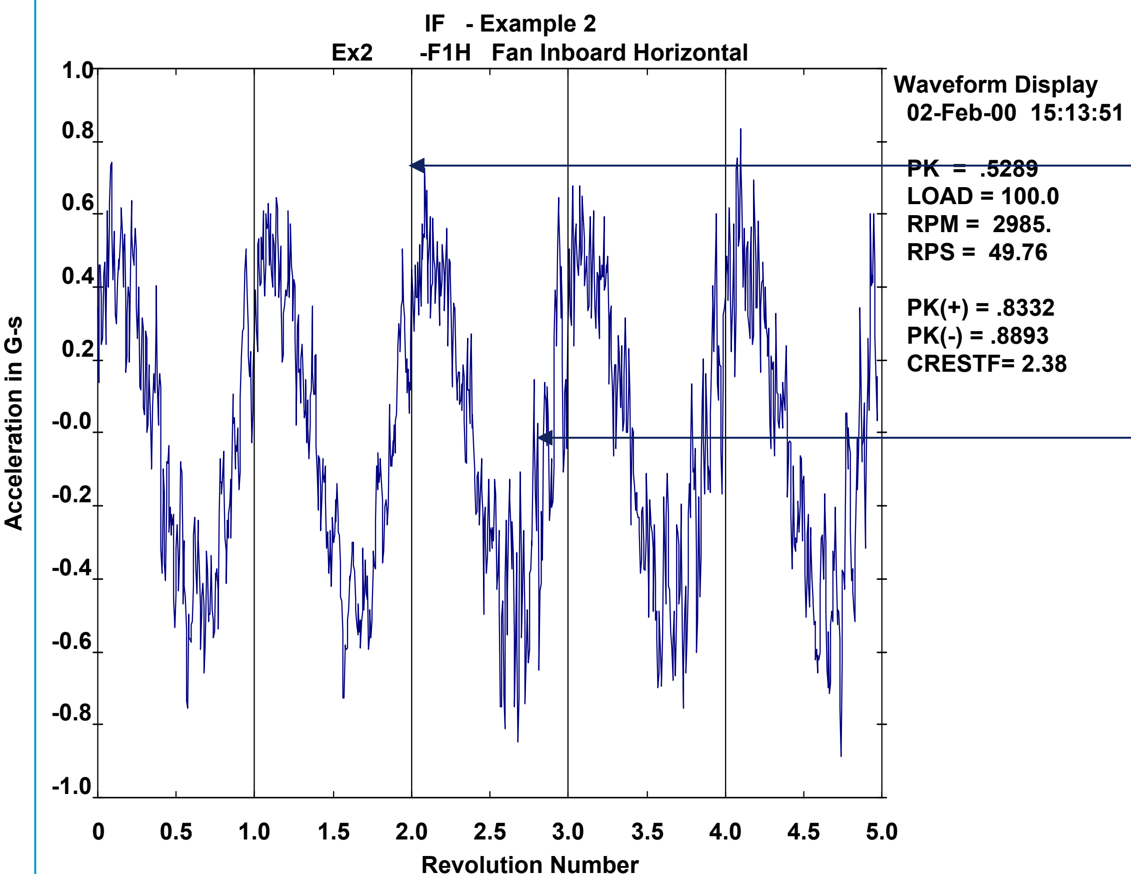
Imbalance in a Waveform



- Imbalance occurs once per revolution
- Sinusoidal time waveform is expected

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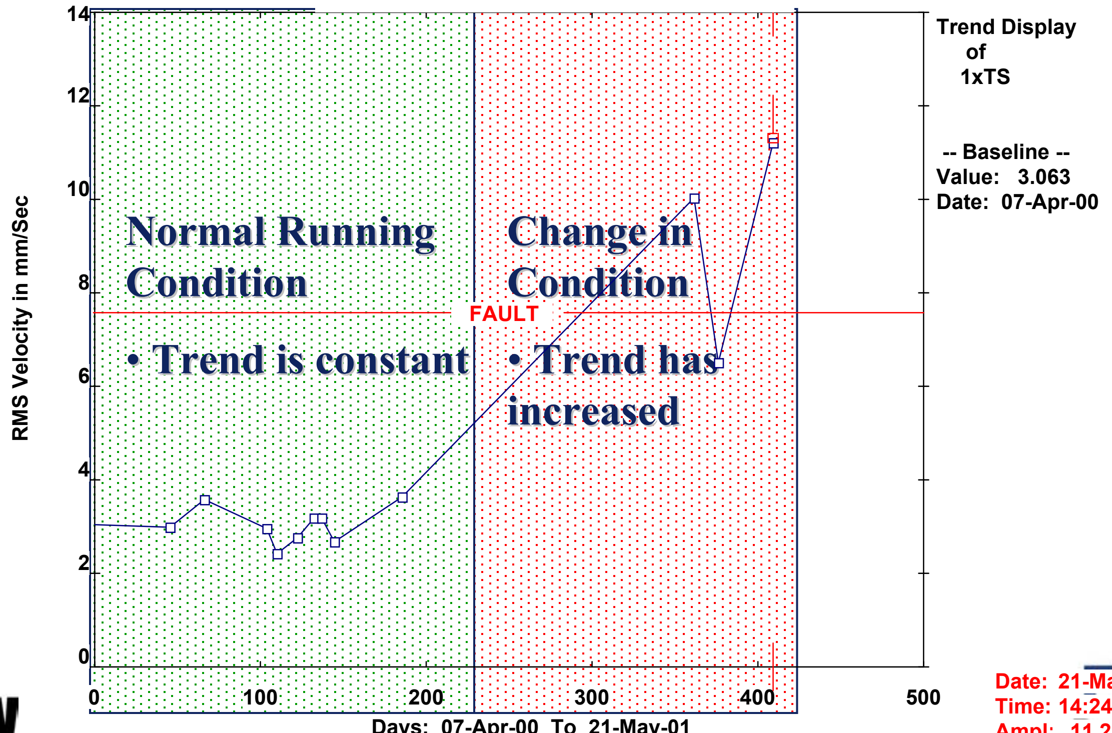
Trendable Data.

- There should always be a peak at 1 x turning speed (1 Order) as nothing can ever truly be balanced.
- Therefore we have to decide what is an imbalance condition and what is normal running conditions
- The best way is to look at the trend data, and determine the 'change' over time



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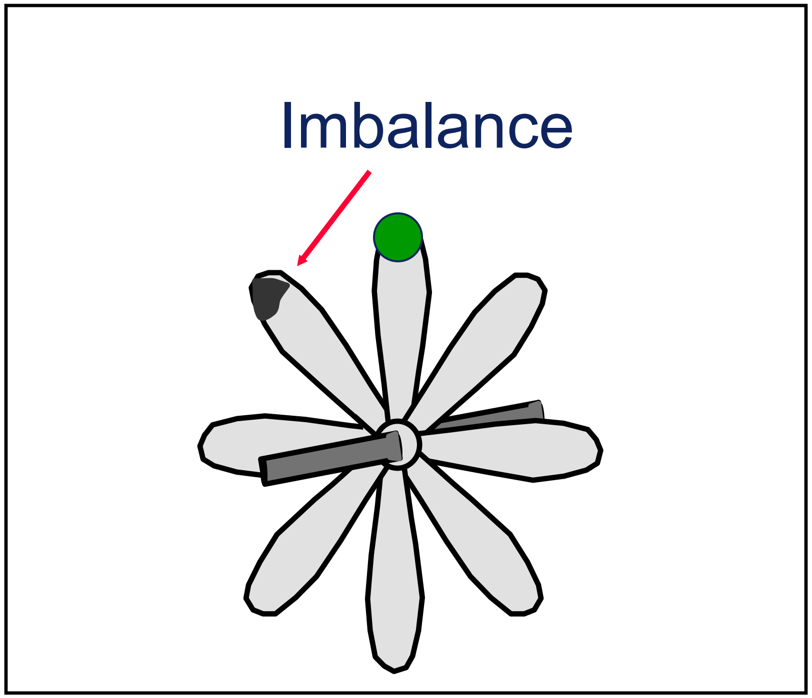
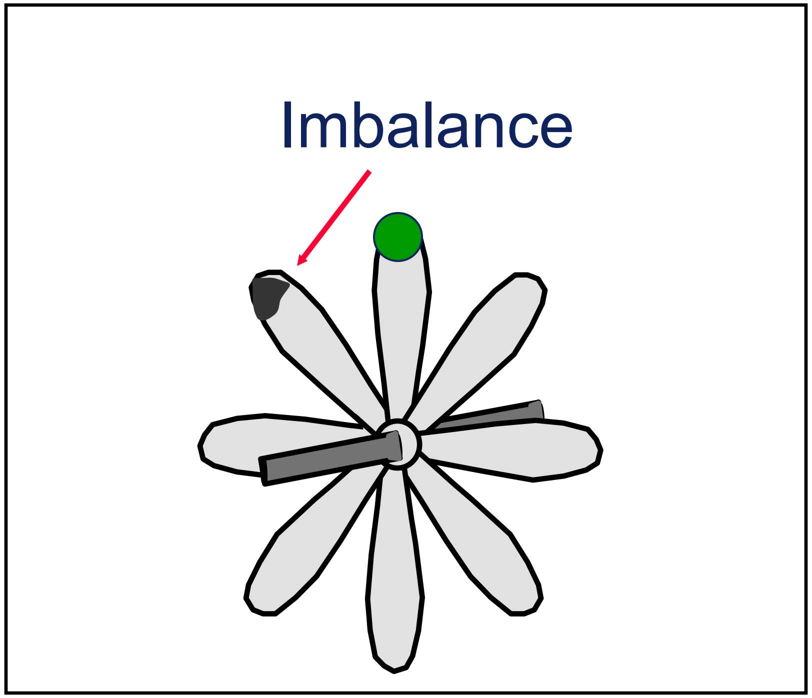
Imbalance Problem?



- An imbalance is being detected on a fan unit (As Shown)
- What would we expect to see in both the spectrum and waveform?
- We would have a high 1xTs peak in the spectrum
- A once per revolution sine wave, in the waveform
- **What would happen to our data if we had another mass added to our fan blade?**

Imbalance Problem



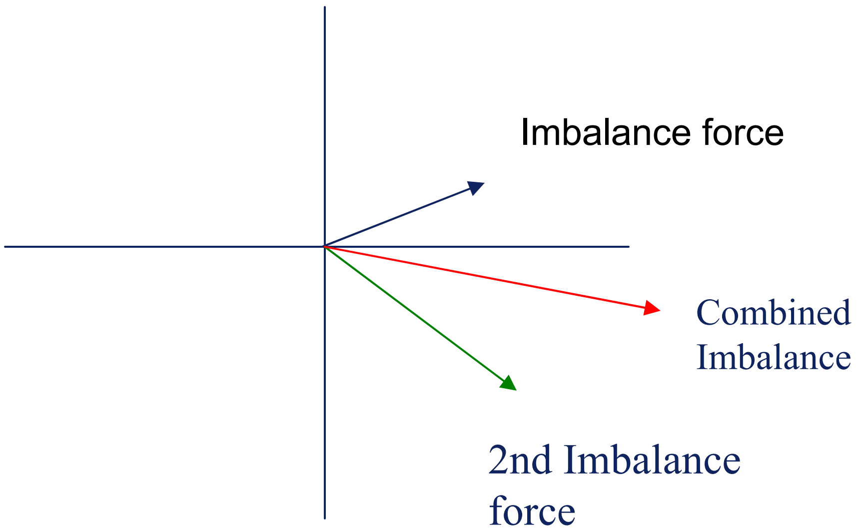
- We would see an increase in amplitude at 1x Ts on our spectrum plot
- Also an increase in our amplitude in our time waveform

Imbalance Vector Plot

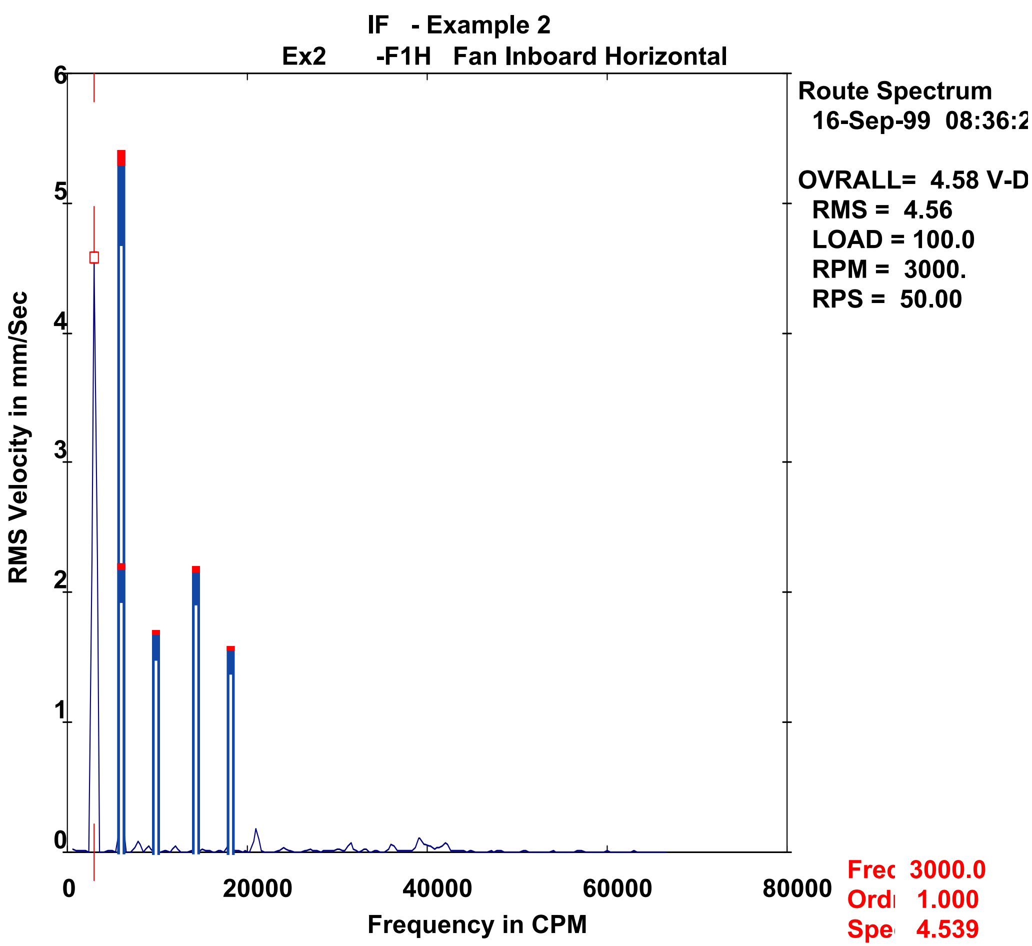
- If we have a single imbalance, the force will be applied at a set amplitude and will be there every revolution.

- If a second mass is added

The resulting force is combined, giving a higher force generated that is still there every revolution



Imbalance in a Spectrum



- If other synchronous peaks appear in the spectrum, such as:
- Misalignment
- Looseness
- You must correct these faults first before attempting to correct the imbalance

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Imbalance Summary

- Imbalance occurs at 1 Order (1 x every shaft revolution)
- The amplitudes will increase with speed - force is greater
- **No high frequency** data is related to an imbalance
- We expect to see this very clearly in the horizontal and vertical direction. Very little axial vibration is expected
- Amplitudes should be **similar** between the horizontal and vertical direction. (If they differ greatly then imbalance is not the problem)
- Both Spectrum and Waveform can alert you to an Imbalance condition
- Look for Trend increases - Indicates something has changed in the machine
- A good way to remember the rules for imbalance is:
  - What goes around must come around

Shaft Misalignment

(Radial/Axial)

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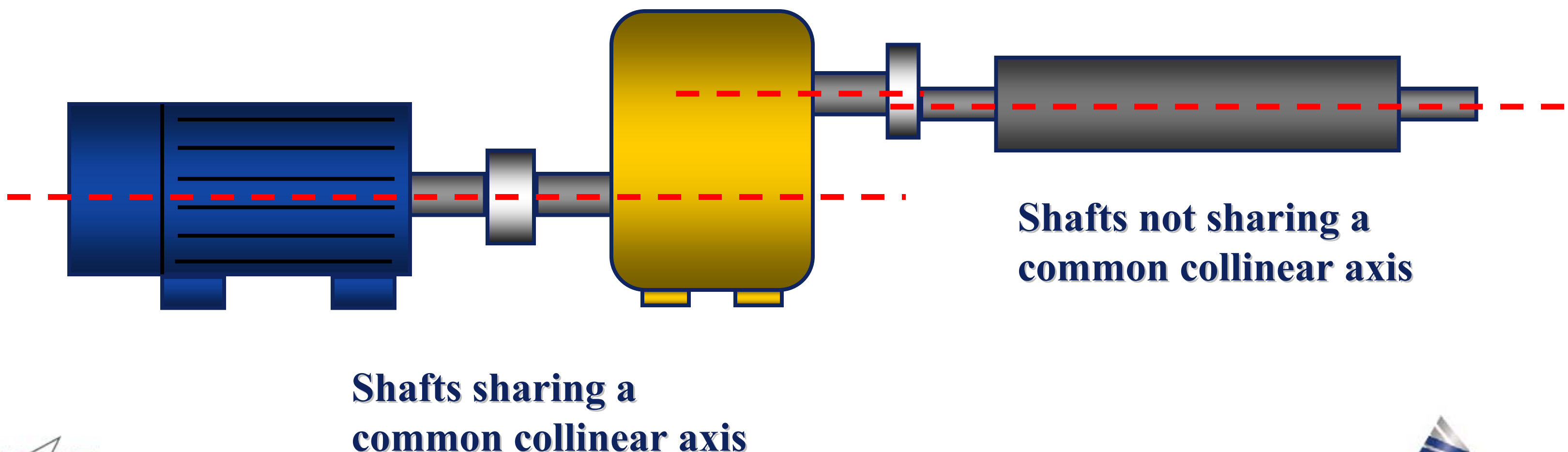
What is Shaft Misalignment?

- Who can give me a definition of shaft misalignment?

- Misalignment is:
  - the deviation of each shafts position from a common collinear axis, during operation
  - Misalignment is not a deviation of coupling faces!

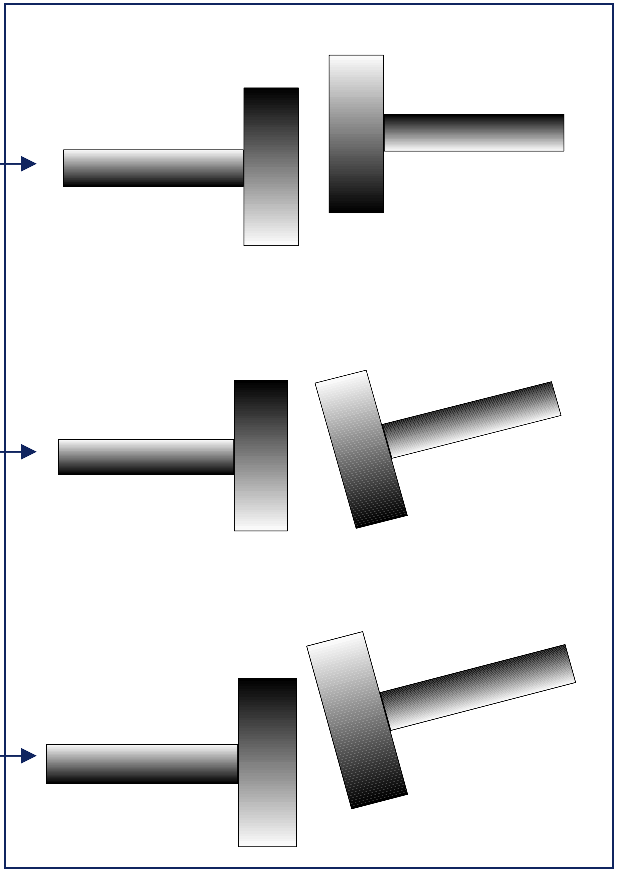


The Three Types of Misalignment

1) Radial - Shaft faces are parallel but the shaft centers are offset

2) Angular - Shaft centers are parallel but the shaft faces aren't

3) Combination of the above



Characteristics of Misalignment

- Misalignment can be present in both Axial and Radial plains
  - Angular Misalignment is seen in the axial direction
  - Radial Misalignment is seen in the radial direction
  - Combination of the two shows up in both plains
- Repeatable periodic time waveform
- Spectrum peaks at 1 or 2 x Ts (turning speed)
- Present on both the Driver and Driven machine (either side of the coupling)

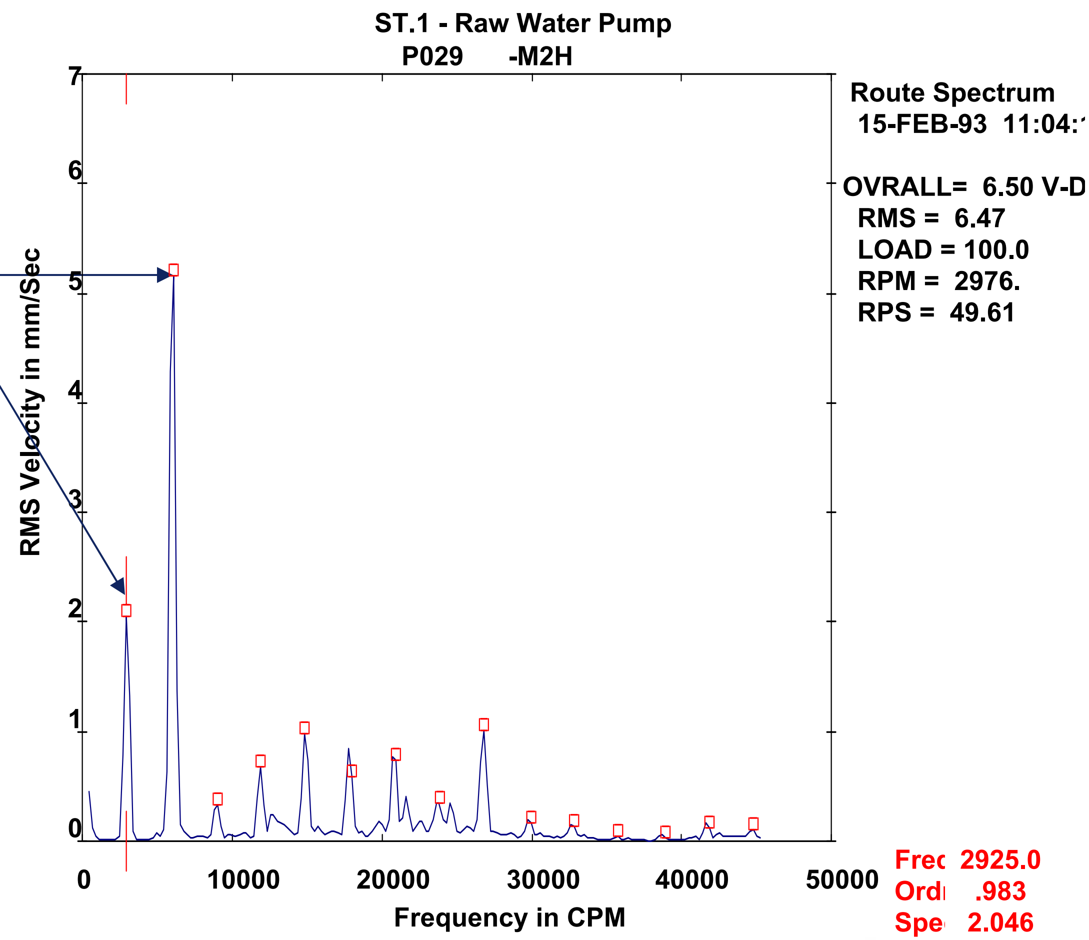
Misalignment in a Spectrum

Misalignment appears at 2 Orders but can also appear at 1 Order

The second peak generally is greater than the first (1 Order). However if there is a slight imbalance a high 1x peak may also be present

Misalignment is synchronous energy.

Velocity is the best unit of measurement as no high frequency data is present



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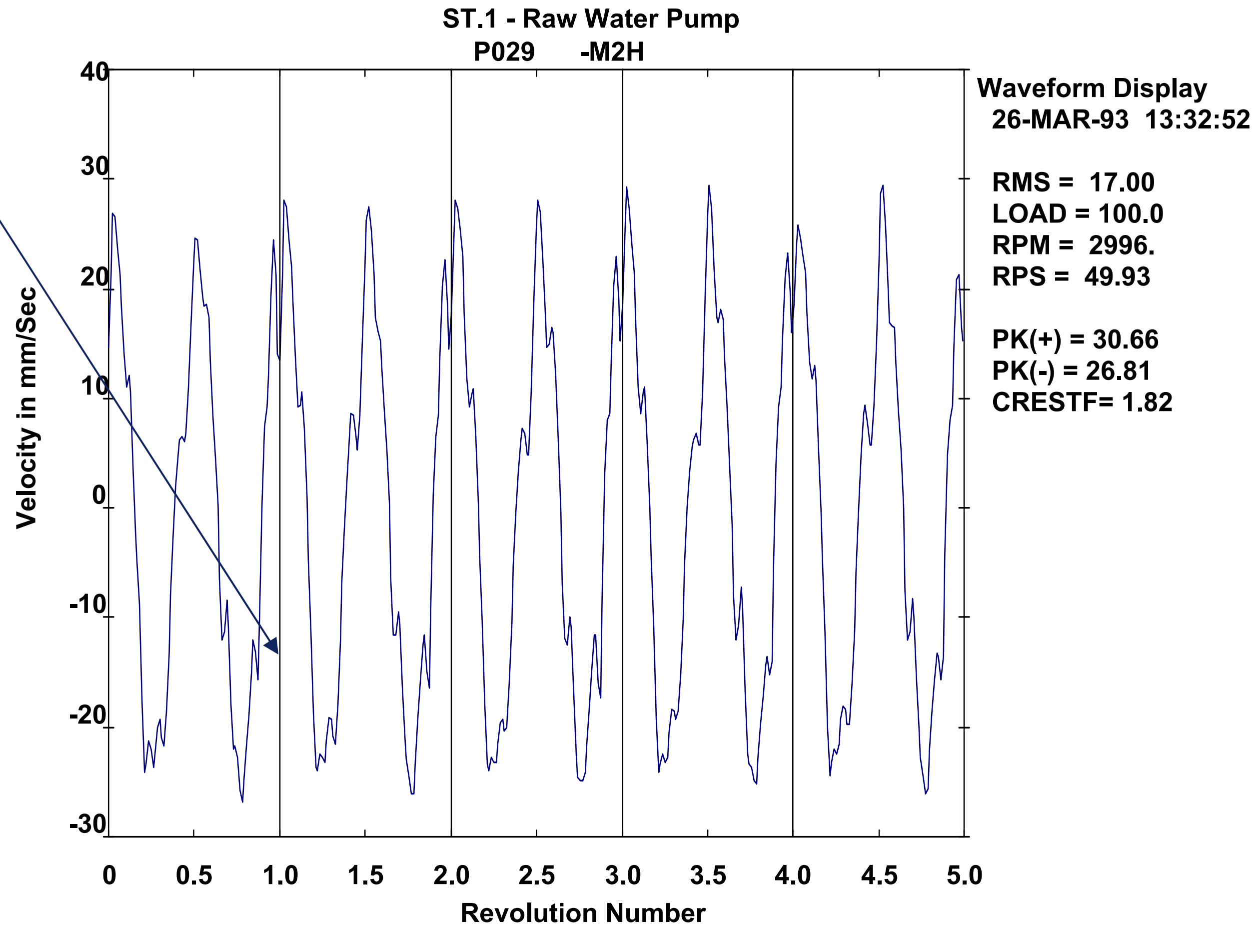
Misalignment in a Waveform

Two Sine waves per revolution if a 2xTs peak is present, may only be 1 sine wave if a 1xTs peak is present

This pattern is often referred to as ‘M’ and ‘W’



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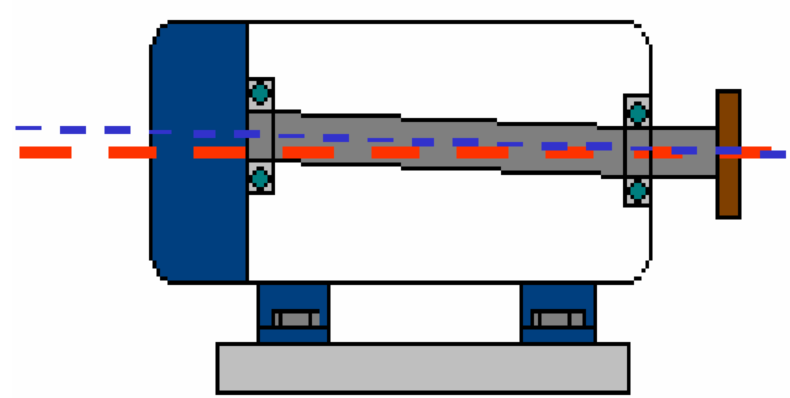
Bearing Misalignment

- We have just covered misalignment between 'two' shafts.
- One other type of misalignment is bearing misalignment.
- Bearing misalignment is when the two bearings supporting the shaft do not share a common collinear axis.
- This causes the shaft to bend, as the shaft rotates it is constantly trying to bring itself back into alignment
- The characteristics of bearing misalignment is the same (2xTs Peak) except this is seen between the outboard and inboard of the same machine. (not across the coupling)



Example of bearing misalignment

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Misalignment Summary

- If a high 2 x Ts peak is present then misalignment should be suspected
- 2 x per revolution Sinusoidal time waveform is expected (‘M’ and ‘W’ pattern)
- Misalignment can be present in all plains (horizontal, vertical and axial) depending on the type.
- Shaft misalignment should be seen on the driver and driven unit (either side of the coupling)
- Bearing misalignment will be seen across the one machine (outboard to the inboard)
- The rule of thumb is:
  - If the 2 x turning speed amplitude is equal to 50% or more than the 1 x turning speed amplitude, Misalignment should be suspected

Looseness

(Structural & Rotating)

Characteristics of looseness

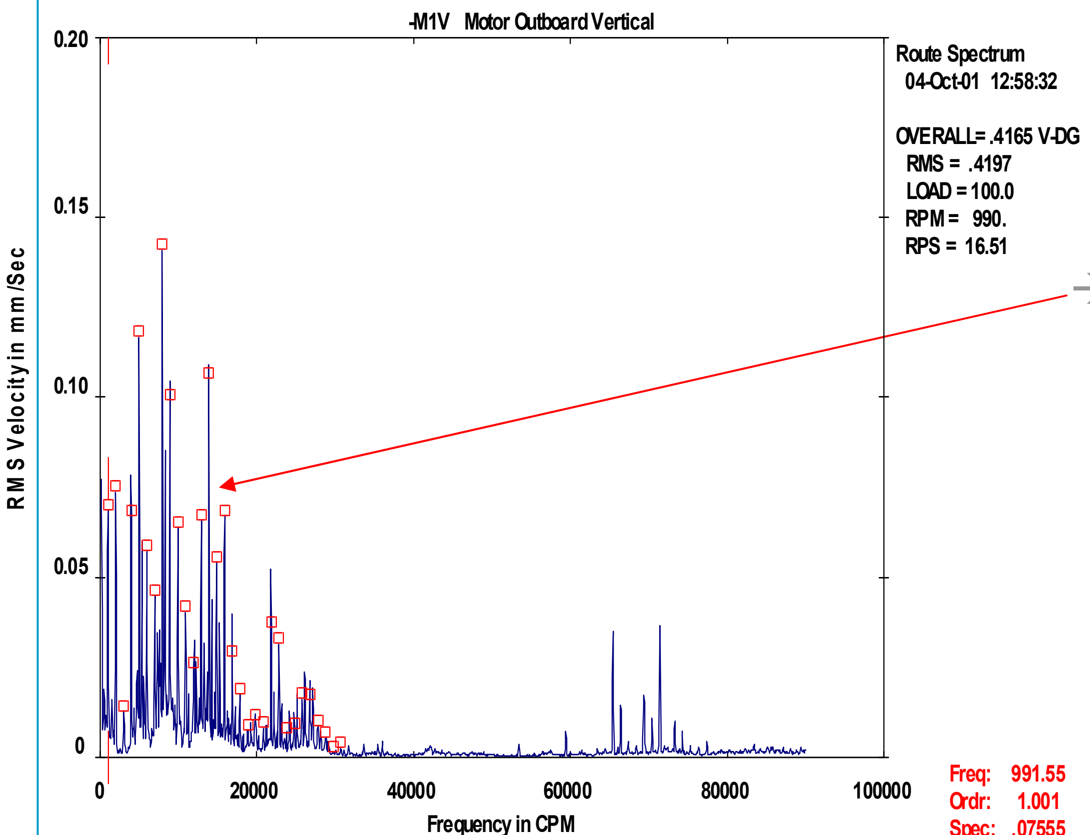
- Presence of a large number of harmonics of turning speed
- Often directional in nature, horizontal and vertical amplitudes may differ greatly
- Random, non-periodic time waveform
- Occasional occurrence of half-harmonics

Two Types of Looseness

- **Structural**
  - Base Mounts
  - Split Casings
  - Bearing Caps
  - Bearing Supports
- Looseness peaks appear at 1 order and may have harmonics up to 10 orders.

- **Rotating**
  - Impellers
  - Fans
  - Couplings
- Harmonic peaks appear at equal orders apart to the loose object. E.g. Impeller with 6 vanes, harmonics at 12,18 Orders

Structural Looseness

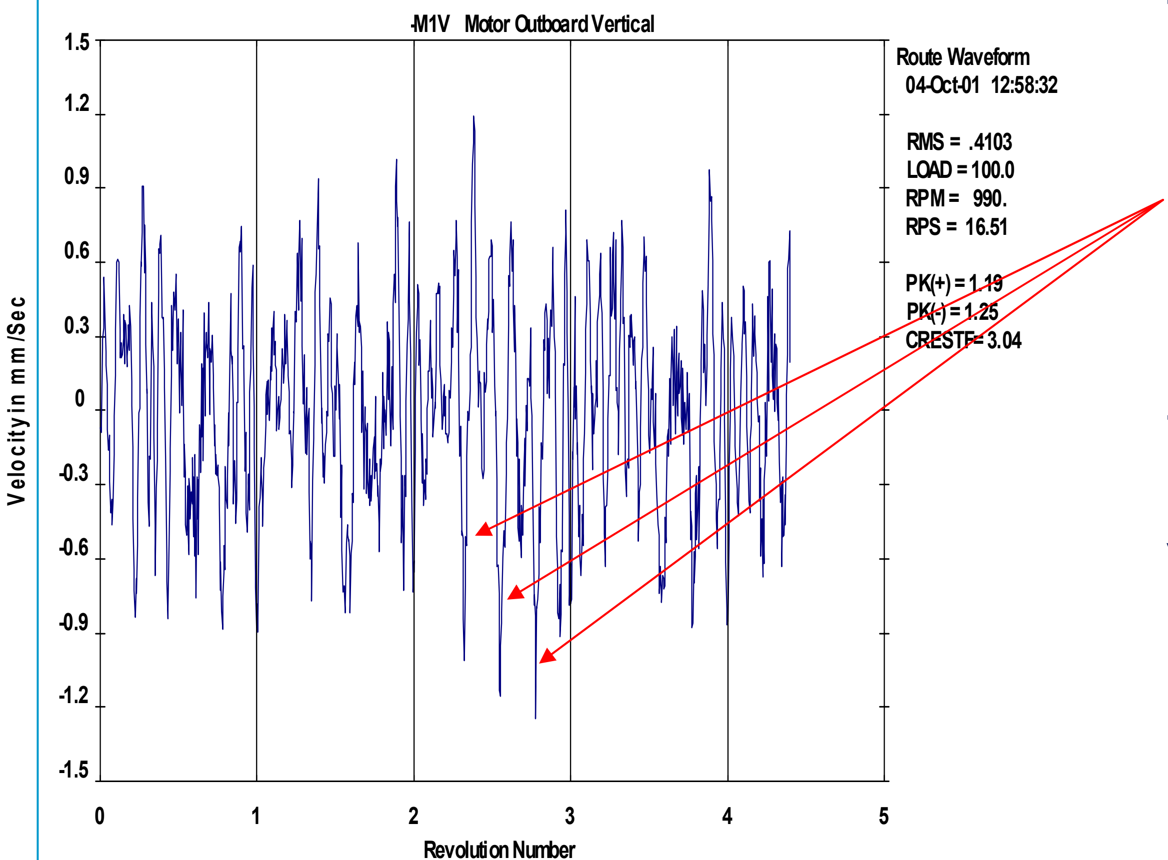


The spectrum on the left shows numerous harmonic peaks

All these peaks are related to 1 Order - (1xTurning speed)

This is indicating structural looseness.
As the forcing function is the drive shaft, everything is synchronousied to that frequency

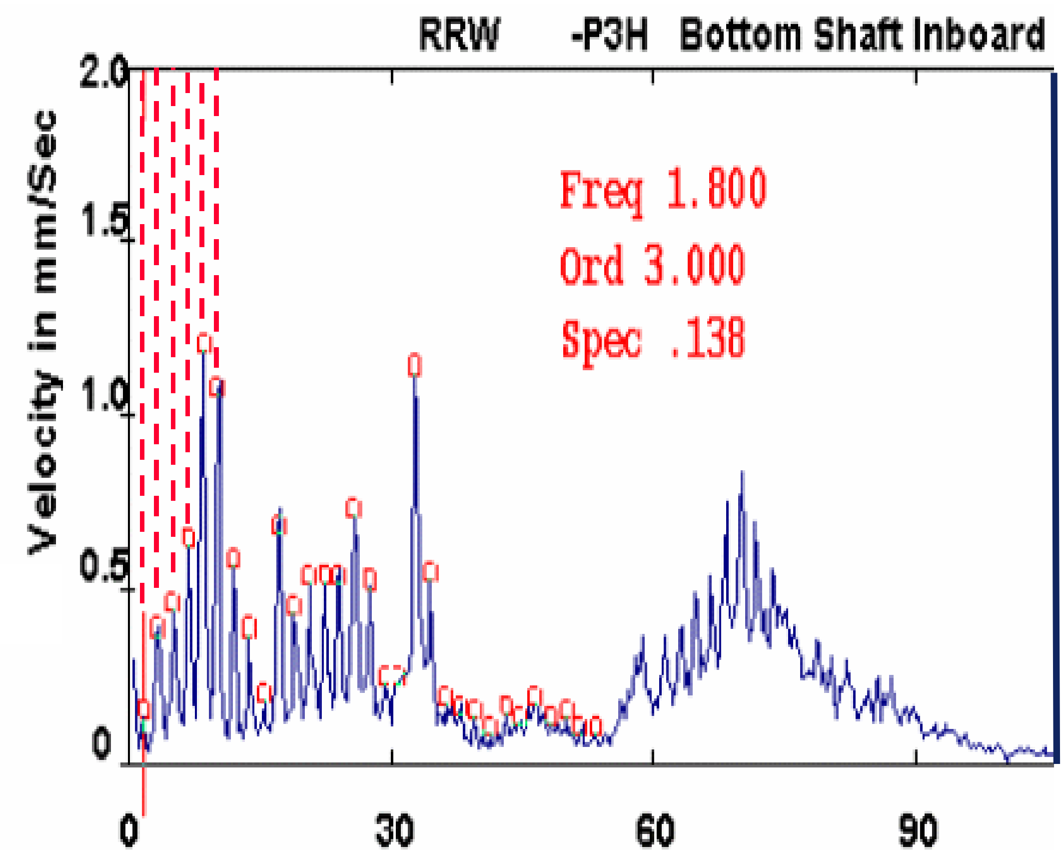
Structural Looseness in a Waveform



The waveform on the left shows numerous **random** sinusoidal patterns per revolution.

This is a typical pattern for looseness.
Velocity is the best unit to use to detect structural looseness in a waveform

Rotating Looseness



- We've got multiple harmonics as with structural looseness
- Note the first harmonic starts at 3 Orders
- This is pointing towards the lobes in the pump

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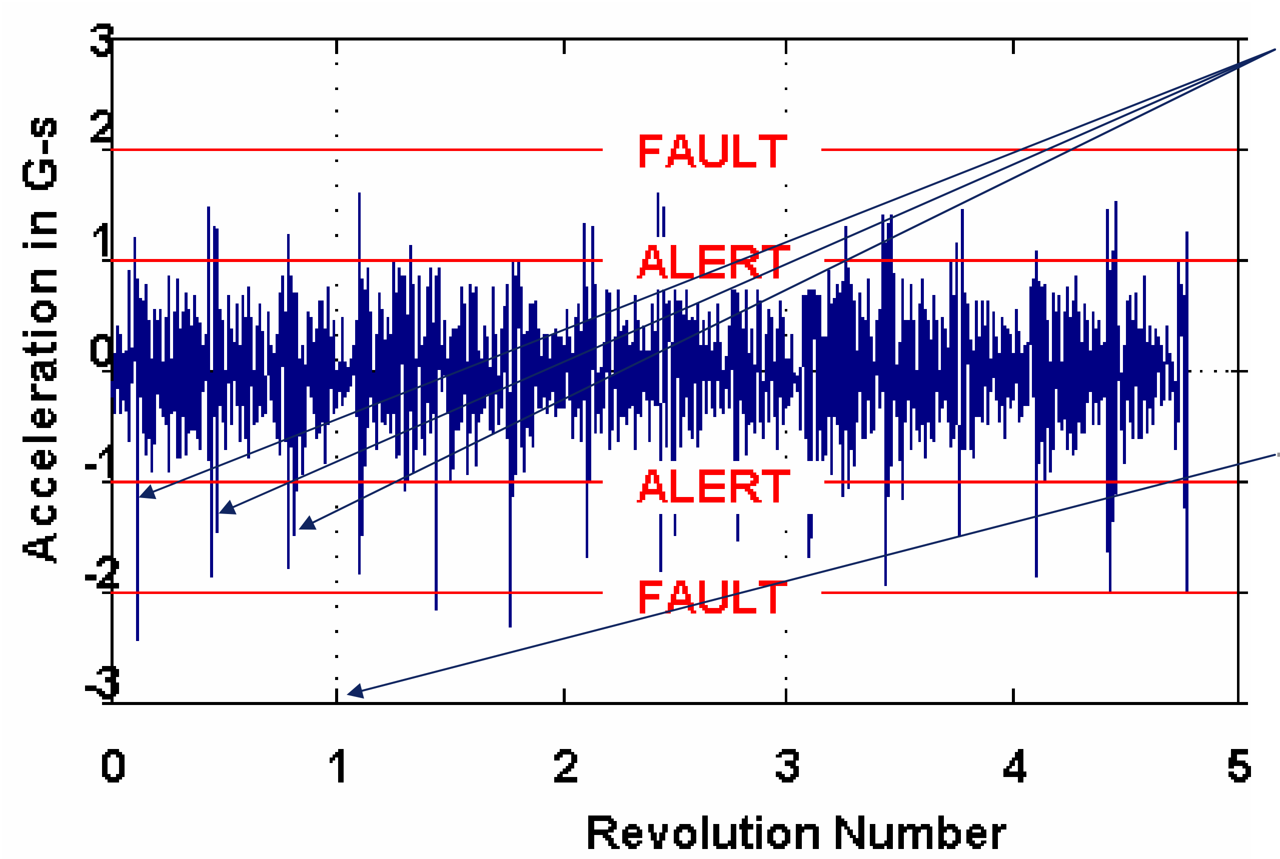
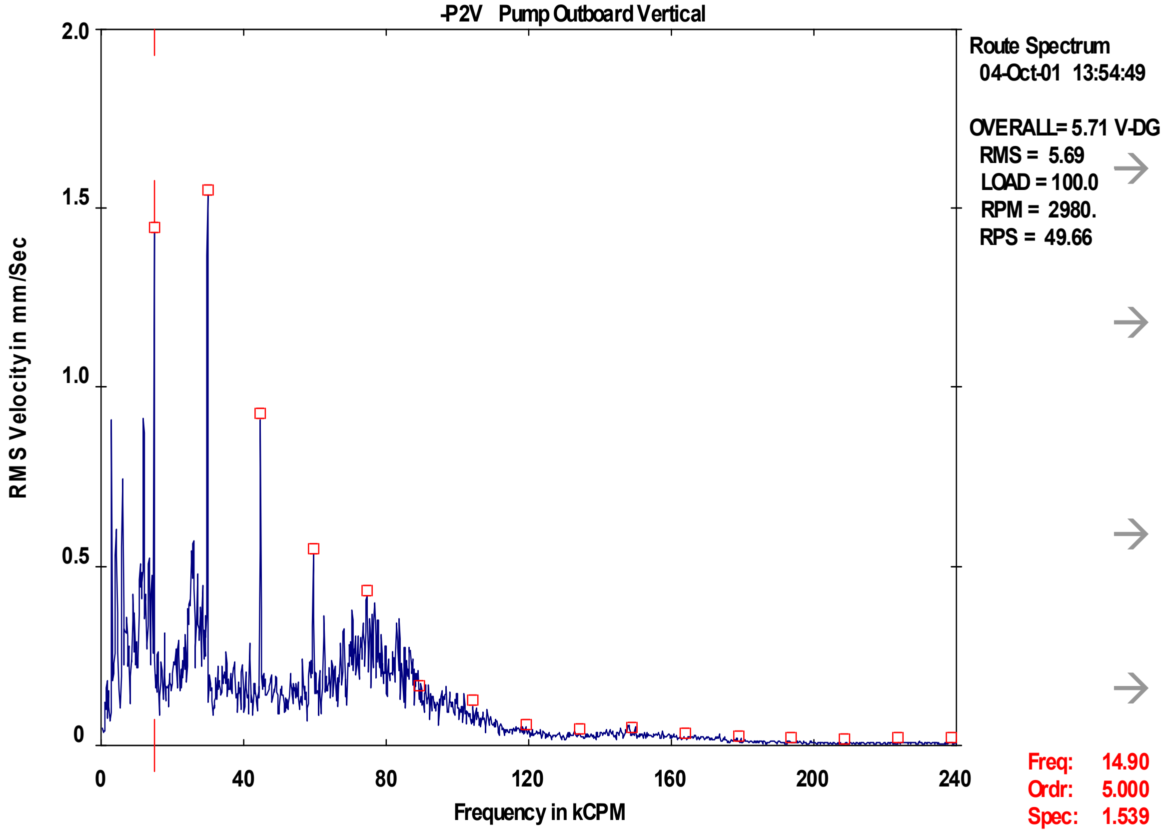
Looseness in a waveform



We can see three clear impacts per revolution

There's no clear sinusoidal waveform per revolution

Rotating Looseness



- We've got multiple harmonics of 5 Orders.
- The data was taken on the outboard of a pump unit.
- What would we suspect the problem to be?
- A Loose Impeller

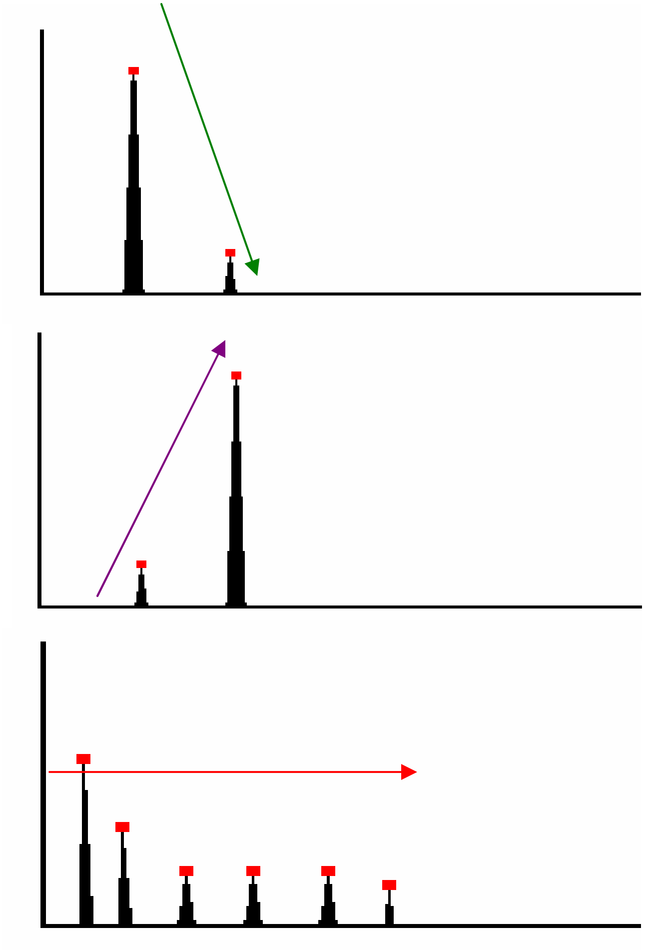
Tips to Identify Looseness

- A good walk round inspection is one of the best ways to identify a looseness problem.
- Looseness may not appear until the machine is at operating temperature.
- Strobe lights are useful tools to help identify:
  - Loose Bolts
  - Loose Keys
  - Belt Problems
  - Coupling Defects
    - Coupling Inserts
    - Loose couplings

Looseness Summary

- Looseness is always 'Synchronous Energy'
- Structural Looseness
  - Multiple Harmonics of shaft turning speed
  - Random Non-Impacting Waveform
- Rotating Looseness
  - Multiple Harmonics of the object that is loose
  - Synchronous impacting pattern within the waveform

Rule of Thumb



Imbalance decreases in a spectrum from 1-2 Orders

Misalignment generally increases in a spectrum from 1-2 Orders

Looseness maintains an average constant level across the spectrum (up to around 10 Orders)

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Gears

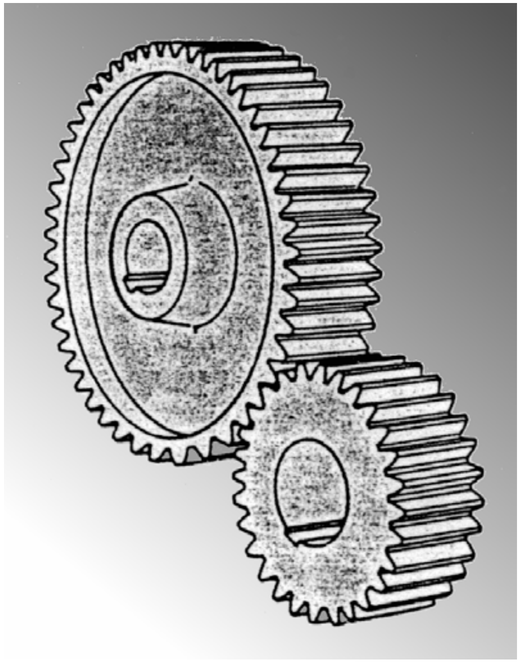
(Helical and Spur)

Gear Characteristics

- Due to the complex nature of gearboxes, vibration analysis is thought to be difficult, but there are a few simple guidelines to make the analysis easier.
- **Gear Mesh Frequency (GMF)**
  - **GMF** is the frequency at which the two gears mesh(drive)
  - Appears regardless of gear condition
  - Amplitude increases with load
- **Side Bands**
  - Sidebands are frequencies which appear at equal intervals either side of the main GMF
  - High level of side bands indicate gear wear
  - Spacing between side bands indicate which gear has the problem

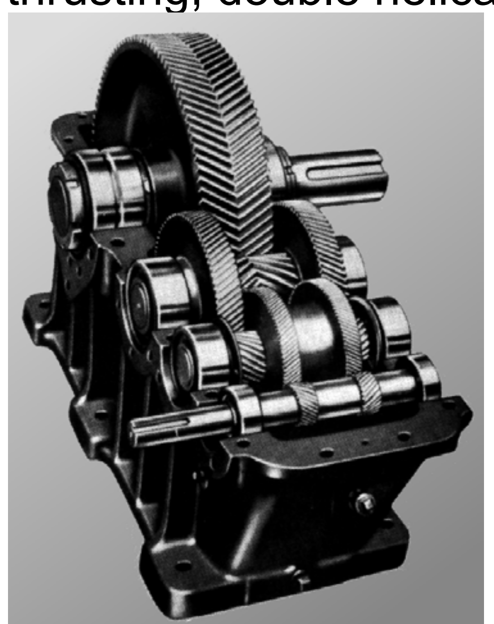
Basic Gear Theory - Spur Gears

- **Spur gears**
  - These gears are most common thought of when discussing gears.
    - The teeth are cut parallel to the shaft
    - Good for power transmission and speed changes
    - Noisier than most gears
  - Vibration defects appear more clearly in the radial plains with these types of gears.



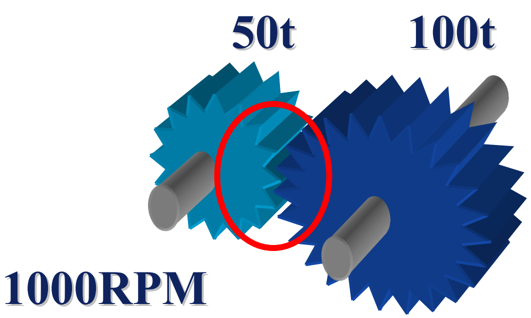
Basic Gear Theory - Helical Gears

- **Helical gears**
  - The teeth are cut angular to the shaft
  - Much quieter than spur gears
  - A lot of axial thrust is created due to the angular mesh
- – Vibration defects appear more clearly in the axial plain with these types of gears.
- – To avoid high axial thrusting, double helical gears are often used.



Gear Mesh Frequency

Gearmesh frequency should be present regardless of condition and the frequency can be calculated using the following formula



- → GMF = Input Speed x Driver Gear
- → Input speed of 1000RPM which has a driver gear with 50 teeth.
- → GMF = 1000 x 50
- → GMF = 50 000 CPM’s (50 Orders)

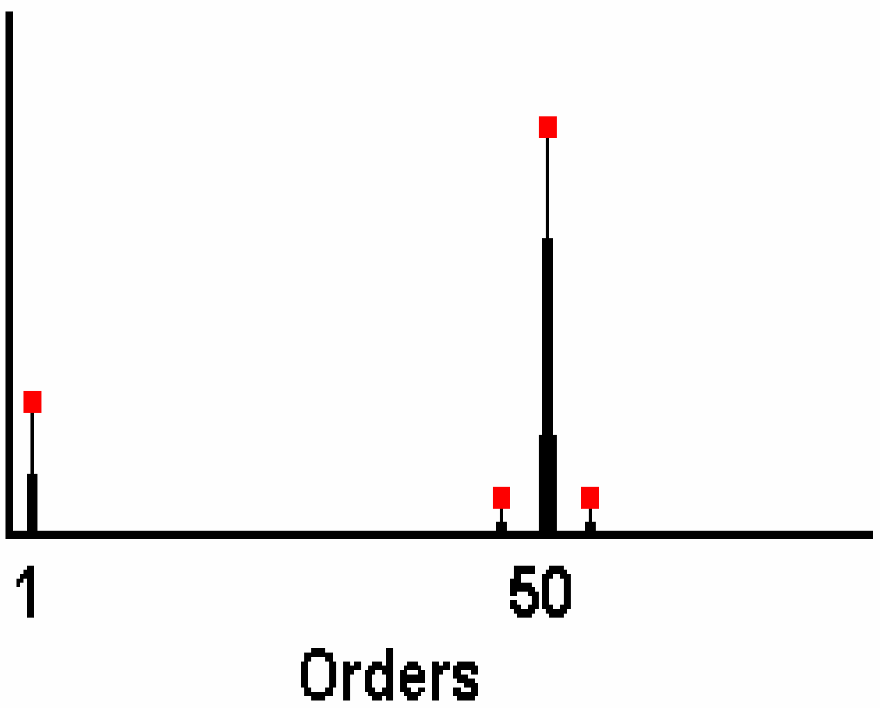
The GMF is the same for both gears as they mesh with each other.

Output speed is 500 CPM

∴ 100 x 500 = 50 000 CPM

– ∴ GMF will always be a multiple of turning speed

Gear Mesh Frequency

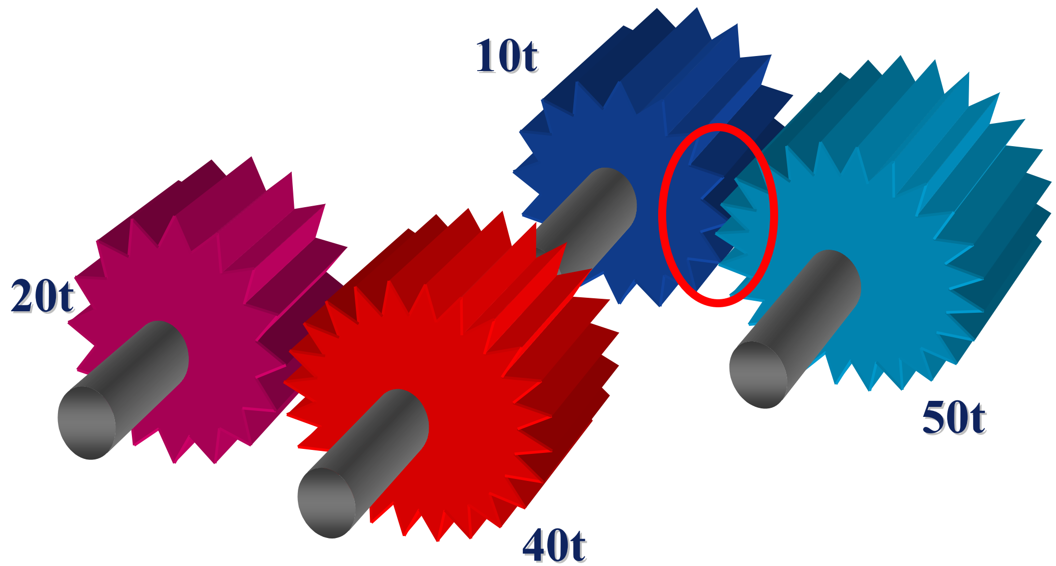


- The spectrum shows the GMF at 50 orders
- The harmonic cursor indicates its synchronous energy

Remember the main GMF amplitude will vary with load

Gear Mesh Frequency

- The same principle applies for multiple shaft gearboxes.



However to calculate the second GMF we need to know the speed of 'shaft 2.'

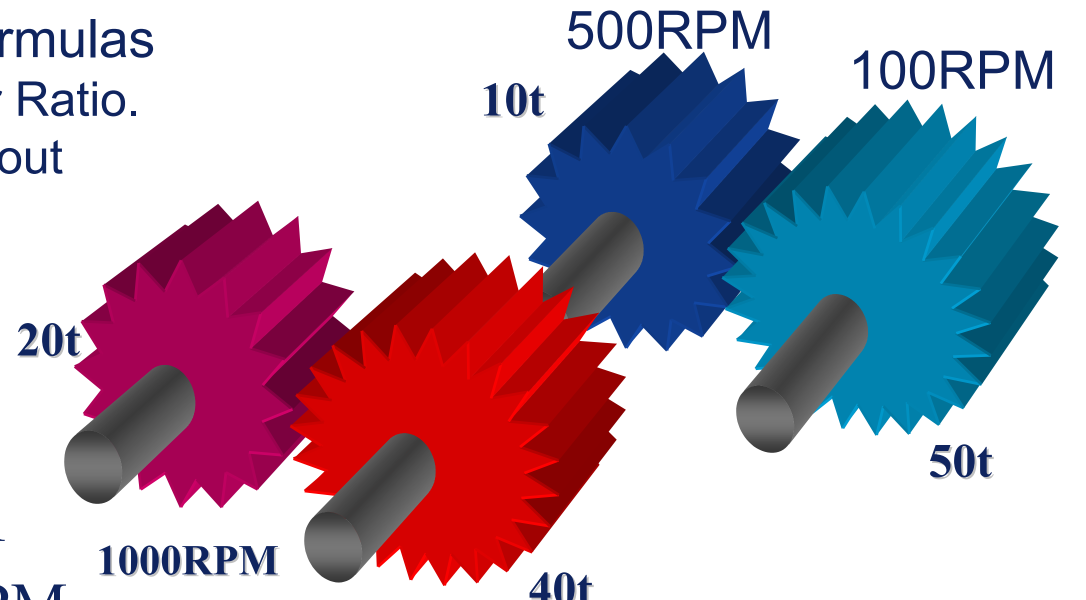
Gear Mesh Frequency

To calculate this, we use the formulas

Speed 2 = Input speed x Gear Ratio.

Gear Ratio = Teeth in / Teeth out

GMF = Speed in x Driver gear



Shaft 1 **ratio** = 20/40 = **0.5:1**

Speed = 1000 x 0.5 = **500**RPM

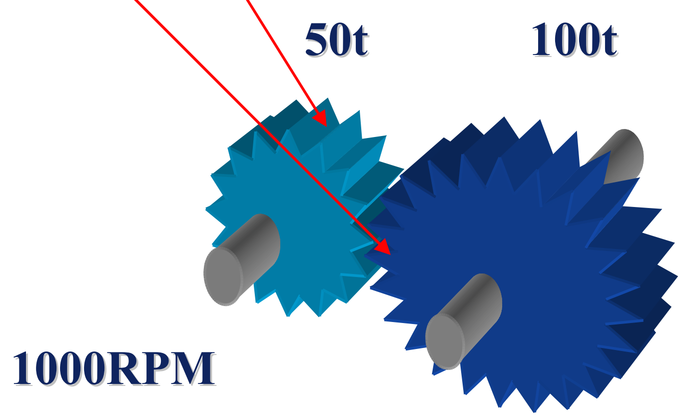
Shaft 2 **ratio** = 10/50 = **0.2:1**

Speed = 500 x 0.2 = **100**RPM

- **GMF 1** = 1000 x 20 = **20000**CPM
- **GMF 2** = 500 x 10 = **5000**CPM

Side Bands

- Sidebands are peaks that appear either side of the GMF
- The side band spacing indicates which gear has the problem.
- The side band spacing relate to shaft speed.
- If the driver gear has a problem the side bands will be at 1000CPM's apart.
- If the follower gear has a problem then the side bands will be at 500 CPM's apart



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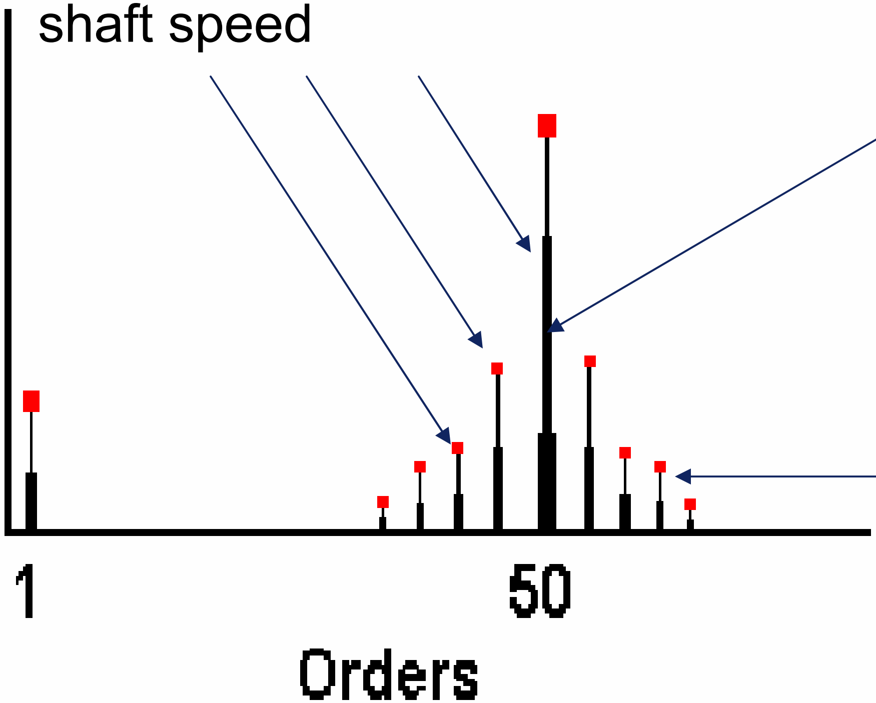
Side Bands

The difference in frequency between each peak will equate to a shaft speed



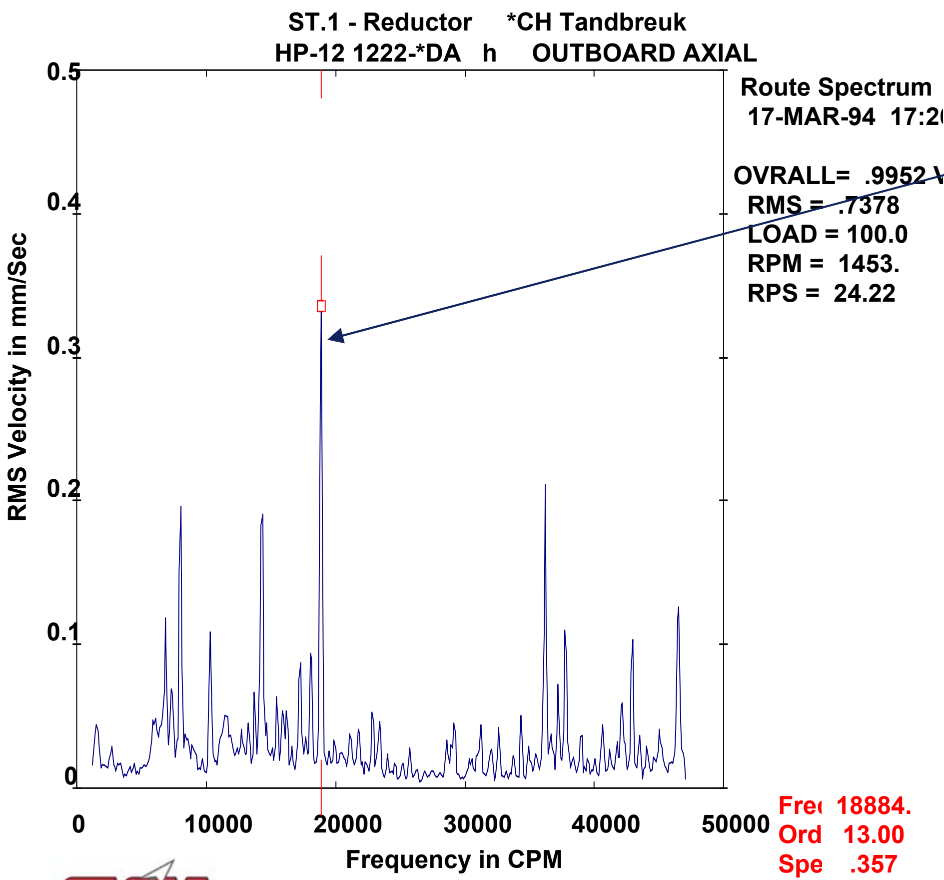
As the wear develops in the gearbox the sidebands increase in amplitude

The higher the amplitude of the sidebands the more severe the wear

The number of sidebands may also increase

This is also a sign that the wear is increasing

GMF in a Spectrum



The GMF in this case is clearly visible.

Remember GMF increases with load.
This does not indicate a problem in the gearbox

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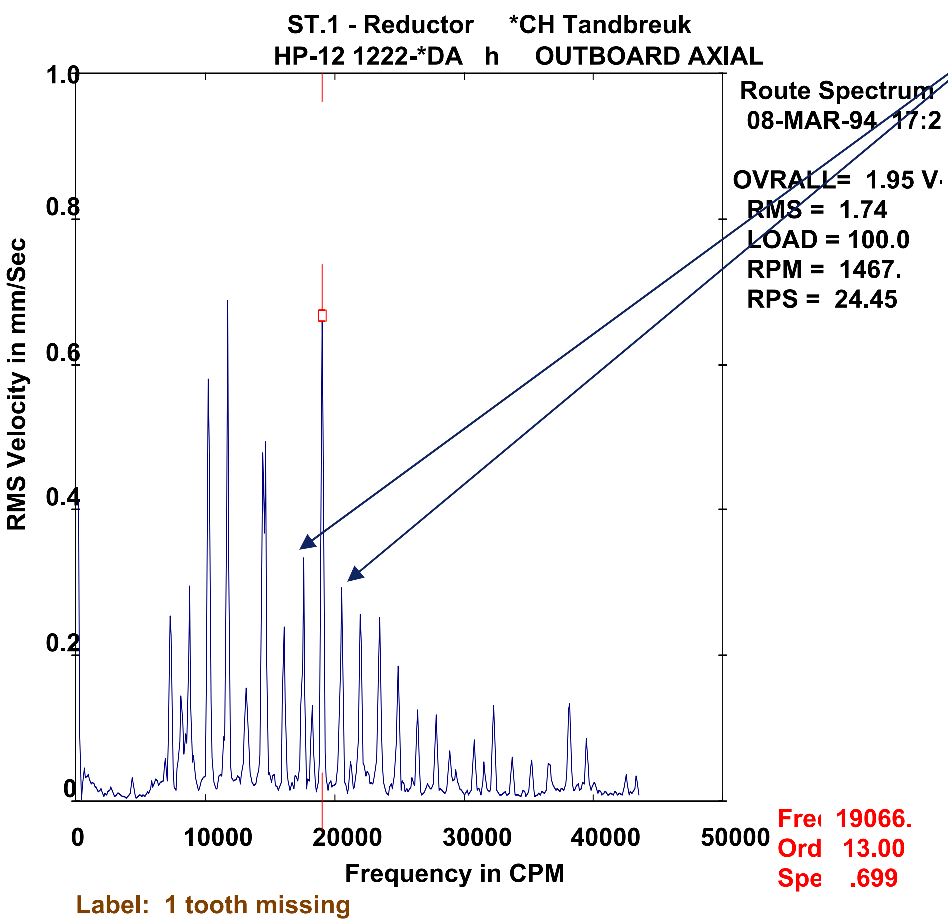
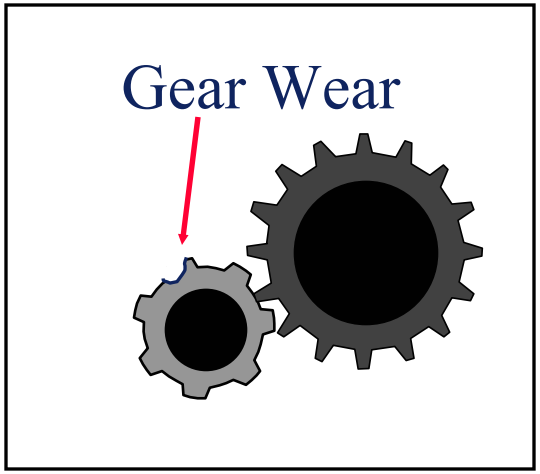
GMF in a Spectrum



As a problem develops the side bands start to increase.



This is a clear indication that a problem is developing.

The spacing between these sidebands will be equally spaced at a frequency related to a shaft speed

Gears Summary!

- GMF - Gear Mesh Frequency
  - Appears regardless of gear condition.
  - A high GMF does not indicate a problem.
- Sidebands
  - Equally spaced frequencies either side of the GMF
  - Indication of wear developing
- Waveform
  - Should show signs of impacting
  - Acceleration shows the impacting more clearly

Bearings.

(Rolling Element)

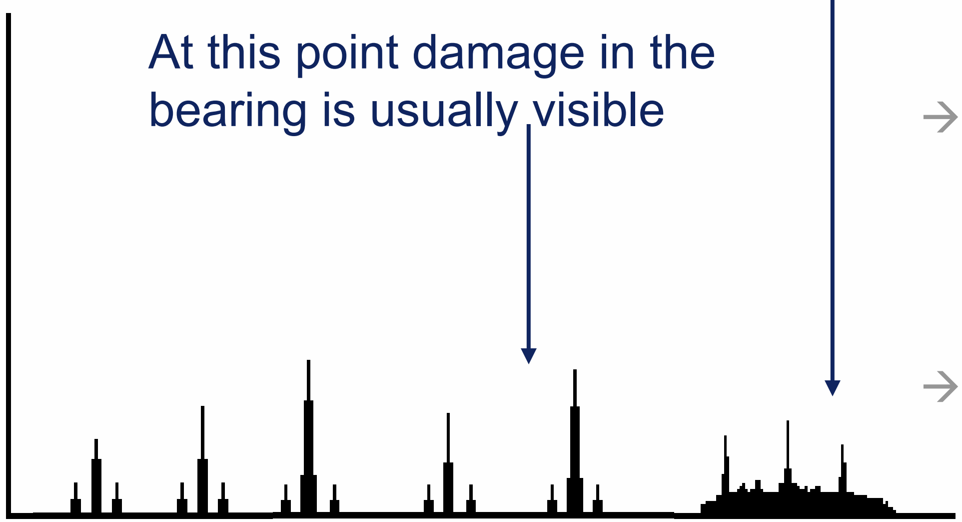
Bearing Characteristics + Causes

- **Characteristics**
- Visible harmonics of **non**-synchronous peaks.
- Broad band energy humps can occur (High Frequency)
- Time waveform should show signs of impacting
- Acceleration is the best unit for detecting bearing impacts
- **Causes**
- 43% - Improper Lubricant (Under/Over Greased)
- 27% - Improper Fitting (Hammers/Retainer)
- 21% - Other Sources (Excessive Vibration/Manufacturing Defects etc)
- 9% - Normal Life Expectancy

Bearing Failure Modes

Indication of poor lubricant in the bearing

At this point damage in the bearing is usually visible



Failure is imminent at this point and action should be taken

- The early stages of bearing wear produce low amplitudes at high frequencies. The fundamental frequency is not normally present at this stage
- Distinct harmonics of non-synchronous peaks of the fundamental bearing frequency appear
- Sideband data may also be present (normally of shaft turning speed)
- Fundamental frequencies will appear (normally low frequency). Sidebands of other bearing defects may be present (BSF, FTF)

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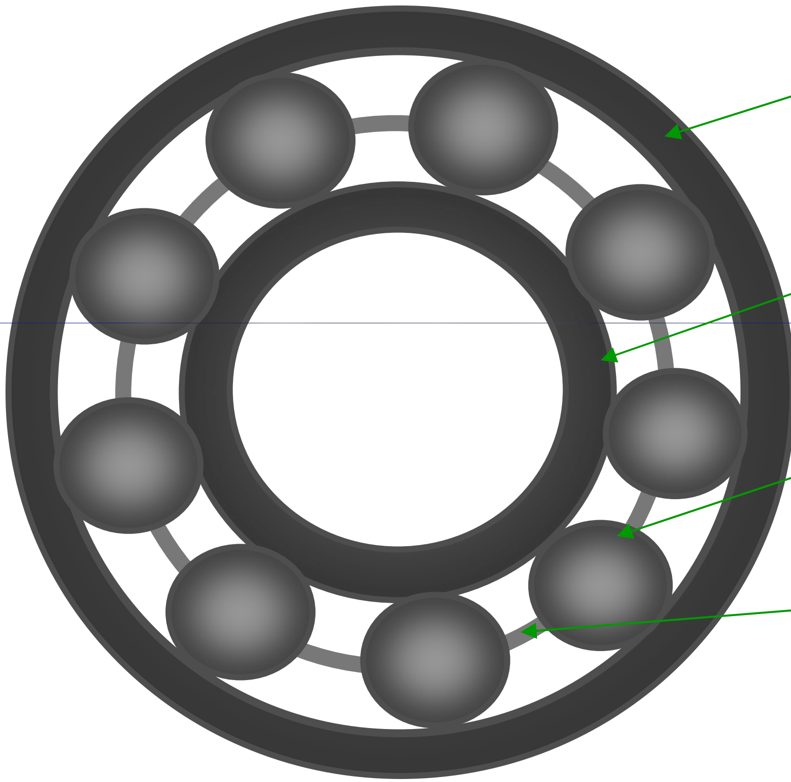
Bearing Defects (Fault Types)



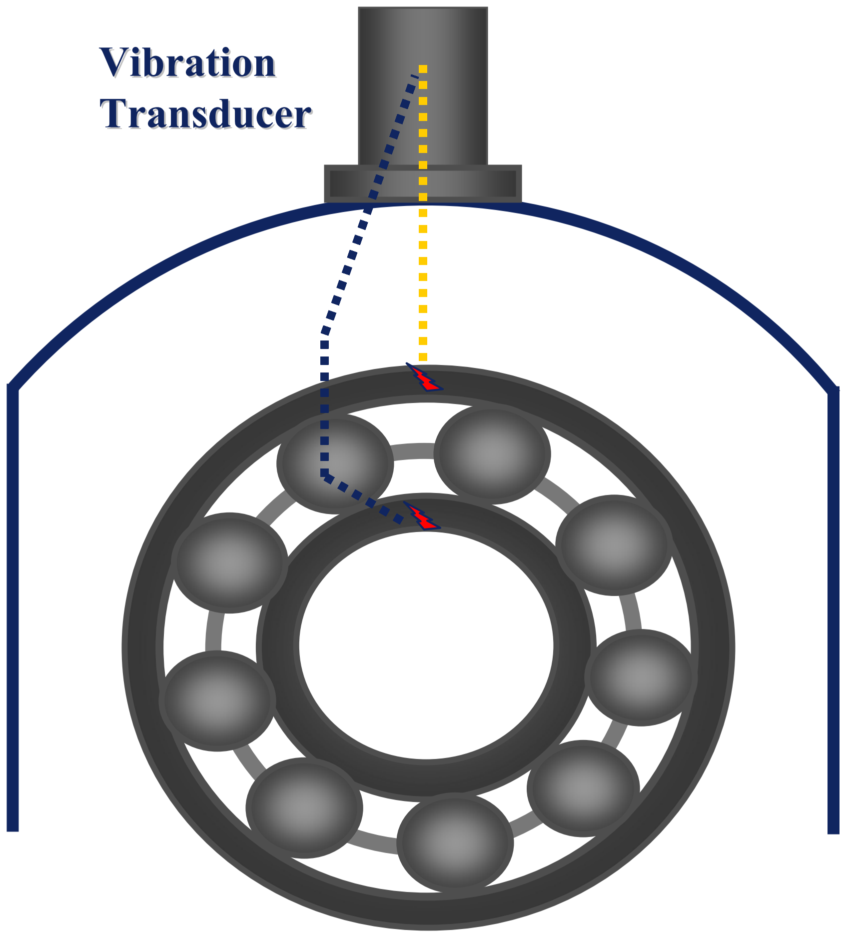
BPFO - Ball Pass Frequency Outer

BPFI - Ball Pass Frequency Inner

BSF - Ball Spin Frequency

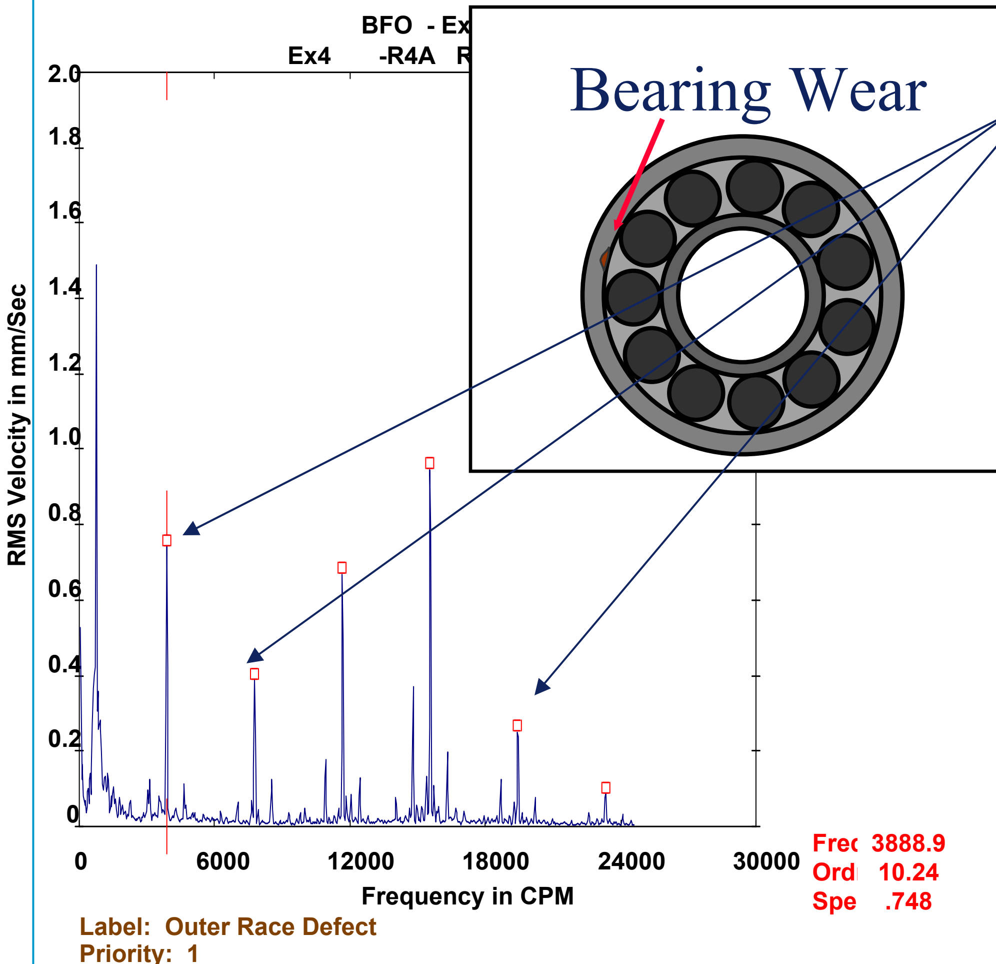
FTF - Fundamental Train Frequency (cage)

Bearing Defects (Fault Types)



- Why would we want to know if we had an inner race (BPFI) or an outer race (BPFO) defect?
  - If a bearing is defected then its defected?
- Due to the transmission path an inner race defect has to travel further to reach our measurement point than an outer race defect would.
  - A severe inner race defect will be lower in amplitude than a severe outer race defect

Bearing Fault Frequencies



Bearing wear shows up at specific frequencies on the spectrum.

These are related to the geometry of the bearing

- Number of Rolling Elements
- Rolling Element Diameter
- Pitch Diameter
- Contact Angle

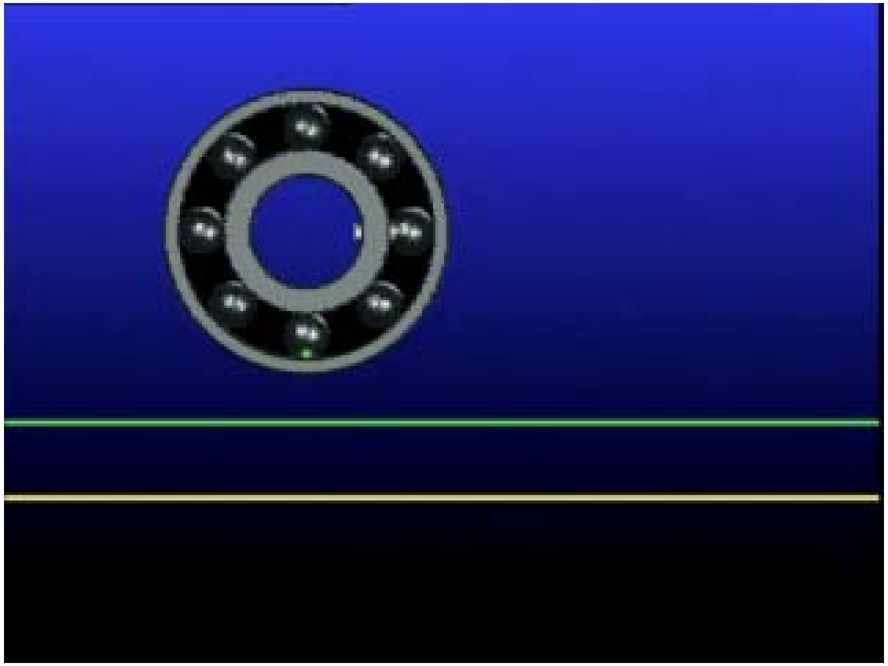
Bearing Defects

- Bearing impacting occurs as non-synchronous energy.

Outer race impacting

Inner race impacting

Outer and Inner



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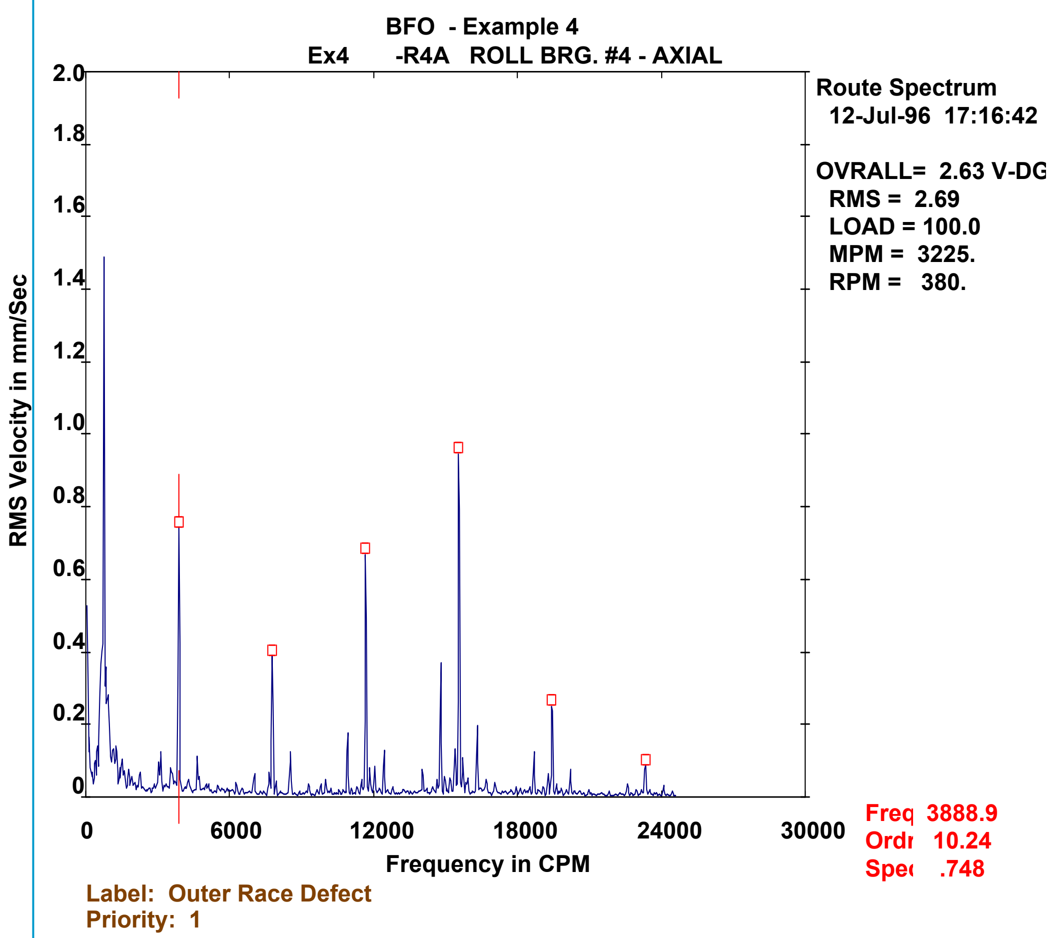
Advanced Bearing Wear

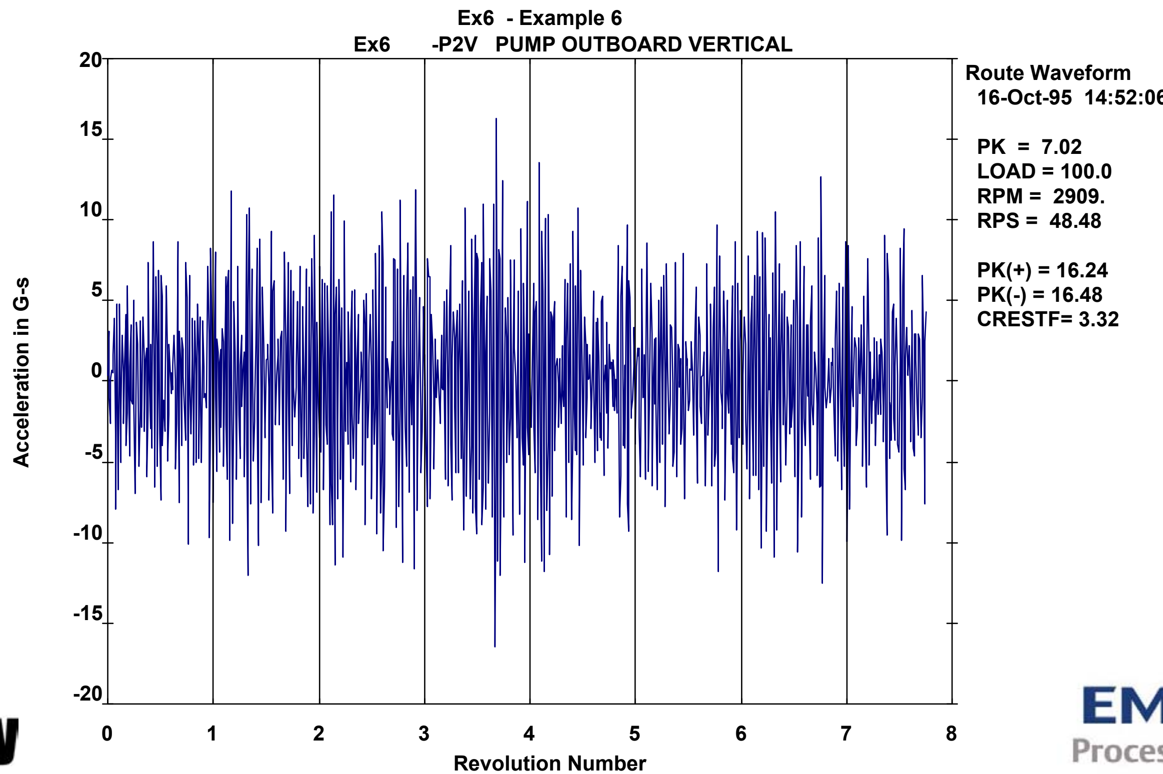


- Advanced stages of bearing wear is easy to detect with vibration

- Defined non-synchronous impacting peaks show up clearly in the spectrum

Bearings and Time Waveforms

- What do we expect to see in a waveform when a bearing fault is present
  - Appearance of impacting within the waveform (acceleration should be used as impacting is seen more clearly than velocity)
  - High G-s (Peak+ and Peak- values) - Indicate severity
  - Possibly an ‘Angel Fish’ pattern may be present



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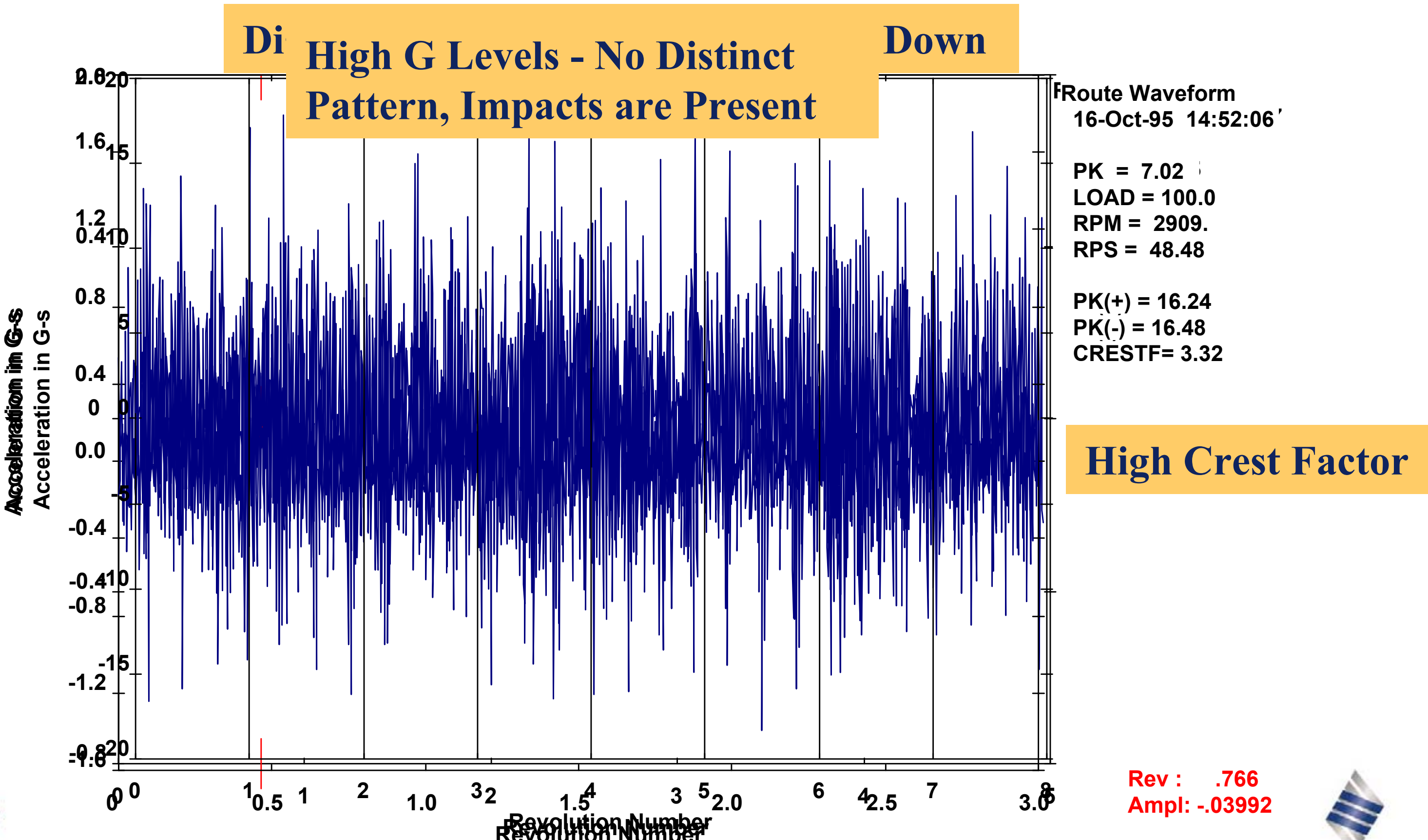
Bearings and Time Waveforms

- There are different types of waveform patterns when it comes to bearings, some of these are shown below:



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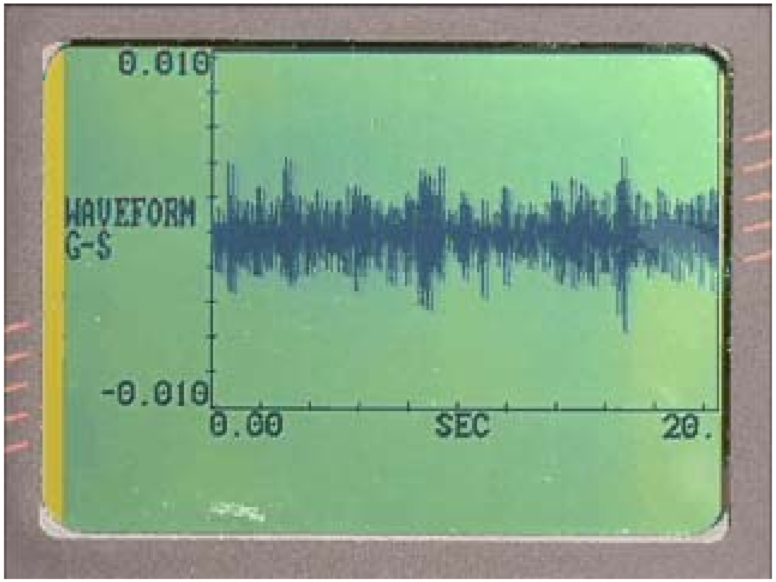
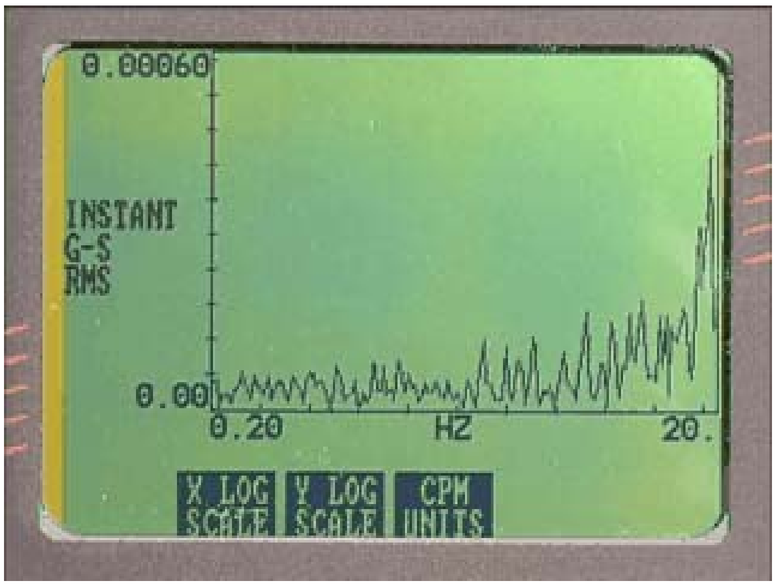
Bearing Defects in a Time-waveform



- We look for bearing defects in 'acceleration - G-s'
- Time waveform is showing multiple impacting
- Impacting is Not Synchronous (will Not happen the same per revolution)

Bearing Defects in a Spectrum



- We look for bearing defects in 'acceleration - G-s'
- Impacting is non-synchronous
- Early bearing wear appears in the HFD and often appears as humps of energy.
- May be difficult to detect so Peakvue should be used to help determine bearing faults

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Peakvue™

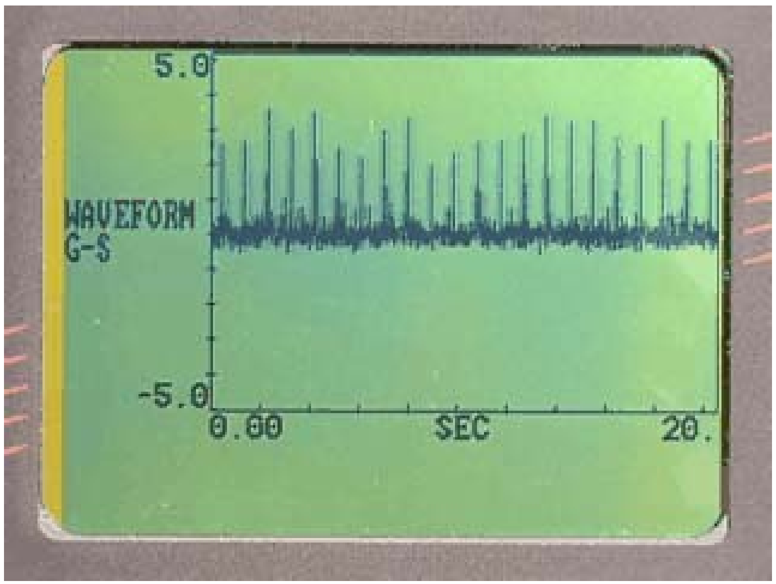
- What is Peakvue technology?
- Peakvue is a technology unique to CSI and concentrates on stress wave analysis.
- These stress waves travel further than conventional vibration signals so a truer indication of fault severity is obtained.
- What is a Stress Wave?
- Stress waves accompany metal-metal impacting. These stress waves are short-term (fractional to a few milliseconds) transient events, which introduce a ripple effect on the surface machinery as they propagate away from the initial event.
  - If you think of a stone being dropped into a pool of water. The stone is the initial impact generated by the fault. The effect of the stone being dropped into the water cause a ripple on the surface of the water which, spreads over a wide area.

Peakvue™

- The animation shows a stress wave being generated by a soft spot under the surface of a bearing race.
- As the bearing passes the soft spot a small short duration impact occurs causing a stress wave

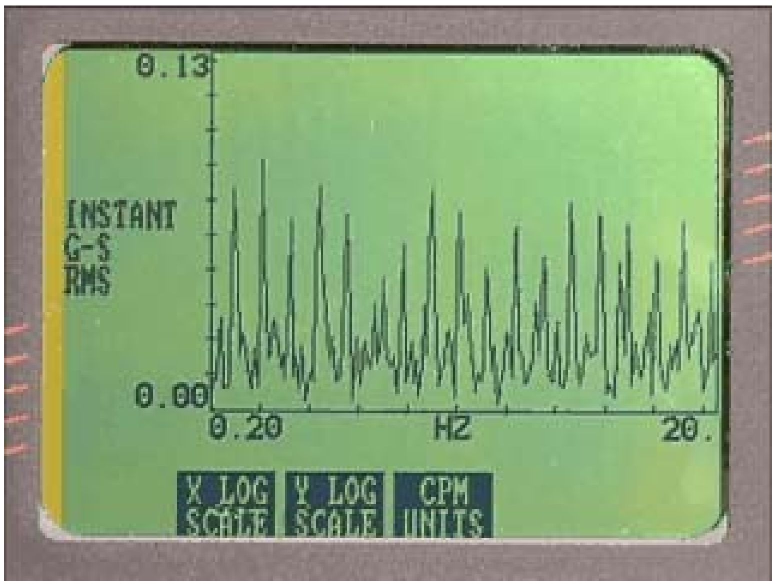
Peakvue™

Bearing Defects using Peakvue



- Peakvue filters out all low frequency vibration and looks at the real high frequency stress waves
- Impacting is very clear
- Still looking in ‘acceleration - G-s’

Bearing Defects using Peakvue



- High frequency signals are brought back down to low frequency
- Impacting in the spectrum is clearly visible

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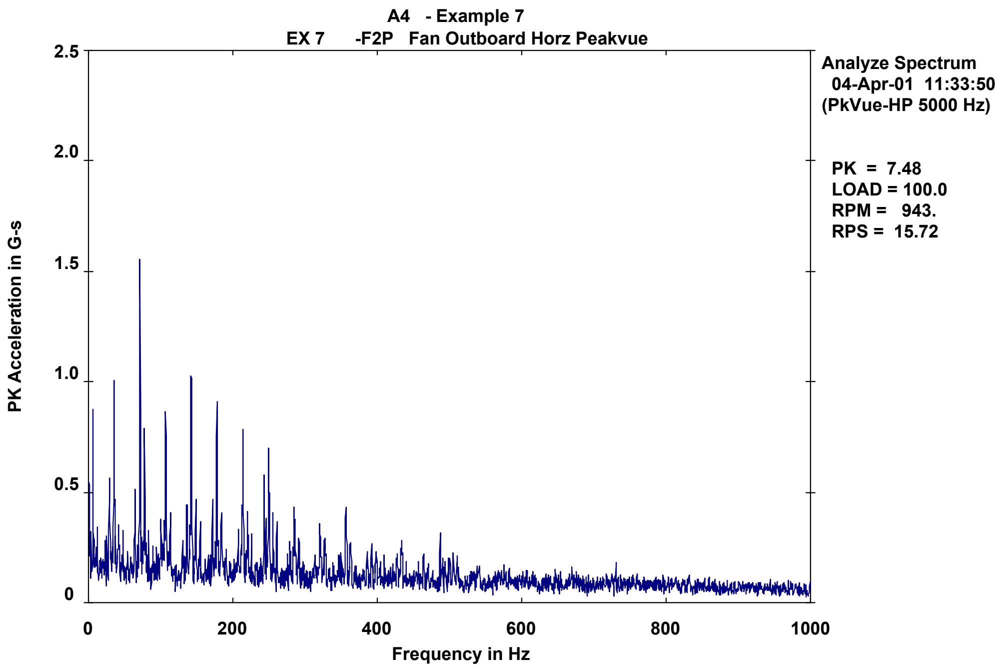
Bearing Defects using Peakvue

- All low frequency events such as:
  - Imbalance / Misalignment / Resonance

  Are filtered out (this can be seen by the band of noise along the spectrum floor)
- If any stress waves are detected (caused by metal to metal impacts) they appear above the filtered noise level as shown



Bearing Summary!

- Bearings are Non-Synchronous Energy
- They appear at different frequencies within the spectrum
  - Early Bearing Wear - Appears at high frequency
  - Advanced Bearing Wear - Appears at low frequency
- High ‘G’ levels in the waveform normally indicate a bearing defect
  - Look for distinct impacts
  - A repetitive pattern in the waveform
  - Possibly an ‘angel fish’ pattern
- Look for bearing defects using ‘Acceleration’

Electrical

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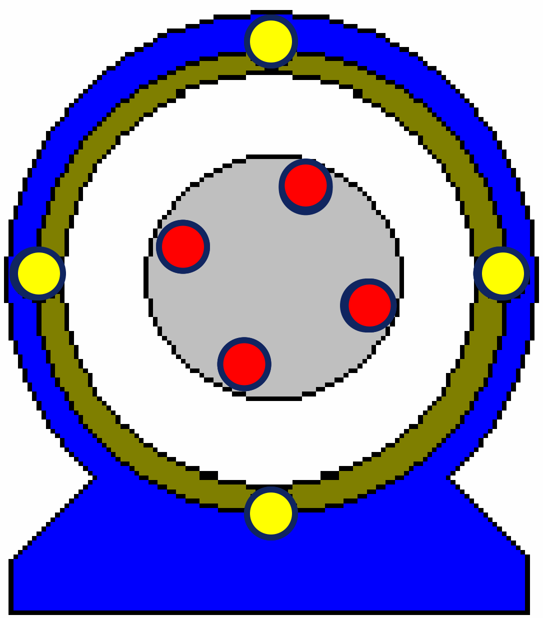
Electrical

- To pin point an exact electrical fault by using vibration is very difficult.
- The best way is to use ‘motor analysis’ technology. (Flux coil, Current clamp) etc.
- How ever this does not mean that detecting an electrical fault is impossible by using vibration. There are certain patterns we look for.
- Electrical faults show up at 2xLf (line frequency is 50Hz.)
- 2xLf = 100Hz.

Electrical

- Why do electrical defects appear at 2 x the line frequency?

- If we take a 4 pole A.C induction motor
  - The magnetic field frequency will be 1500 CPM (25Hz)



- As each pole in turn generates a frequency of 25Hz. This causes the rotor to rotate.

- If there are 4 Poles each generating a frequency of 25Hz. The sum of the 4 poles = 4 x 25 = 100Hz

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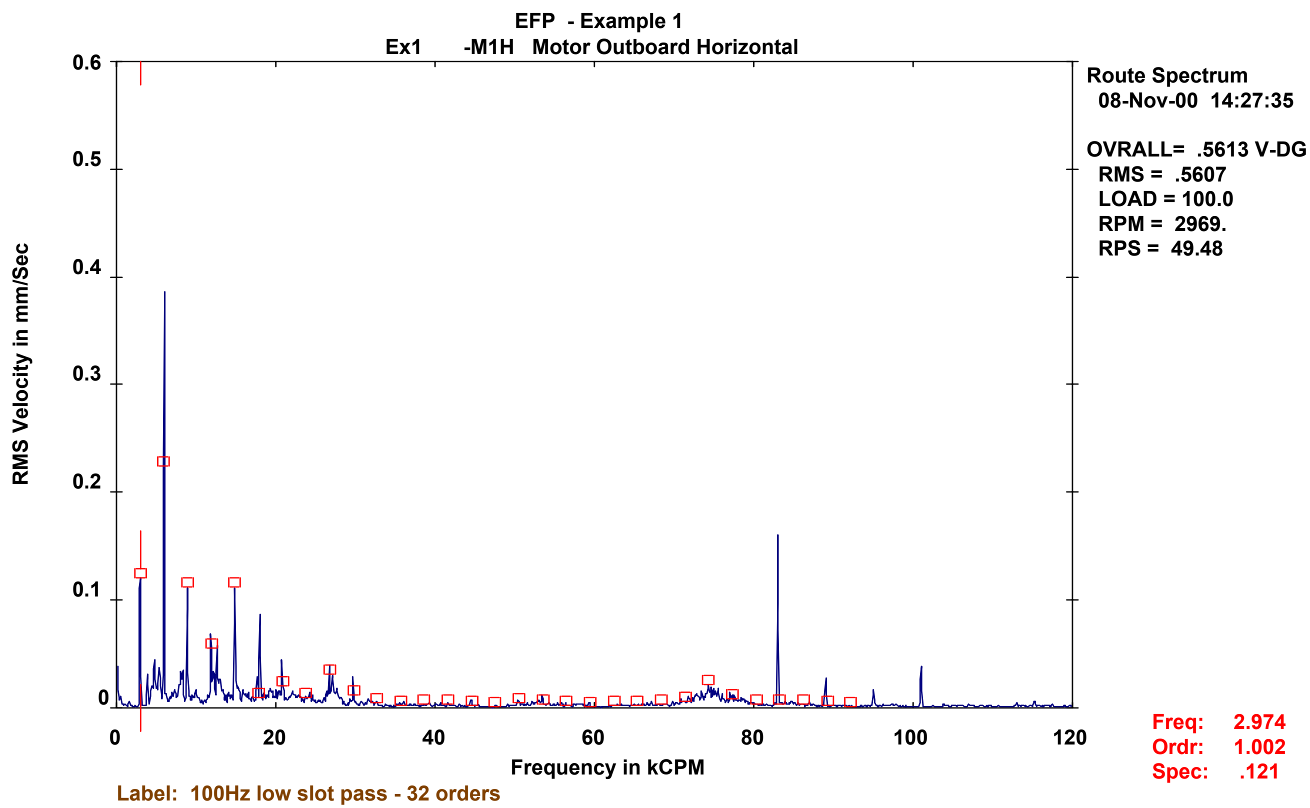
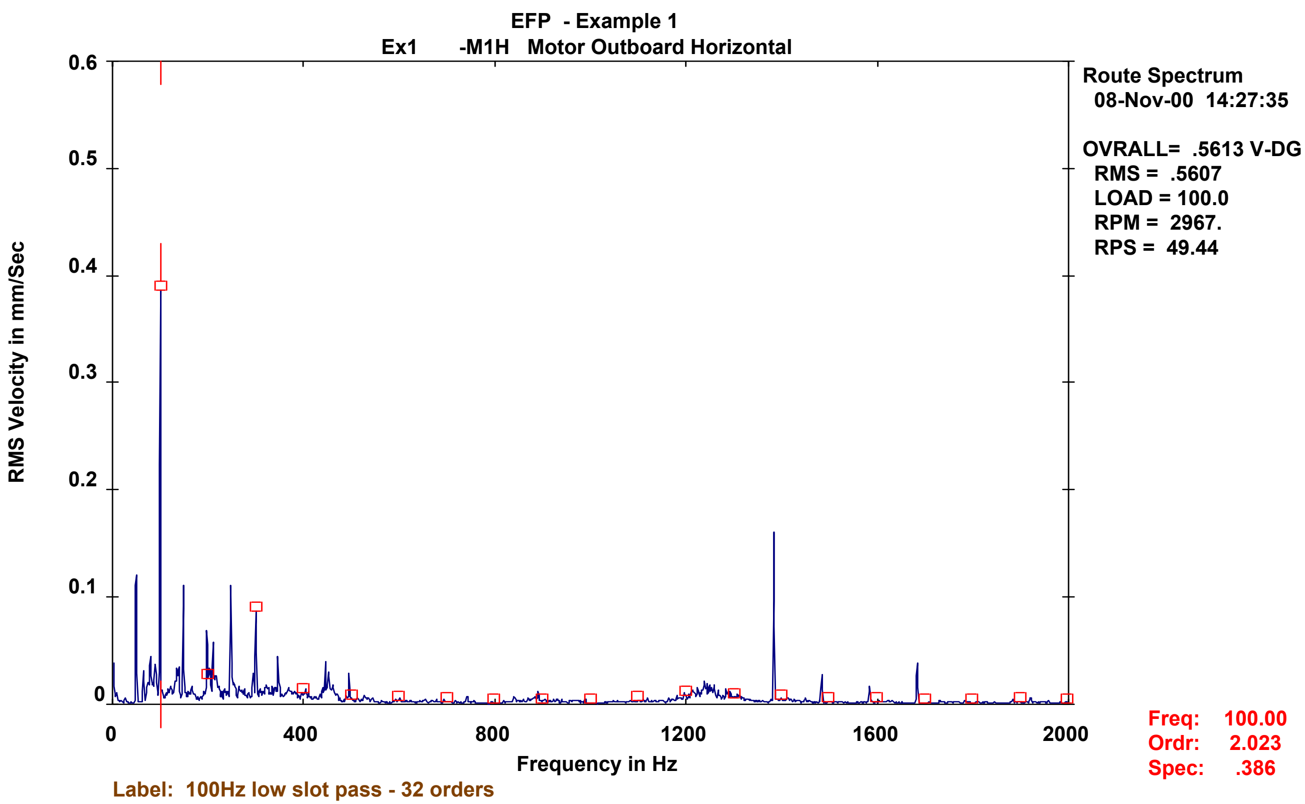
Electrical

- The problem that can occur here is it can easily be passed for misalignment



Electrical

- The motor is a two pole motor (3000CPM) 2xLf is at 6000CPM (100Hz) very close to 2xTs (turning speed)



Increasing L.O.R will help determine the individual peaks

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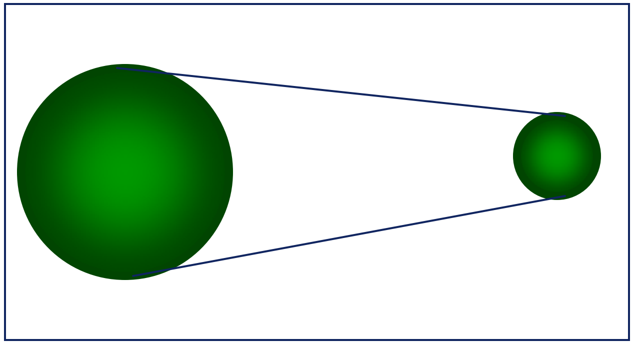
Electrical or Mechanical

- There are a number of simple tests we can do to determine whether a defect is caused by a ‘mechanical’ or ‘electrical’ source.
  - 1. Switch of the Power
    - This is not always possible as it is not always practical to do so.
    - Monitor the peak in question using ‘Live Mode’ (Monitor Mode) on the 21XX analyser, while the machine is running.
    - Switch the power off to the motor and watch the peak on the analyser
      - If it is Electrical the peak will disappear immediately
      - If it is Mechanical the peak will disappear as the machine slows down
  - 2. Increase Lines of Resolution
    - Acquire an additional spectrum with the 21XX analyser
      - Set the Fmax (Upper Frequency) just above 100 Hz (6000 CPM) - 8000 CPM
      - Increase lines of resolution to 1600 / 3200 lines
      - This will help distinguish the exact frequency of the peak - Electrical is Non-Synchronous due to slip of the rotor

Belts

Belt Characteristics

- Belt frequency appears as ‘Sub-synchronous’ data
- This is due to the belts slipping while driving

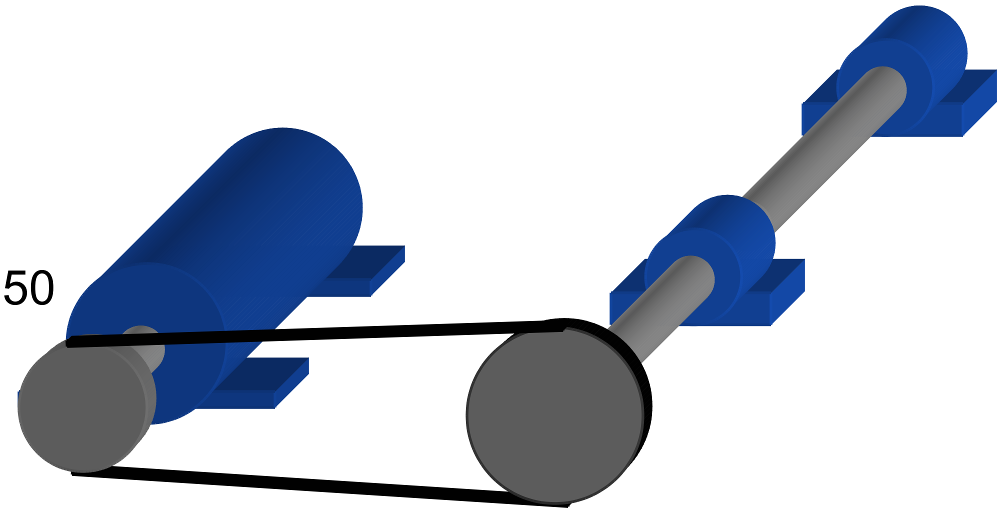


The belt frequency can be calculated using the following formula:

$$\text{Belt Frequency} = \frac{3.14 \times (\text{Pulley Speed}) \times (\text{Pulley Diameter})}{(\text{Belt Length})}$$

Belt Frequency Calculations

- Using the formula given, calculate the belt frequency for the data given
  - Motor turns at 1480 RPM
  - Motor Pulley Diameter = 300
  - Lay Shaft Pulley Diameter = 250
  - Belt Length = 2000
    - All Dimensions in ‘mm’



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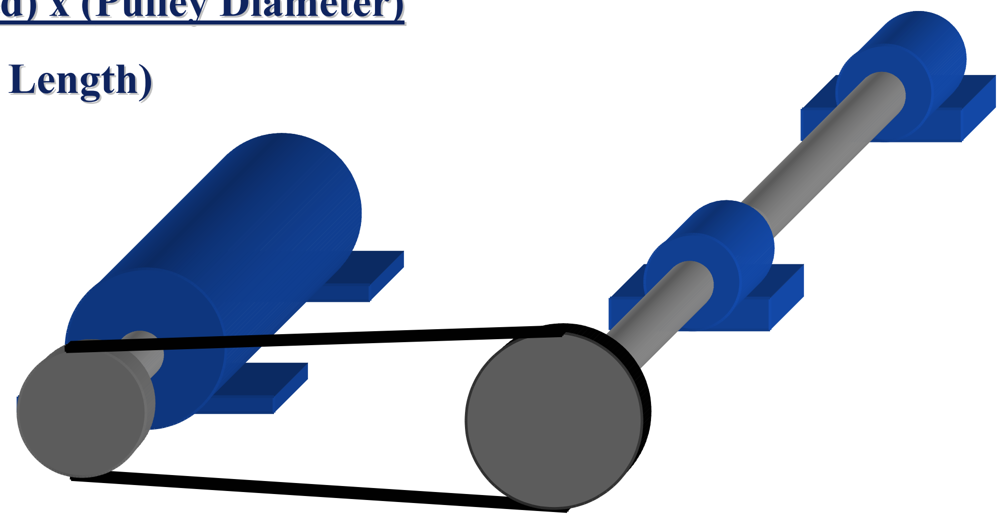

- Belt Frequency = $\frac{3.14 \times 1480 \times 300}{2000}$ = **697.08 RPM**
- This is 'Sub-Synchronous' appearing at 0.47 Orders (Below Motor Turning Speed

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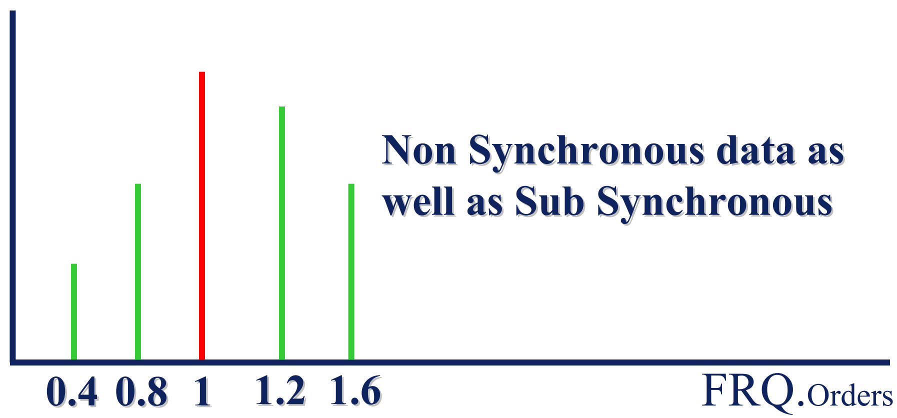
Belt Characteristics

- The diagram below indicates motor turning speed at 1 Order. Belt frequency is shown as sub-synchronous data (in this case at 0.4 Orders)
- As the belt defect gets worse, the number of harmonics increase
  - Usually 3x and 4x belt frequency appear as non-synchronous energy as they surpass 1x Turning speed
- To help distinguish the individual peaks high lines of resolution should be used - 1600 minimum



Belt Characteristics

- The fundamental belt frequency will always be Sub-synchronous
- Usually the harmonics of belt frequency drown the turning speed peak, so higher resolution data should be taken. This will distinguish the different frequencies more clearly
- Belt defects can be detected in the Axial and Radial plains. **Severity** is judged by the number and amplitude of the harmonics
- Some belt drives run noisily as far as vibration analysis is concerned

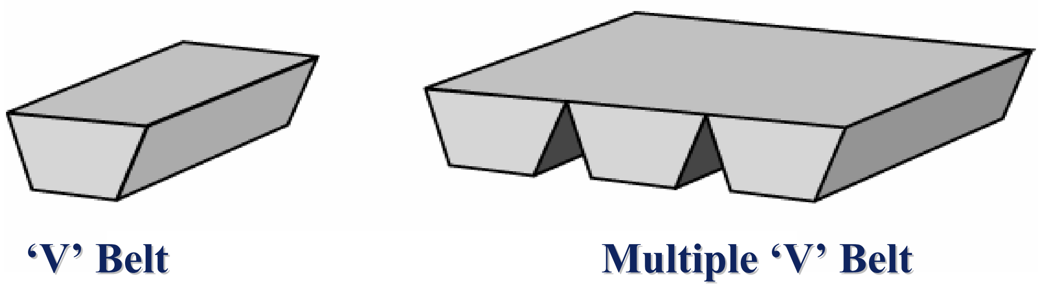
Belt Drives

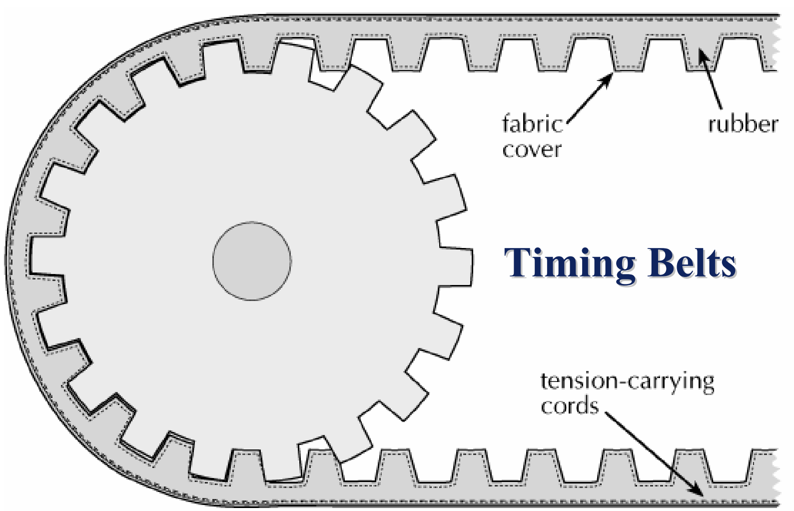
- The table shows various belt types related to their expected noise level
  - (Table taken from 'Handbook of Vibration' - Art Crawford CSi)
- **100** being the **lowest** vibration and **0** being the **highest.**

Belt Type	Severity
Endless Woven	100
Poly-V	60
Link (without rivets)	50
Link (with rivets)	40
Wide Angle	30
Timing	25
Multiple V	12
Standard V	10
Open End	5

Common Belt Types

- Shown below are the three most common types of pulley belts used in industry.
  - These generally produce a lot of vibration

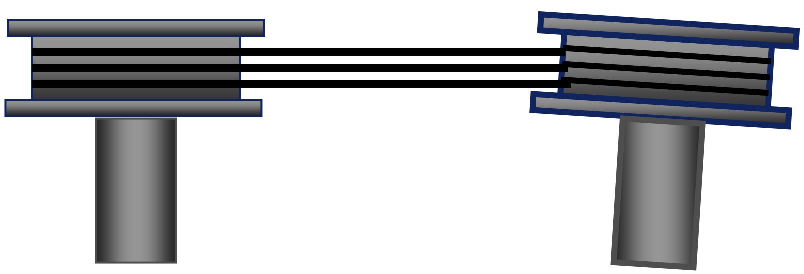




Timing belts are toothed belts that use their teeth for power transmission, as opposed to friction. This method results in no slippage.

Belt Misalignment

Offset Misalignment



Angular Misalignment

- Belt misalignment is one of the primary reasons for reduced belt life
- There are two types of belt misalignment:
  - Angular
  - Offset

For every 0.15cm (1.5mm) of misalignment per 30cm span (center to center). Very rapid belt wear will occur

Physical Observations

- An extremely effective technique for analyzing belt system faults is to use a strobe, in conjunction with your data collection
- Belt defects are often visible when the belts are frozen
- The CSi strobe can be connected to the 2120 and flashed at the monitoring frequency to help determine speeds and faults

Resonance

What is resonance

- Resonance is an excitation of ‘Natural Vibration’ (f_N).
- Everything has a ‘natural frequency’, everything vibrates!
- This f_N does not cause any problems until another vibration source runs at a same/similar frequency.
- When this happens the f_N excites the other vibration source causing increases in vibration amplitude.
  - Simply put - Resonance when excited is a vibration magnifier

Factors that Determine f_N

- The main characteristics that determine the specific f_N of a structure are:
  - 1) Stiffness
  - 2) Mass
  - <u>Stiffness</u>
  - What effect does 'Stiffness' have on the f_N ?

The stiffer or more rigid a structure is, the higher its natural frequency will be. The less stiff or rigid a structure is the lower natural frequency will be.

E.G. By tightening a guitar string, the rigidity increase and the pitch (Frequency) of the note increases. Similarly loosening the string reduces the rigidity and also the frequency!

Factors that Determine f_N

- <u>Mass</u>
- What effect does mass have on f_N?
- Mass has the opposite effect to stiffness
- The heavier the structure the lower the natural frequency.
- Using the guitar example:
  - The lower notes (frequency) are produced by the heavier strings
- There is one other factor associated with f_N, this is Dampening.
  - Dampening of a structure controls the ‘resonant response’. The higher the dampening effect the lower the amplitude of vibration, however it does not cure the resonating condition only controls the amplitude response

Resonance

- In order to have a resonant condition, two things are required:
  - 1) The right combination of stiffness and mass to create the natural frequency
  - 2) A source vibration that matches the natural frequency

- What can we do solve a resonance condition?
  - 1) Change the Mass
  - 2) Change the Stiffness
  - 3) Eliminate the Source
  - 4) Dampening

Resonance

- The key to solving a resonance problem is to determine whether or not the structure is vibrating due to a resonant condition or due to a mechanical influence.

- How can we tell if a machine is vibrating to resonance or some other influence?

There are several different indicators we can look for to help determine a resonant condition these are:

Resonance Analysis

- **Characteristics of Resonance**
  - Very directional in nature
  - Speed sensitive
  - Big increase in amplitude (5-20 x normal operating conditions)
  - Radial readings differ greatly from each other
    - Rule of thumb is a 3:1 ratio in amplitude

- Lets have a look at in more depth at the basic expectations of resonance in our data.

Resonance Analysis

- **Resonance in a Spectrum**
  - (What to look for)

- Resonance can occur at any frequency in our spectrum, E.G. Vane pass which will occur at NxRPM could be the exciting frequency of our resonance problem.

- However most machine designers eliminate resonant frequencies before we get the machine.

- The most common resonance frequency is a 1xTs and is usually related to the area surrounding our machine
  - Base Plates
  - Pipework

Resonance Analysis

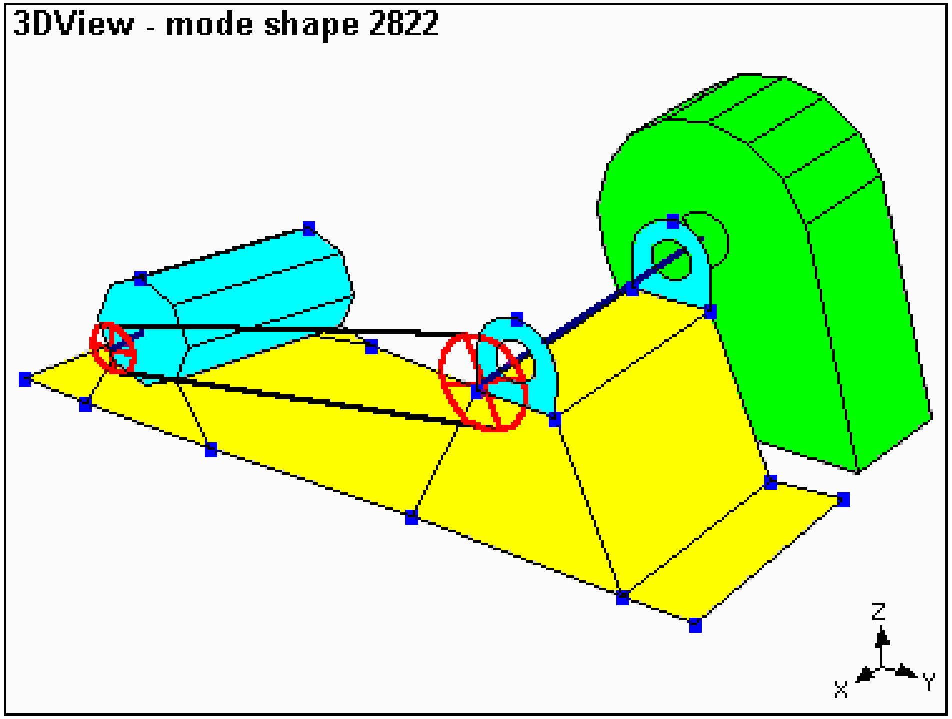
- So what we expect to see when our machine is in a resonant condition is a major increase in amplitude (usually at 1xTs)
  - Can often be mistaken for an Imbalance fault if precaution isn't taken

- There can be major differences in amplitude between horizontal and vertical readings (around 3:1 amplitude ratio)

- Resonance is also speed sensitive, a small increase or decrease in speed can have major effects on our amplitudes

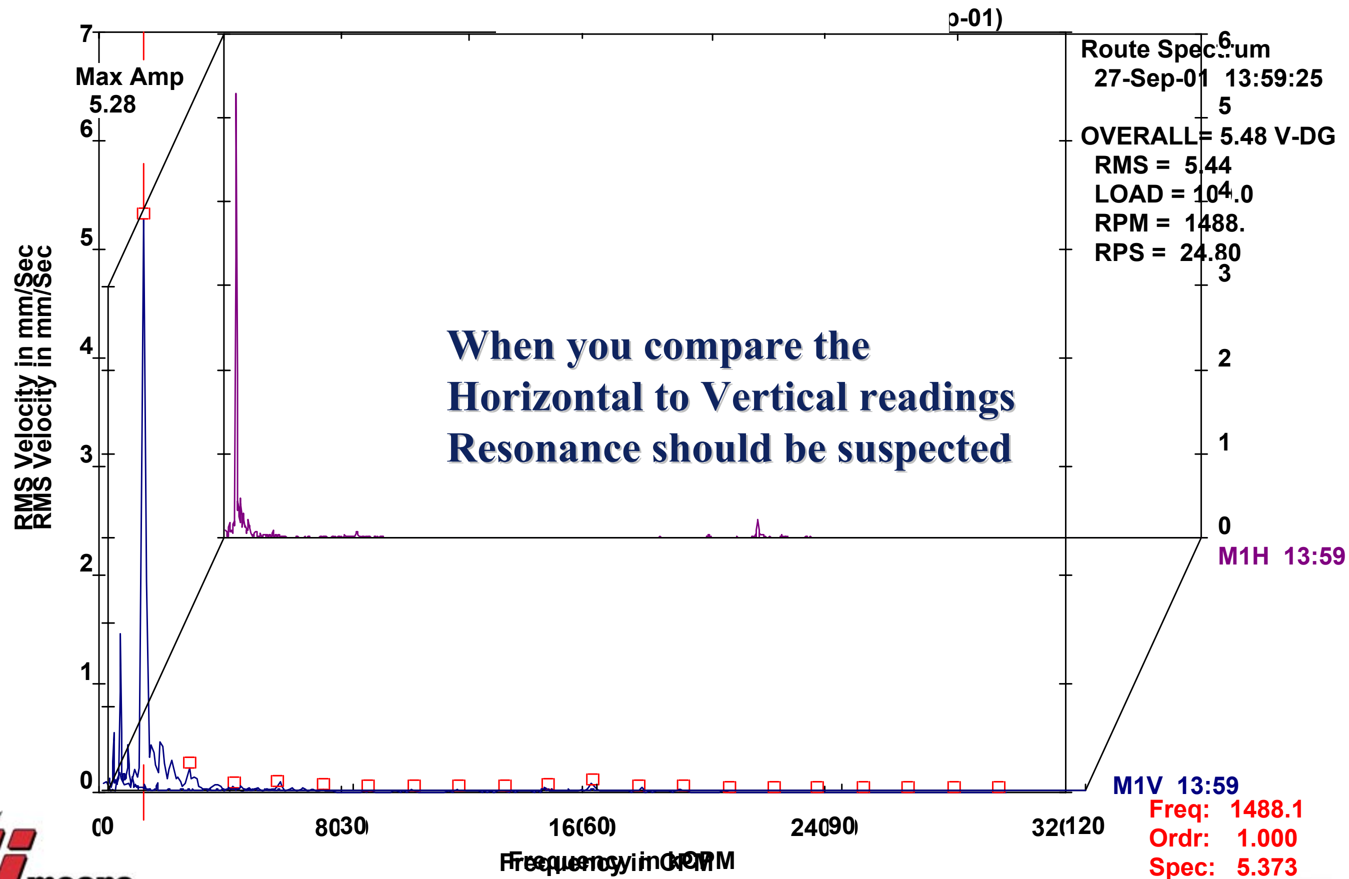
Resonance

- This picture shows the movement of a motor under resonant conditions
- Notice how the motor is moving in the vertical direction and not in the horizontal
- This is typical machine movement when in resonance



Resonance

- Have a look at the spectral data shown. The cursor indicates a 1xTs peak (1 Order). What Fault appears at 1xTs?



Resonance Summary!

- Stiffening your structure increases the Resonant Frequency
- Increasing mass decreases the resonant frequency
- Dampening does not remove resonance, it only controls the vibration amplitude
- Resonance does not have to appear at 1xTs. (Most cases it does)
- Resonance is directional in nature
  - Large amplitude differences between horizontal and vertical
  - Usually around a 3:1 amplitude ratio
- Speed affects resonance a lot, small changes in speed can produce large changes in amplitude

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Summary of Faults