

LA-UR-23-29530

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Title: Vibration Analysis Presented to the MMWG Predictive Maintenance User's Group.

Author(s): Foster, Michelle Elizabeth

Intended for: Maintenance Mangers Working Group (MMWG - 02) PdM User's Monthly Call

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Vibration Analysis

Presented to the MMWG Predictive Maintenance User's Group.

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Los Alamos National Laboratory
Maintenance Site Services – Maintenance Programs

6/13/2023

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What is Vibration?

- Movement of a body about a reference.
- Response to some form of excitation or a forcing function.



Vibration Analysis

What is Vibration Analysis?

Monitors the condition of rotating equipment by focusing on the mechanical vibration the equipment transmits.

Why do Vibration Analysis?

For very little investment (a few thousand dollars) you can protect millions of dollars of assets.

Vibration Analysis

Vibration Analysis is used to monitor:

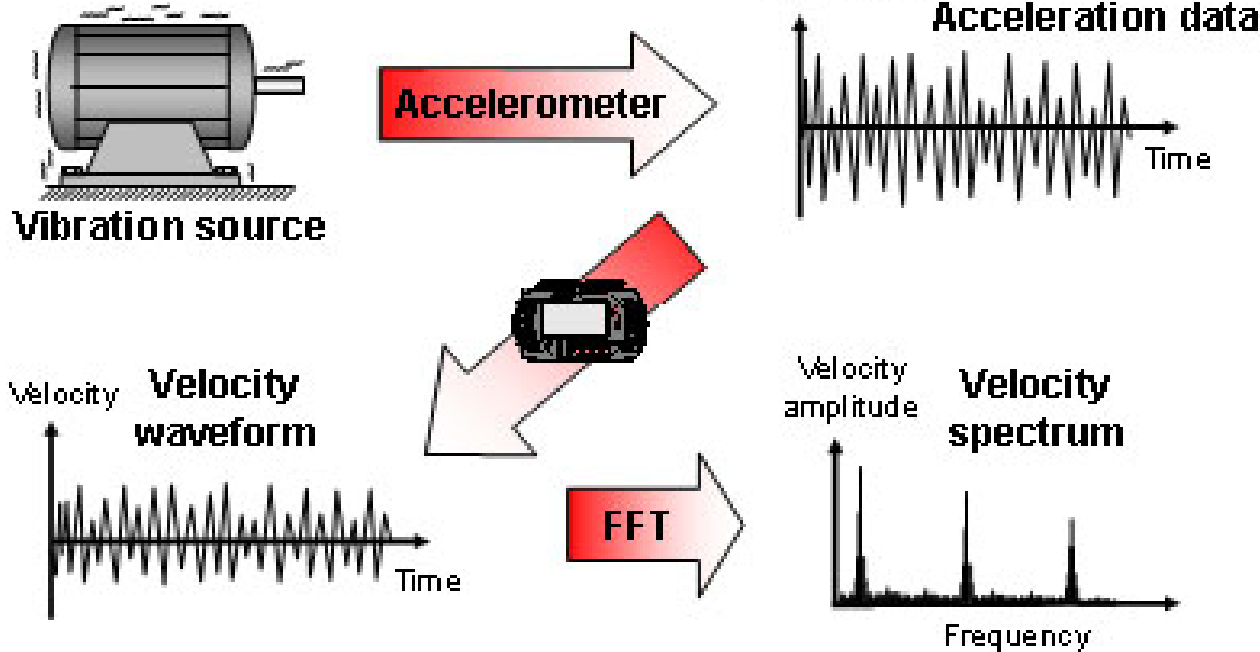
Fans
Pumps
Motors
Compressors
Chillers
Fixed Structures

Vibration Analysis is used to detect:

Bearing Problems
Belt Problems
Bent Shaft
Misalignment
Oil Whirl
Resonance
Cavitation
Recirculation

Gear Problems
Mechanical Looseness
Sheave Problems
Unbalance
Some Electrical Problems
Broken Rotor Bars
Loose Stators

Vibration Analysis - How Vibration Analyzers Work



1. The Accelerometer measures vibration from the source.
2. That measurement is integrated to velocity.
3. The data then goes through a Fast Fourier Transform (FFT) process and a spectrum is produced.
4. The FFT is analyzed

Source: *Beginner's Guide to Machine Vibration*

Vibration Analysis

Where measurements are taken – Medical Analogy

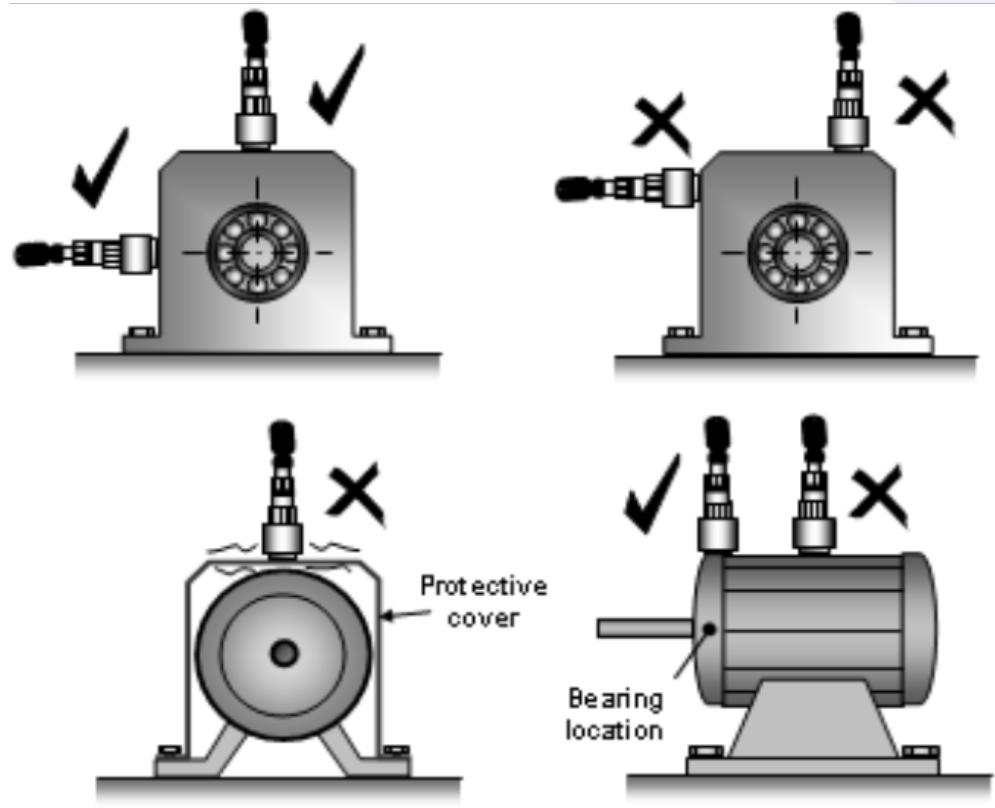


Measurements are taken closest to the heartbeat of the machine – the bearings

Source: *Beginner's Guide to Machine Vibration*

Data Collection techniques

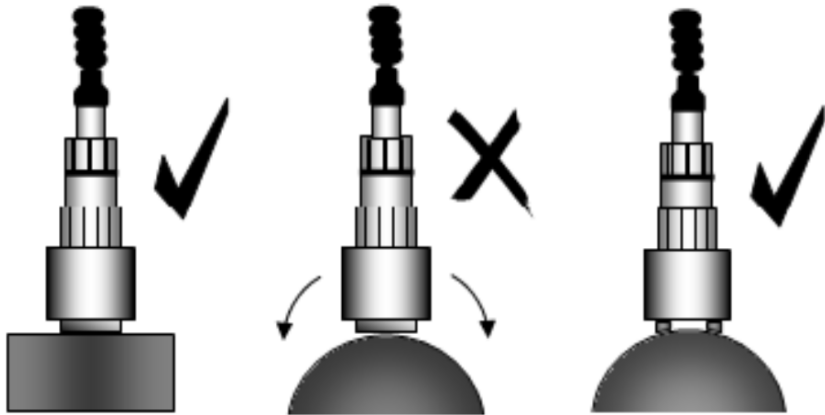
Placing the Accelerometer in the correct place on the machine



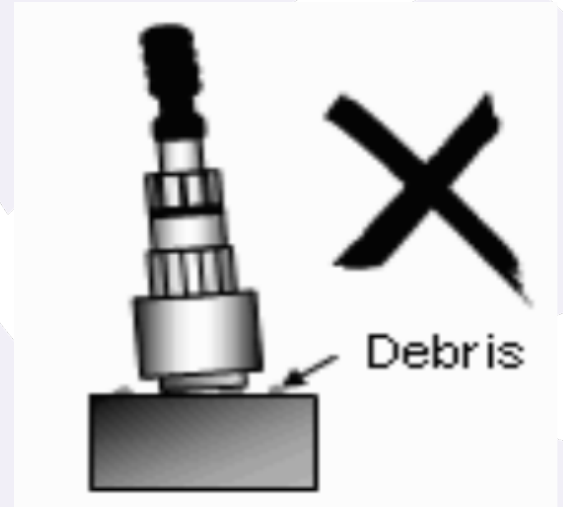
Source: *Beginner's Guide to Machine Vibration*

Data Collection techniques

Make Sure the Accelerometer is
Firmly Attached



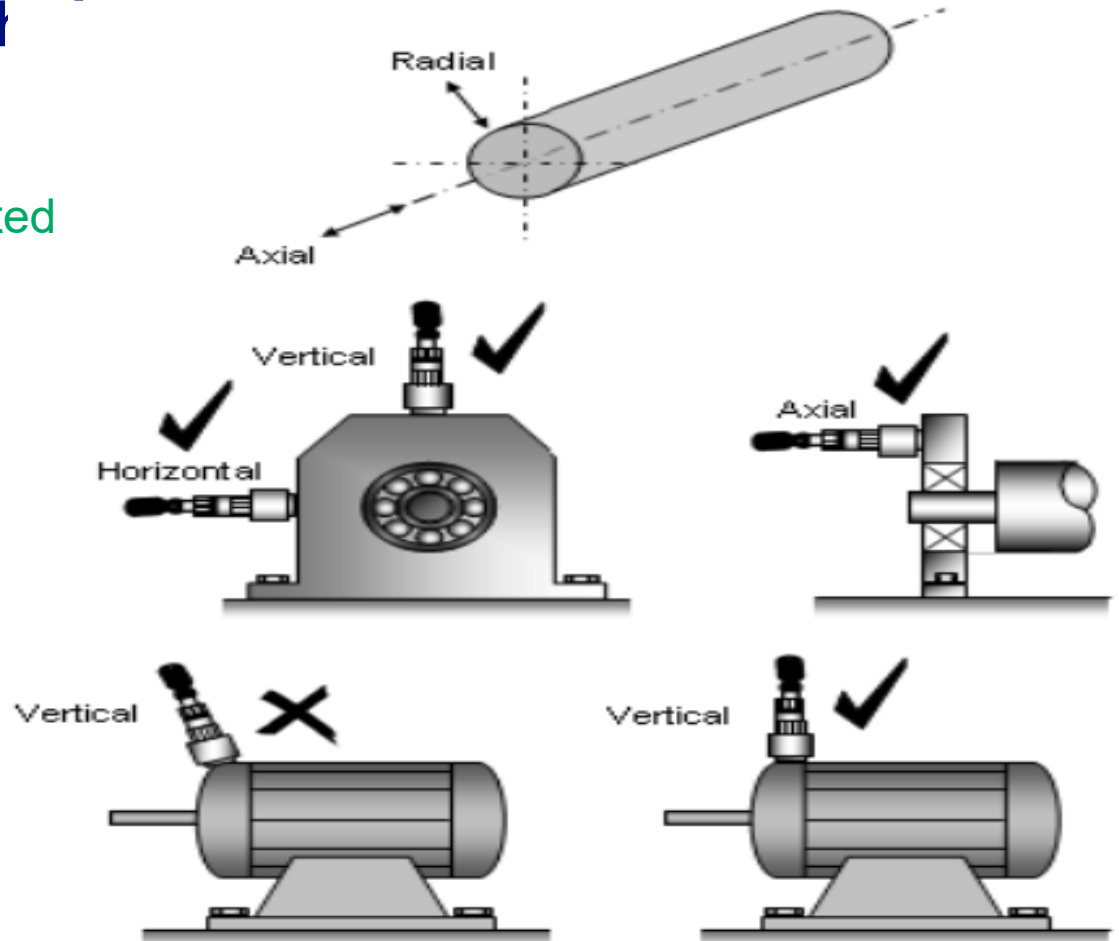
Make sure that the surface is
even, free of debris, rust, and
flaking paint.



Source: *Beginner's Guide to Machine Vibration*

Data Collection tech

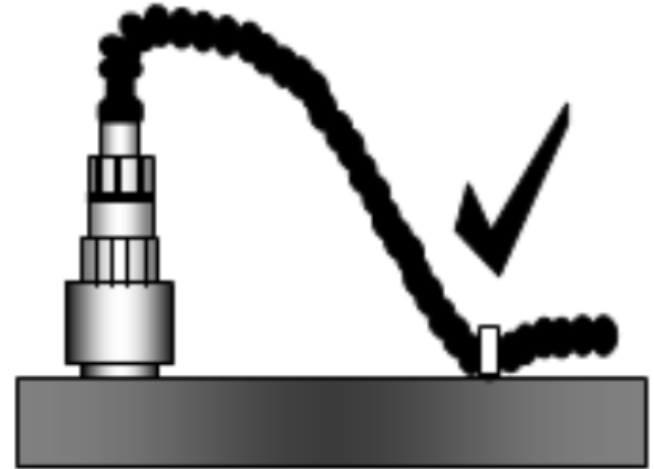
Make Sure the Accelerometer is Oriented Correctly



Source: *Beginner's Guide to Machine Vibration*

Data Collection techniques

Be careful with the cord

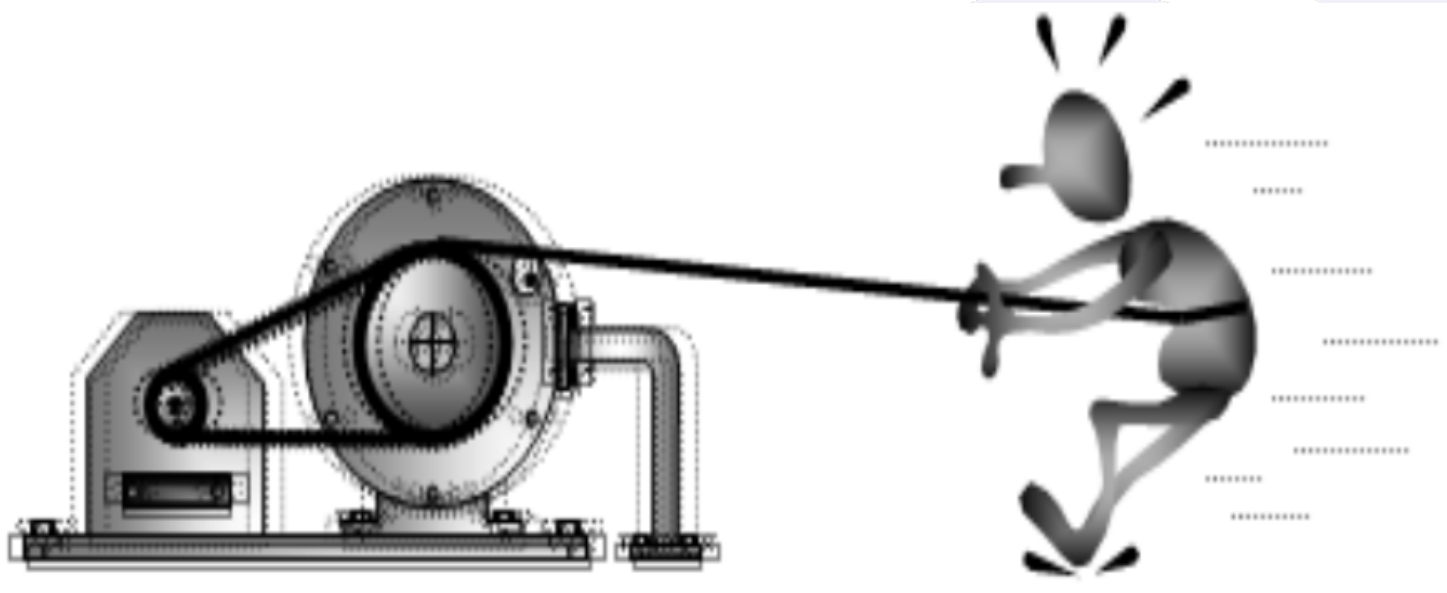


Source: *Beginner's Guide to Machine Vibration*

Data Collection techniques

Always...Always...Always...

SAFETY FIRST!



Remember that you are around rotating equipment so keep cords, lanyards, hair, etc. away from rotating parts.

Data Collection techniques

The Fast Fourier Transform (FFT) and how Vibration Analysis Works

Analyzing the FFT

FFT - Fast Fourier Transform

- Fourier Analysis
- Joseph Fourier – French Mathematician and Physicist (1768 – 1830)

Vibration Analysis

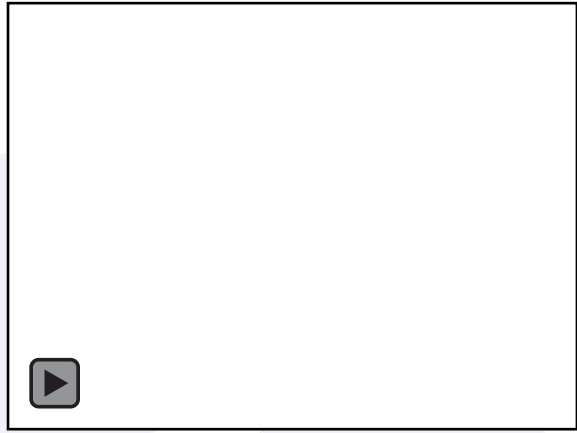
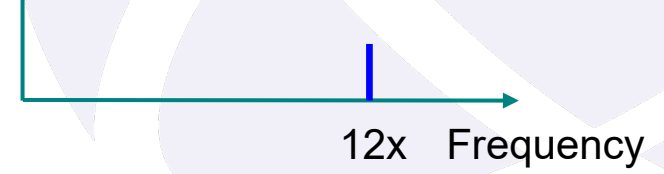
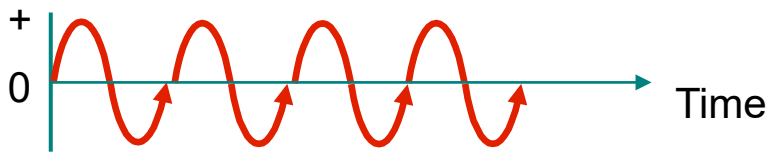
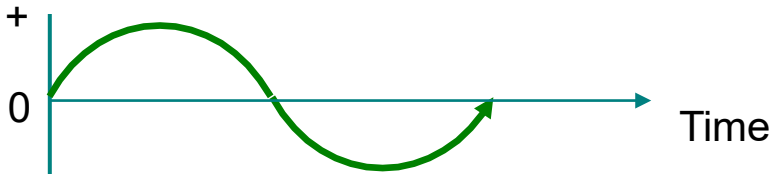
The Fast Fourier Transform and how Vibration Analysis Works

- In 1822 - **Baron Jean Baptiste Fourier (1768-1830)** proposed the idea that the motion of a system in equilibrium, with a complex waveform, could be represented as the sum of many different sine waves of varying frequencies and amplitudes.
- The Fourier transform breaks down complicated waveforms into sine waves. It is a series of equations that identifies all of the frequency components of the waveform.
- **FFT** is an acronym for **F**ast **F**ourier **T**ransform. An FFT is an algorithm that combines groups of identical terms in an orderly fashion.

Vibration Analysis

The Fast Fourier Transform and how Vibration Analysis Works

Time Waveform

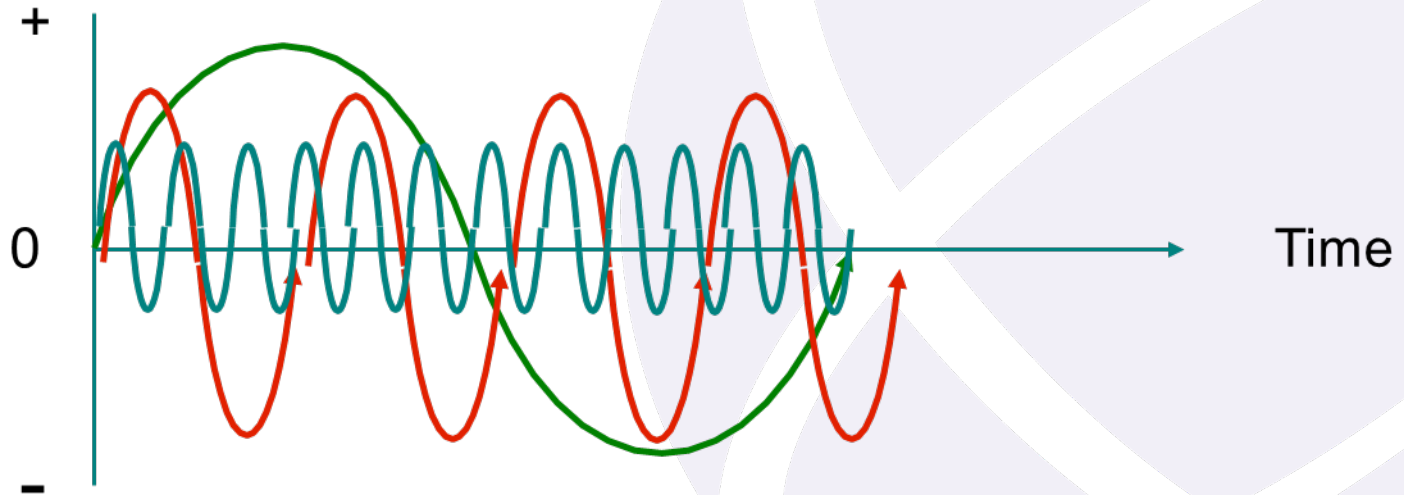


Vibration Analysis

The Fast Fourier Transform and how Vibration Analysis Works

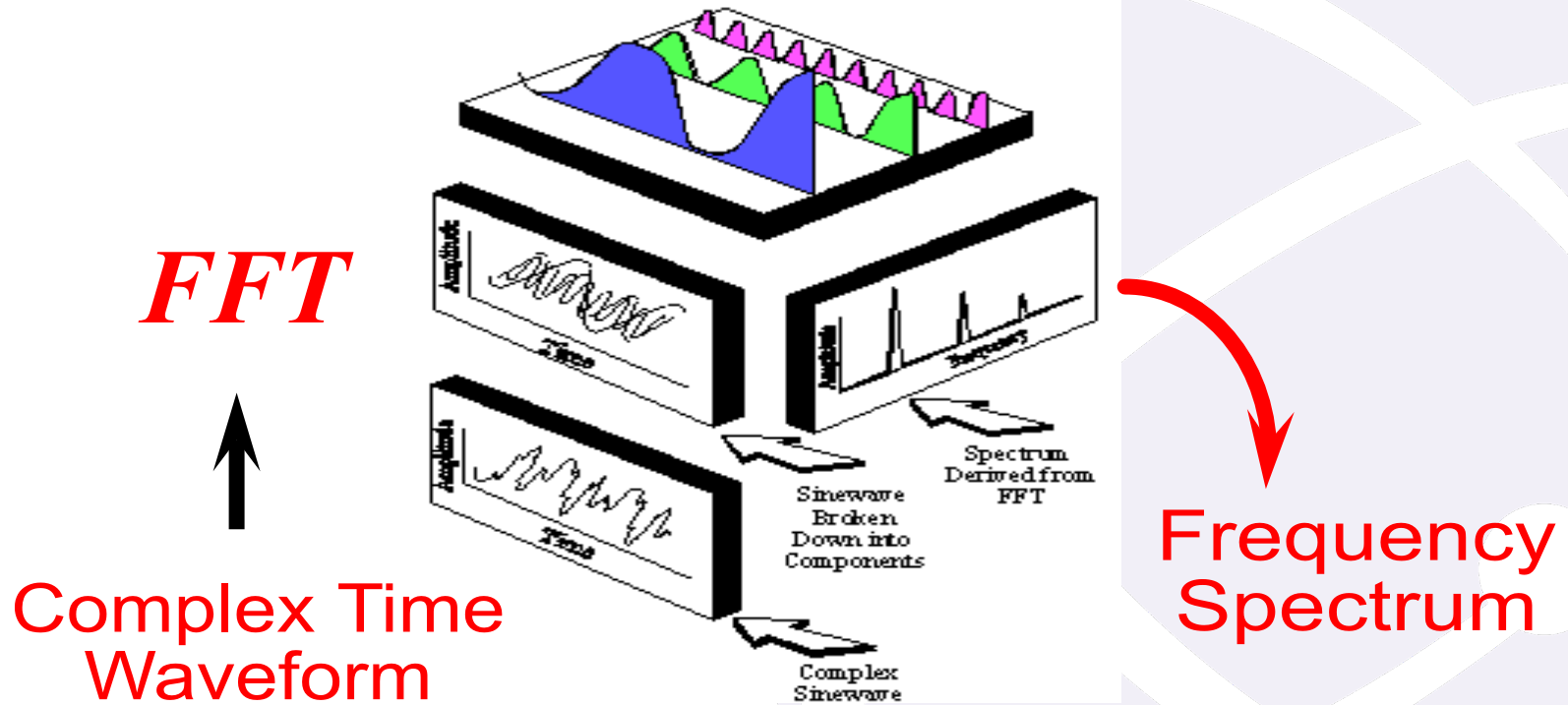
Time Waveform

Time Waveform contains all the different frequencies mixed together



Vibration Analysis

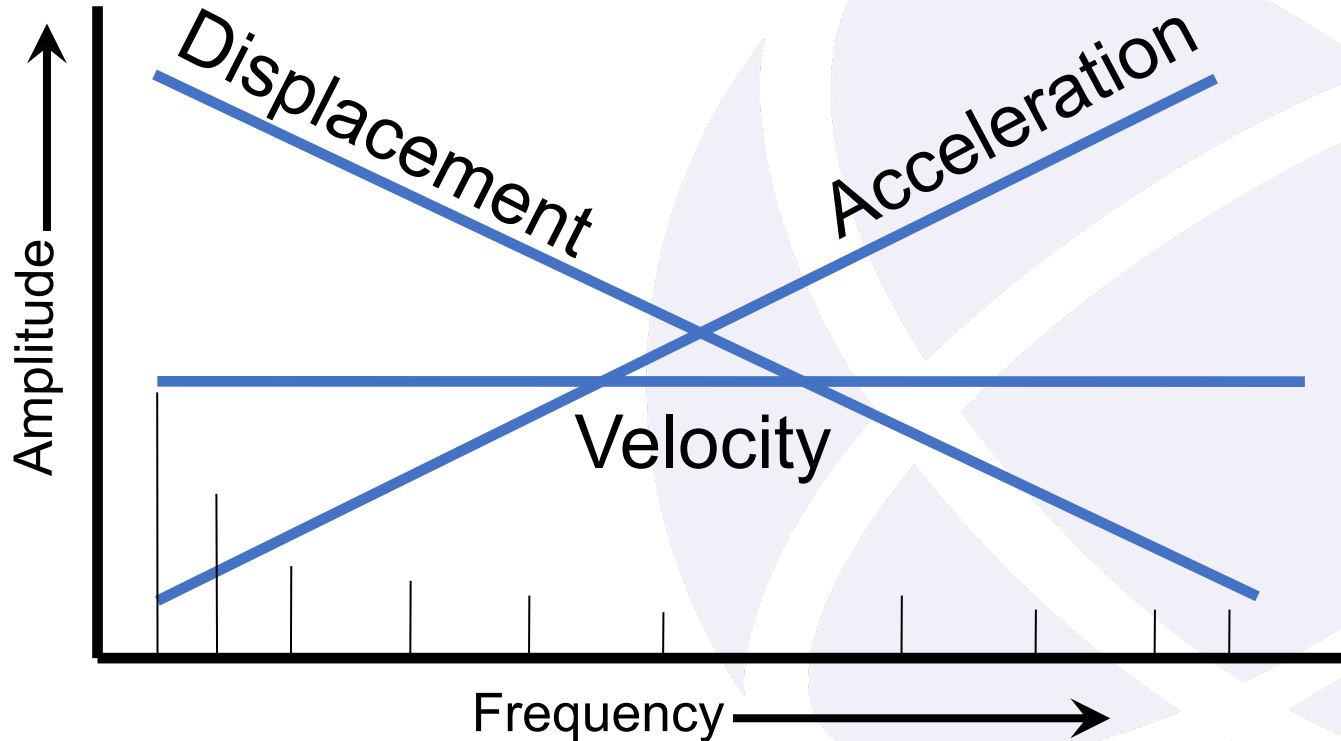
The Fast Fourier Transform and how Vibration Analysis Works



Vibration Analysis

How Vibration Analysis Works – Signal Processing

Why the most common unit is Velocity



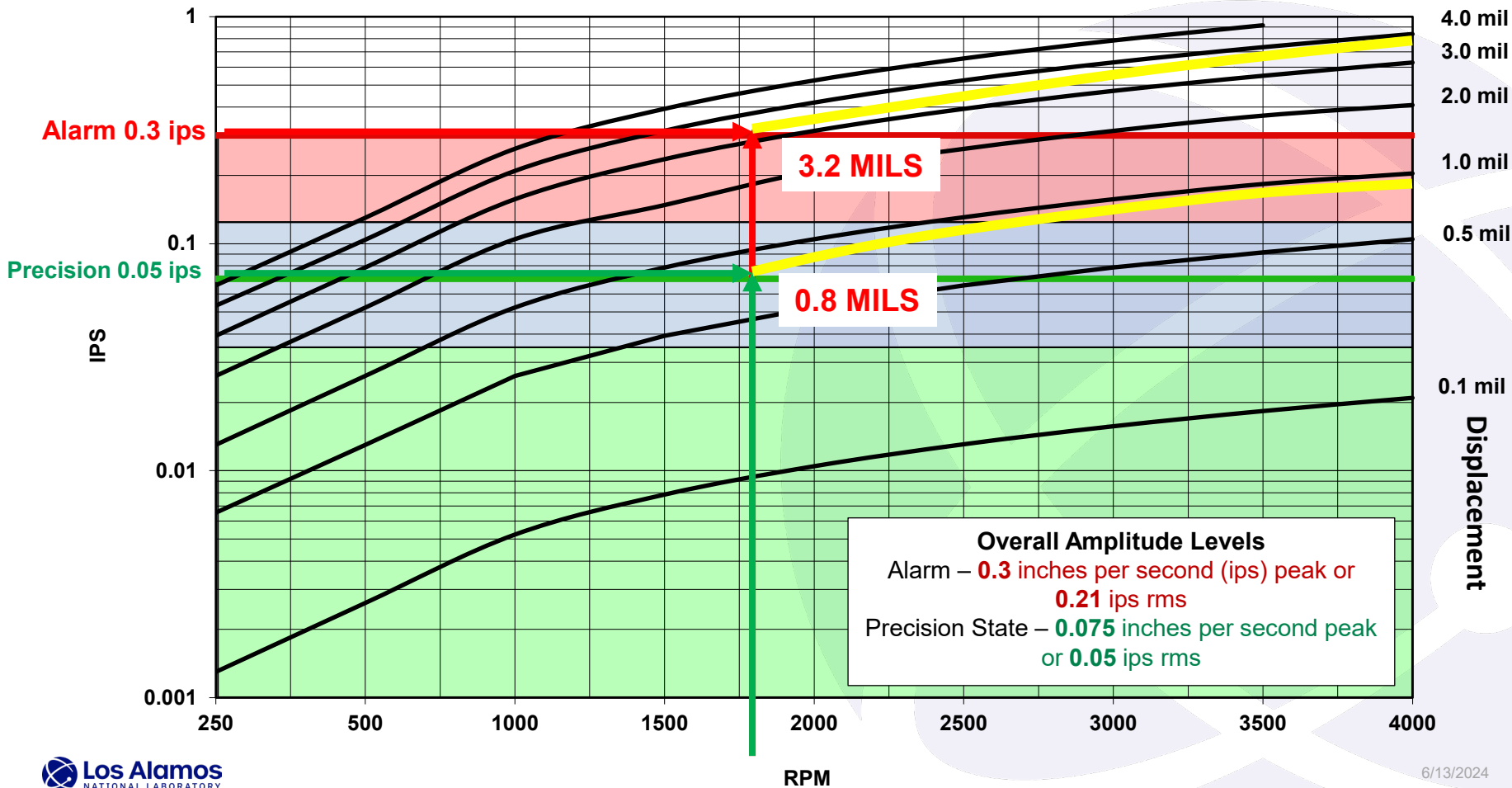
Vibration Analysis

The Fast Fourier Transform (FFT) and how Vibration Analysis Works Analyzing the FFT

When peaks are seen – The Analyst asks the following questions.

- *What are the peaks?*
- *Are they supposed to be there?*
- *What is the severity?*
- *Is it reportable or does it go on or stay on the watch list?*
- *Does another technology confirm or not confirm the problem? What does that technology tell you?*
- *When should maintenance be performed?*

Alarm Limits – Why these general alarm limits were selected

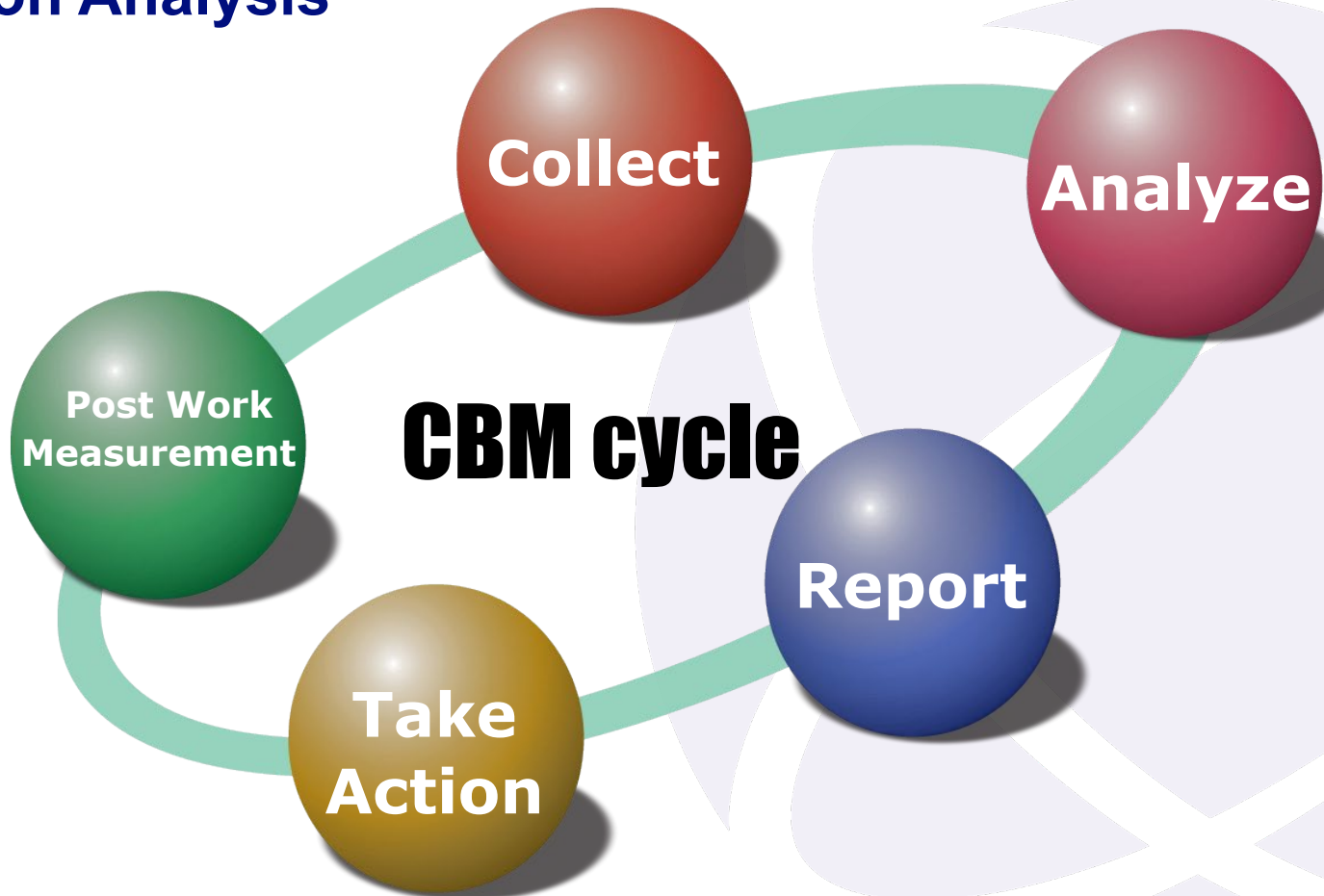


Vibration Analysis

Benefits of Condition Monitoring

- ☺ Can monitor while running – no outage needed most of the time.
- ☺ Service only when needed.
- ☺ More effective planning and scheduling of maintenance work / resources.
- ☺ Increased equipment reliability = availability.
- ☺ Minimizes catastrophic machinery failures.
- ☺ Reduces maintenance costs.
- ☺ Reduces unscheduled/unplanned maintenance.
- ☺ Optimizes machinery performance.
- ☺ Minimizes the possibility that machinery repairs are the wrong repairs.
- ☺ Reduces the time to make machinery repairs.
- ☺ Provides support to the design phase of equipment development.
- ☺ Provides exclusive control of machines that show the beginning of a malfunction.

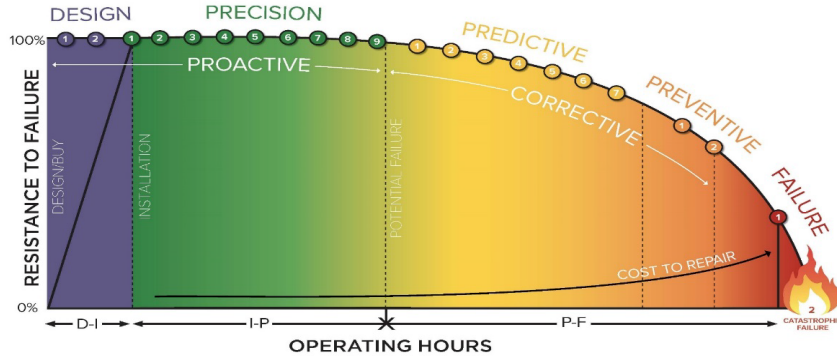
Vibration Analysis



Vibration Analysis

HOW
FAILURE
OCCURS

D-I-P-F CURVE (DESIGN-INSTALLATION-POTENTIAL FAILURE-FAILURE)



Attribution/Inspiration: The D-I-P-F curve was originally developed by Doug Plucknetic, Certified Reliability Leader. Author: RCM 68r (ISBN: 978-0-9838741-6-4) and further modified/evolved by Brian Heimuss, Certified Reliability Leader

DESIGN/BUY

- 1 Design for Reliability (DFR)
- 2 Purchase for Purpose

PRECISION

- 1 Precision Commissioning
- 2 Precision Installation
- 3 Defect Elimination
- 4 Precision Alignment and Balancing
- 5 Work Processes and Procedures
- 6 Asset Condition Management
- 7 Lubrication Reliability
- 8 Clean to Inspect (5S)
- 9 Operate for Reliability

PREDICTIVE

- 1 Condition Directed Tasks
- 2 Ultrasound Testing (UT)
- 3 Fluid Analysis (FA)
- 4 Vibration Analysis (VIB)
- 5 Motor Testing (MT)
- 6 Infrared Imaging (IR)
- 7 Non Destructive Testing (NDT)

PREVENTIVE

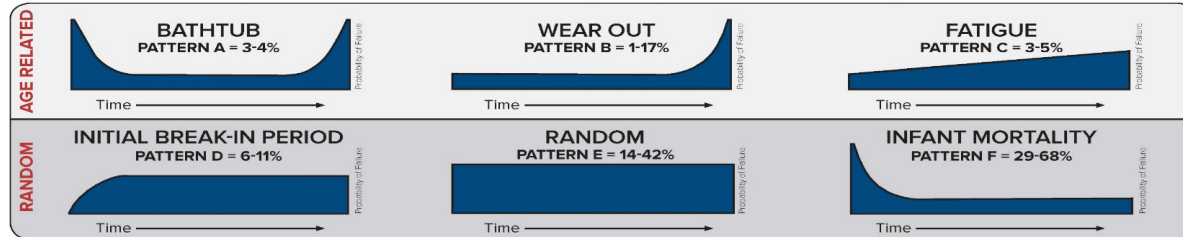
- 1 Time-Directed Tasks
- 2 Human Senses (audible noise, hot to touch, smell)

FAILURE

- 1 Functional Failure
- 2 Catastrophic Failure

FAILURE PATTERNS

Random failures account for 77-92% of total failures and age related failure characteristics for the remaining 8-23%.



Failure Pattern Percentages Sources: RCM by Nowlan and Heagy, US Navy, Bromberg



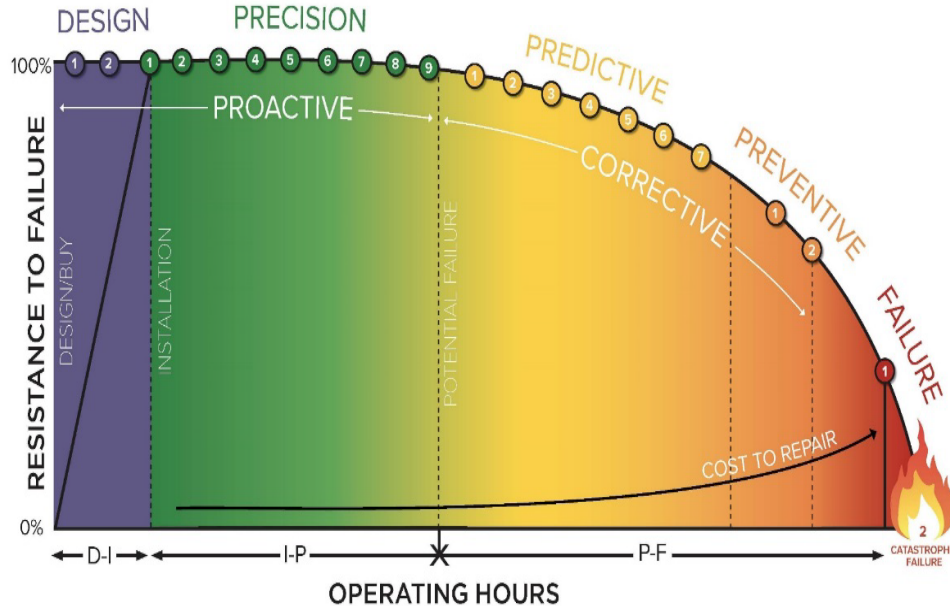
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Vibration Analysis

HOW FAIL

D-I-P-F CURVE (DESIGN-INSTALLATION-POTENTIAL FAILURE-FAILURE)



Attribution/inspiration: The D-I-P-F curve was originally developed by Doug Plucknette, Certified Reliability Leader, Author, *RCM B2i2* (ISBN: 978-0-9838741-6-4) and further modified/revolved by Brian Heinsius, Certified Reliability Leader

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PREDICTIVE

- 1 Condition Directed Tasks
- 2 Ultrasound Testing (UT)
- 3 Fluid Analysis (FA)
- 4 Vibration Analysis (VIB)
- 5 Motor Testing (MT)
- 6 Infrared Imaging (IR)
- 7 Non Destructive Testing (NDT)

PREVENTIVE

- 1 Time-Directed Tasks
- 2 Human Senses (audible noise, hot to touch, smell)

FAILURE

- 1 Functional Failure
- 2 Catastrophic Failure

Vibration Analysis

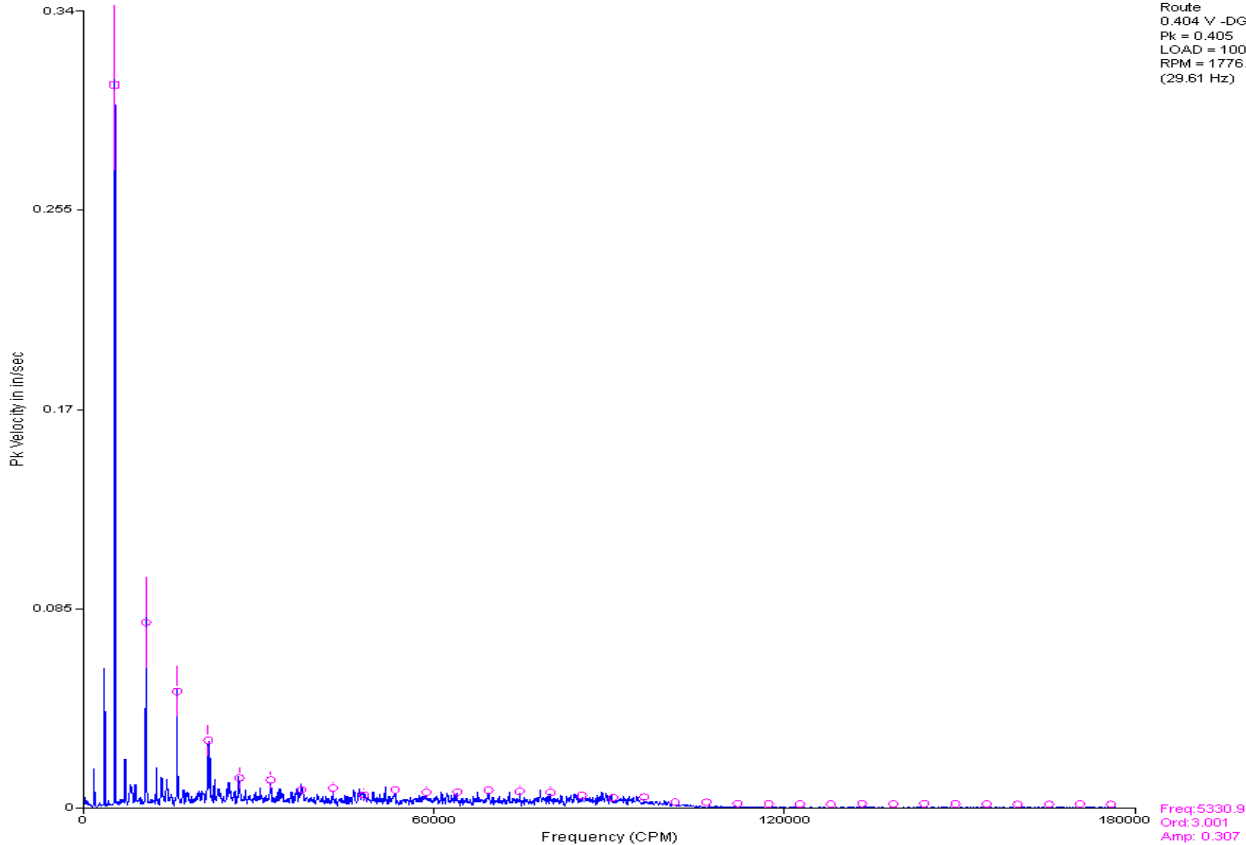
Case Histories

Vibration Analysis

Case History #1A & 1B Hot Water Pumps 24 and 25 Motor bearing faults

Vibration Analysis

ta3-132.rbm / 132 / PHW-24 TA3-132 RM170R
MIV - Motor Inboard Vertical



PHW-24

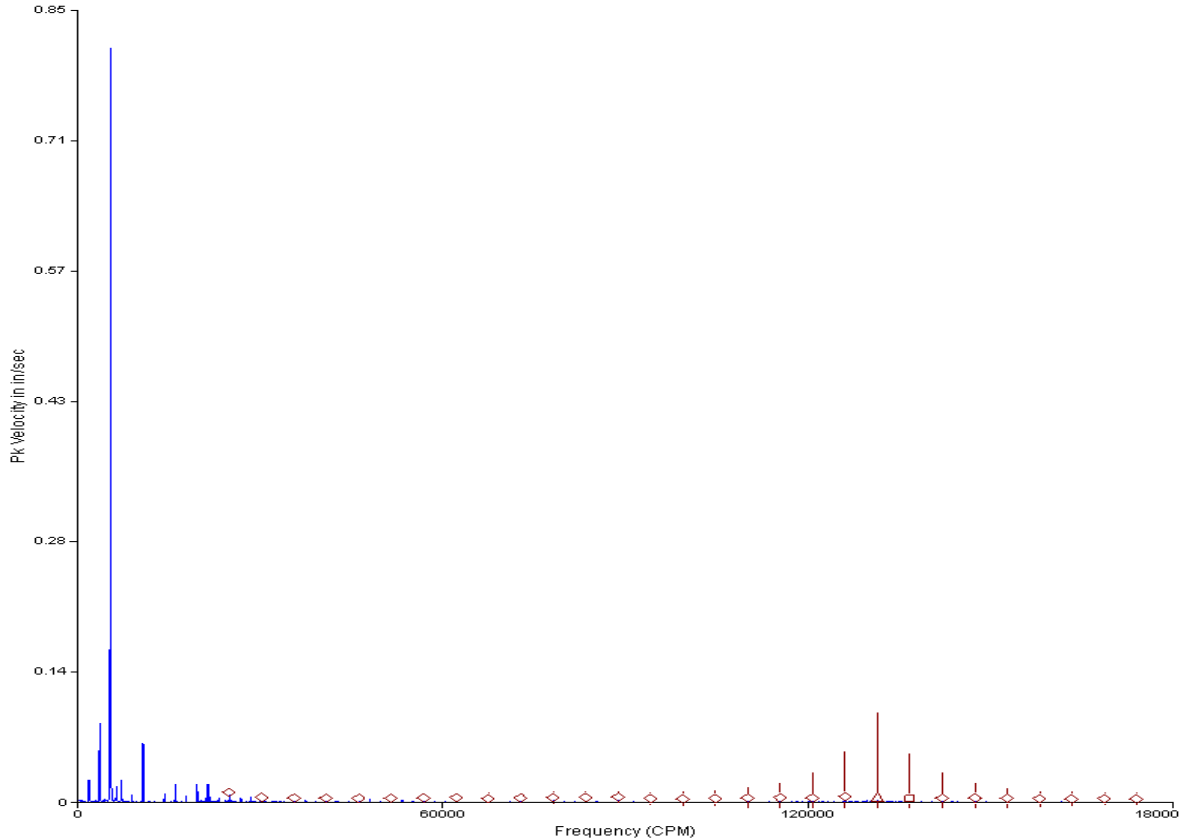
Motor - Drive end data.

Vibration Spectra in normal scale.

Pink cursors indicate misalignment and harmonics.

Vibration Analysis

ta3-132.rbm / 132 / PHW-24 TA3-132 RM170R
MOA - Motor Outboard Axial



7/17/2019 8:09:08 AM
Route
0.902 V -DG
Pk = 0.898
LOAD = 100.00
RPM = 1777.3
(29.62 Hz)

PHW-24

Motor Non - Drive end
data.

Vibration Spectra in
normal scale.

Dark red cursors indicate
a bearing fault but it is
difficult to see.

There is also a very high
3x peak which is an
indicator of misalignment.

The analyst's theory is
that because this motor
ran misaligned, it
developed the bearing
fault.

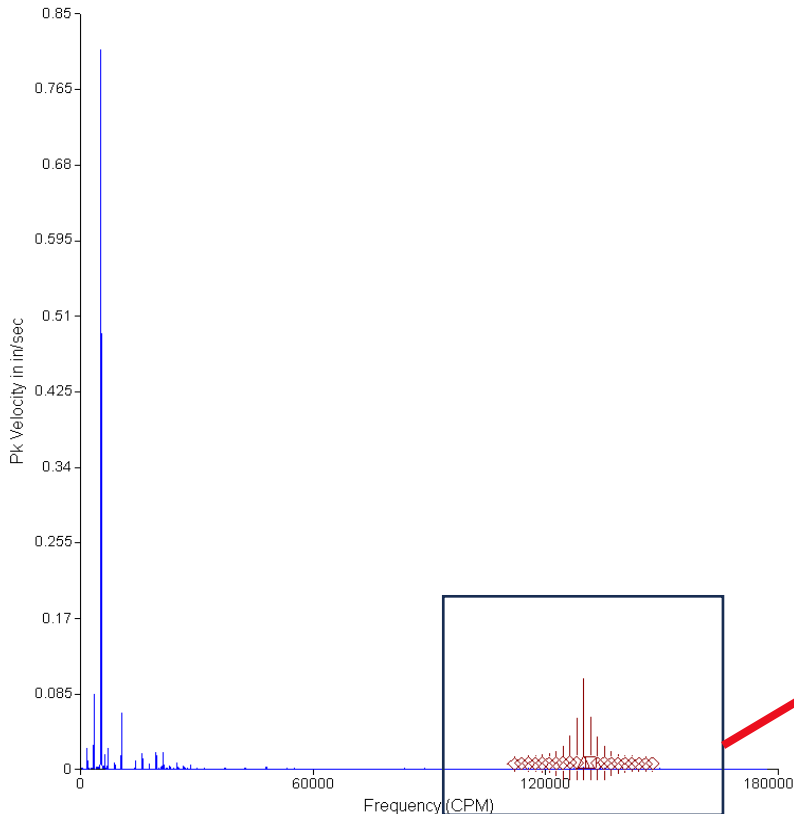
Reference:
Freq:131502.6
Ord:73.99
Amp: 0.00213

Primary:
Freq:136833.9
Ord:76.99
Amp: 0.00076

Dfreq:5331.3

Vibration Analysis

ta3-132.rbm / 132 / PHW-24 TA3-132 RM170R
MOA - Motor Outboard Axial



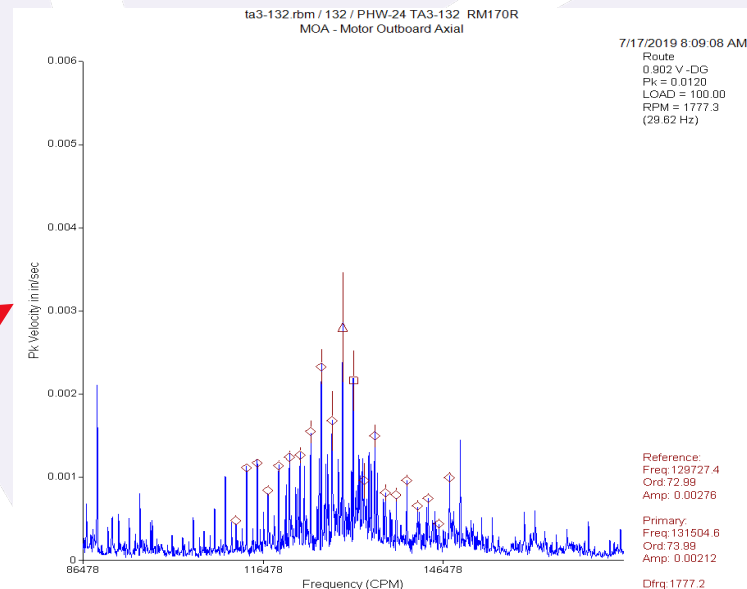
PHW-24

Motor Non - Drive end data.

Dark red cursors indicate a bearing fault. The bearing fault is accentuated below

There is also a very high 3x peak which is an indicator of misalignment.

The analyst theory is that because this motor ran misaligned, it developed the bearing fault.

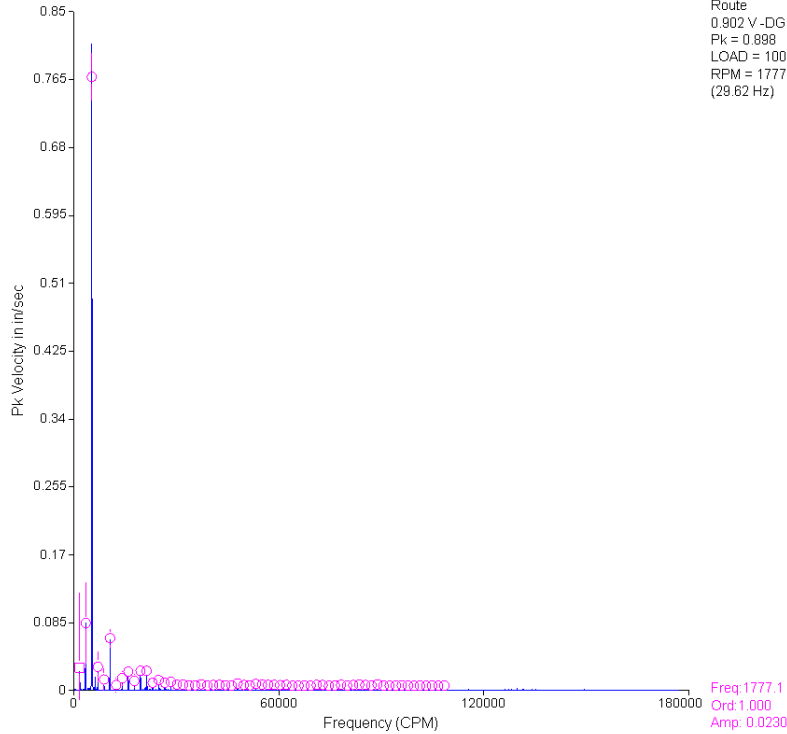


Vibration Analysis

PHW-24 - Data before and after repair

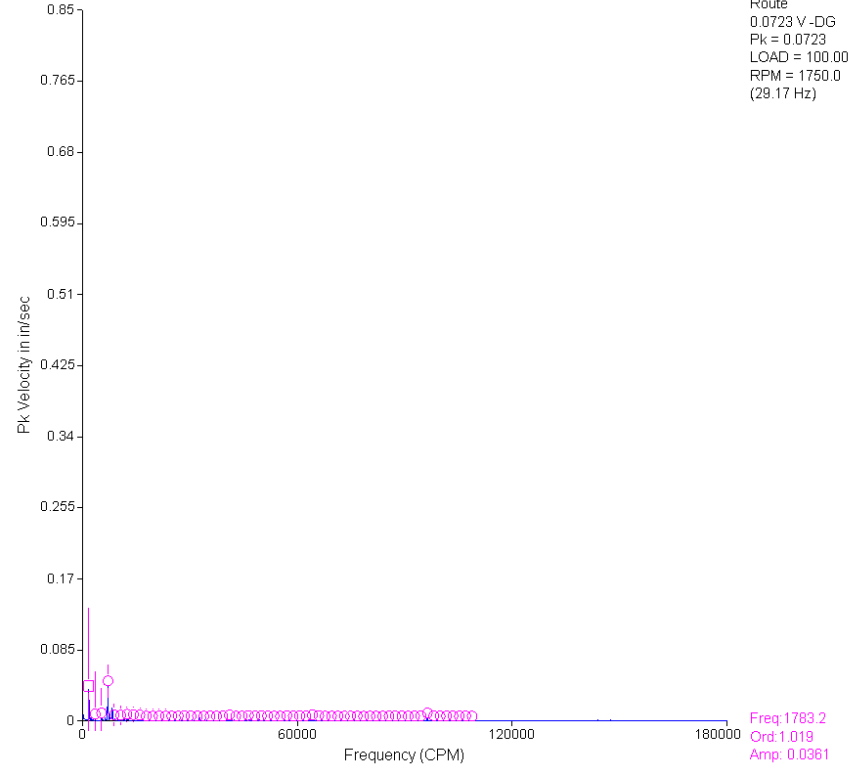
ta3-132.rbm / 132 / PHW-24 TA3-132 RM170R
MOA - Motor Outboard Axial

7/17/2019 8:09:08 AM
Route
0.902 V-DG
Pk = 0.898
LOAD = 100.00
RPM = 1777.3
(29.62 Hz)



ta3-132.rbm / 132 / PHW-24 TA3-132 RM170R
MOA - Motor Outboard Axial

1/5/2021 12:24:12 PM
Route
0.0723 V-DG
Pk = 0.0723
LOAD = 100.00
RPM = 1750.0
(29.17 Hz)

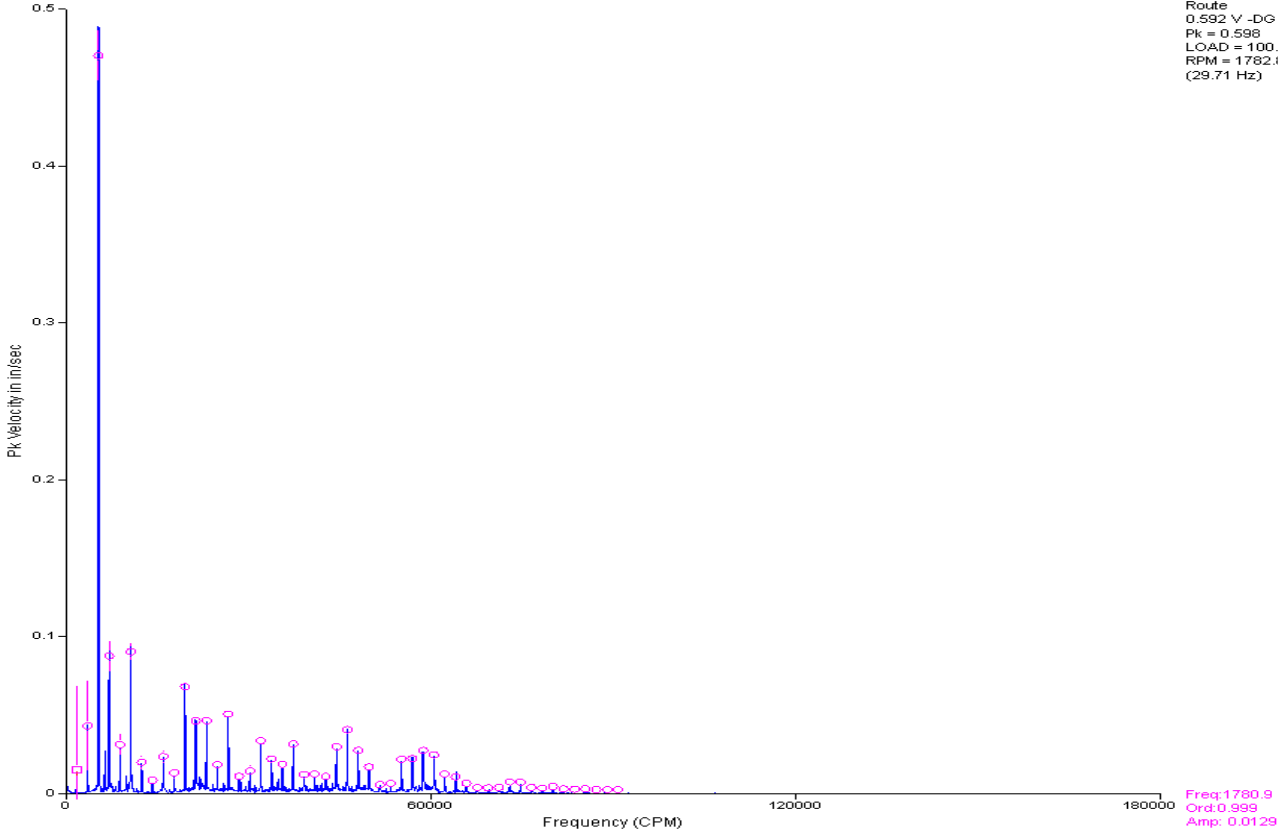


Vibration Analysis

Case History #2B Hot Water Pump 25 Motor bearing fault

Vibration Analysis

ta3-132.rbm / 132 / PHW-25 TA3-132 RM170R
MOA - Motor Outboard Axial



PHW-25

Motor – Non-Drive end data.

Vibration Spectra in normal scale.

Pink cursors are multiples of turning speed – an indication of looseness.

There is also a very high 3x peak which is an indicator of misalignment.

The analyst's theory is that because this motor ran misaligned, it developed the bearing fault.

This bearing fault had advanced to where there are clearances being developed and thus the looseness pattern.

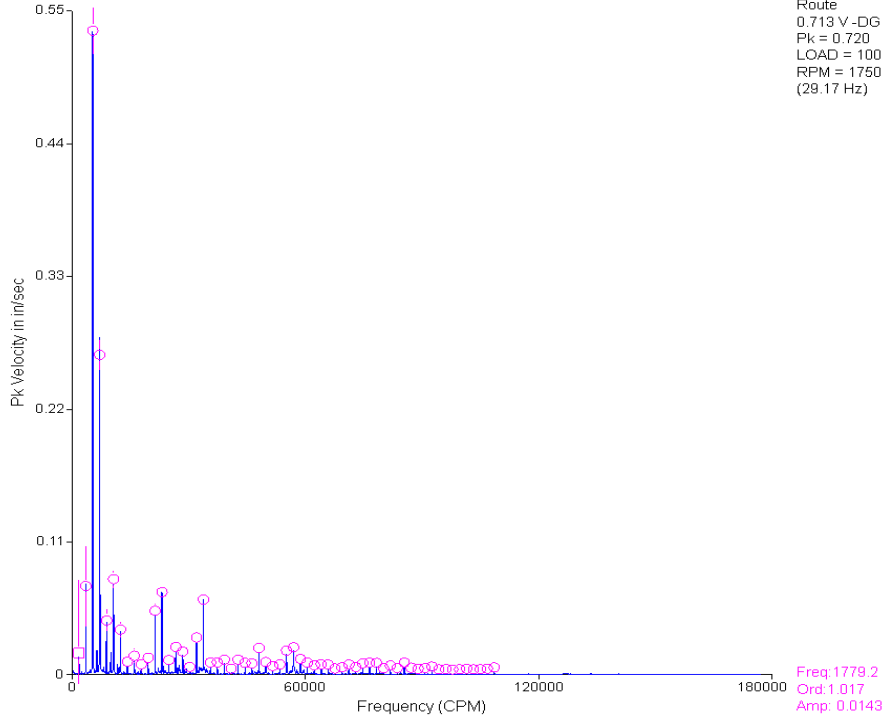
Vibration Analysis

PHW-25 - Data before and after repair

ta3-132.rbm / 132 / PHW-25 TA3-132 RM170R
MOA - Motor Outboard Axial

10/9/2019 8:20:46 AM

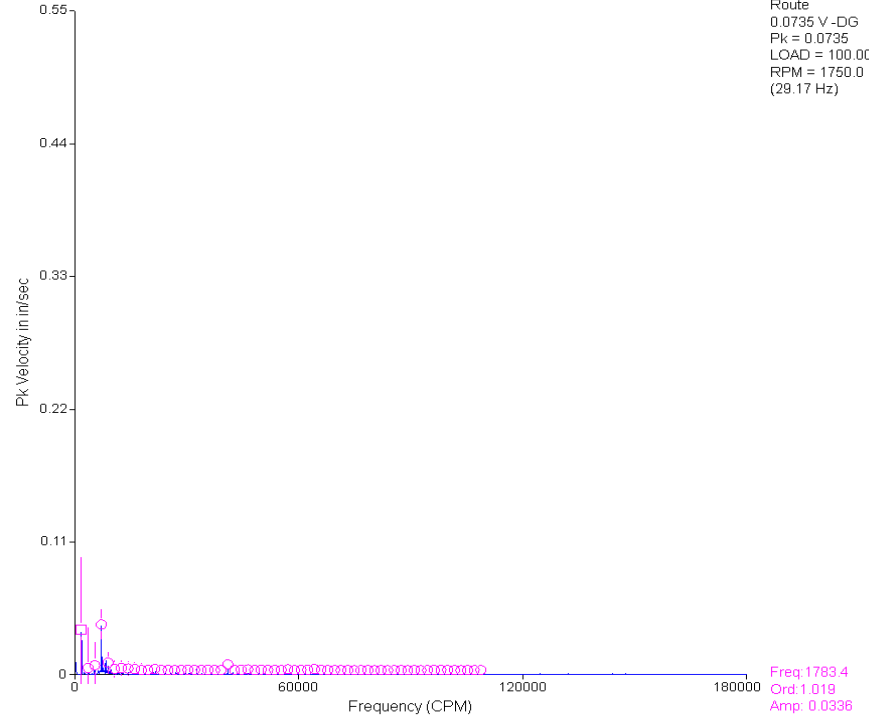
Route
0.713 V-DG
Pk = 0.720
LOAD = 100.00
RPM = 1750.0
(29.17 Hz)



ta3-132.rbm / 132 / PHW-25 TA3-132 RM170R
MOA - Motor Outboard Axial

9/30/2020 2:17:59 PM

Route
0.0735 V-DG
Pk = 0.0735
LOAD = 100.00
RPM = 1750.0
(29.17 Hz)



Vibration Analysis

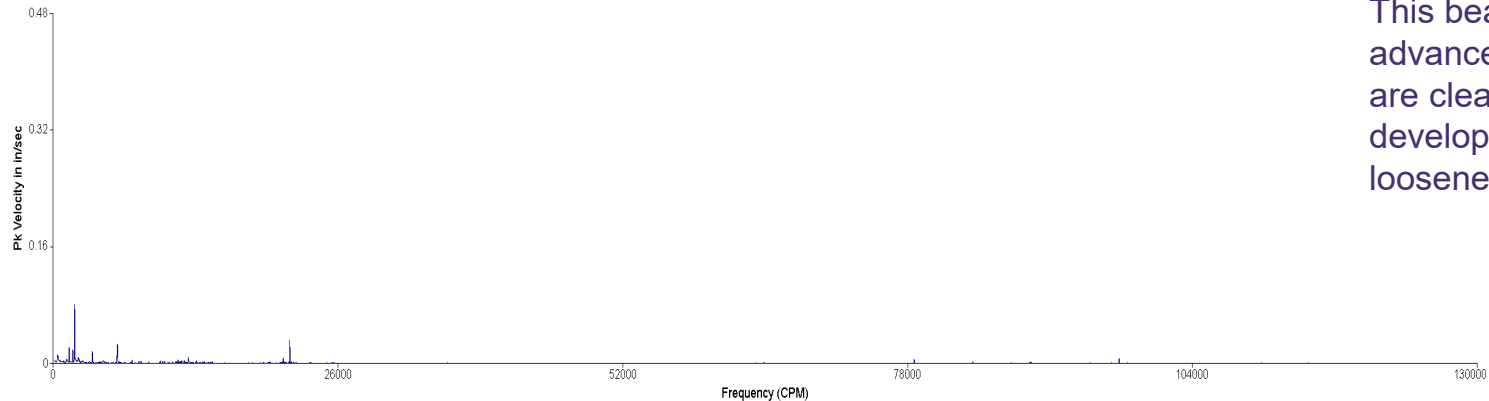
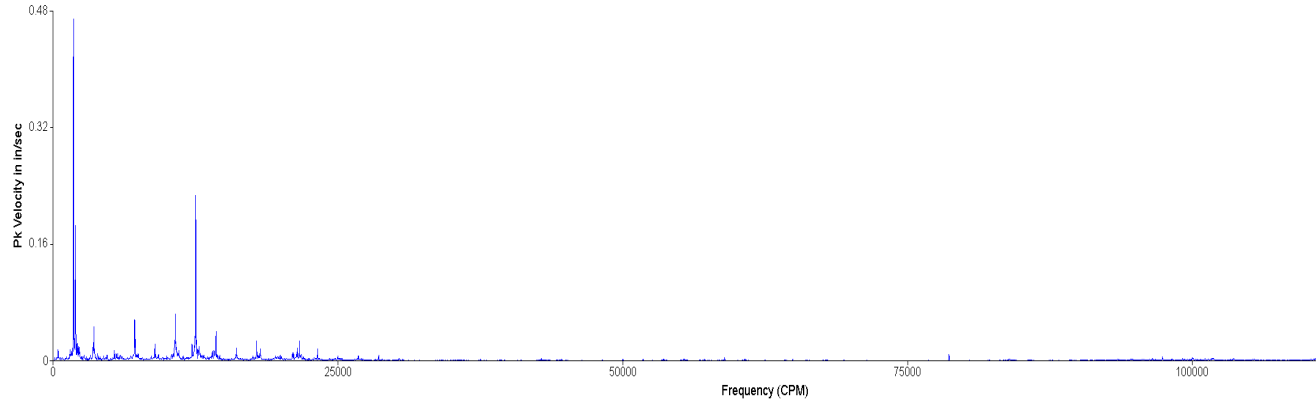
Case History #3

FE-004

Motor and Fan bearing faults

Vibration Analysis

ta16.rbm / 205 / FE-4 Fan / MOH - Motor Outboard Horizontal



FE - 004 Motor – Non -Drive end horizontal data.

Vibration Spectra in normal scale before and after fault developed.

The analyst findings is that this motor has developed the bearing fault.

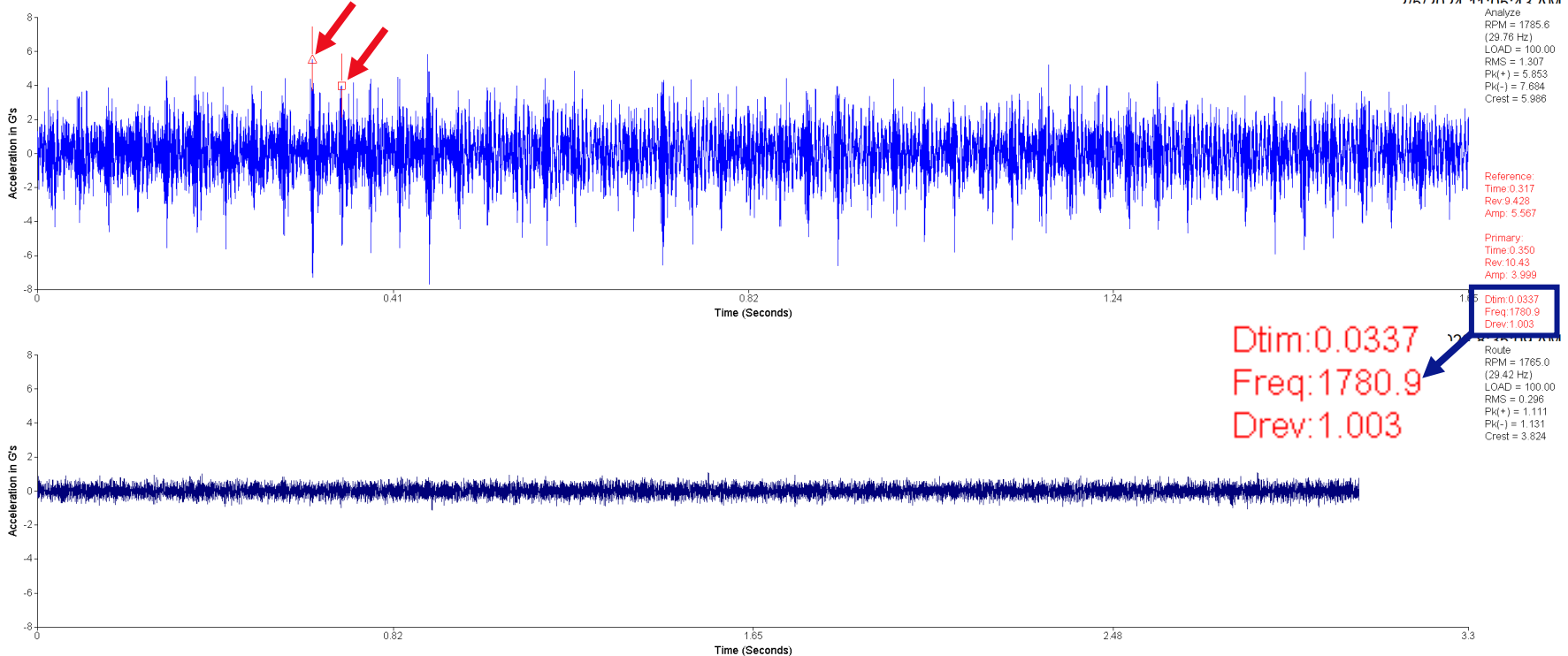
The peaks are 1 times turning speed.

This bearing fault had advanced to where there are clearances being developed and thus the looseness pattern.

Vibration Analysis

ta16.rbm / 205 / FE-4 Fan / MOH - Motor Outboard Horizontal

2/5/2024 11:05:43 AM



FE – 004 - Motor – Non-Drive end horizontal data.

Vibration Waveform (Raw Data) before and after fault developed.

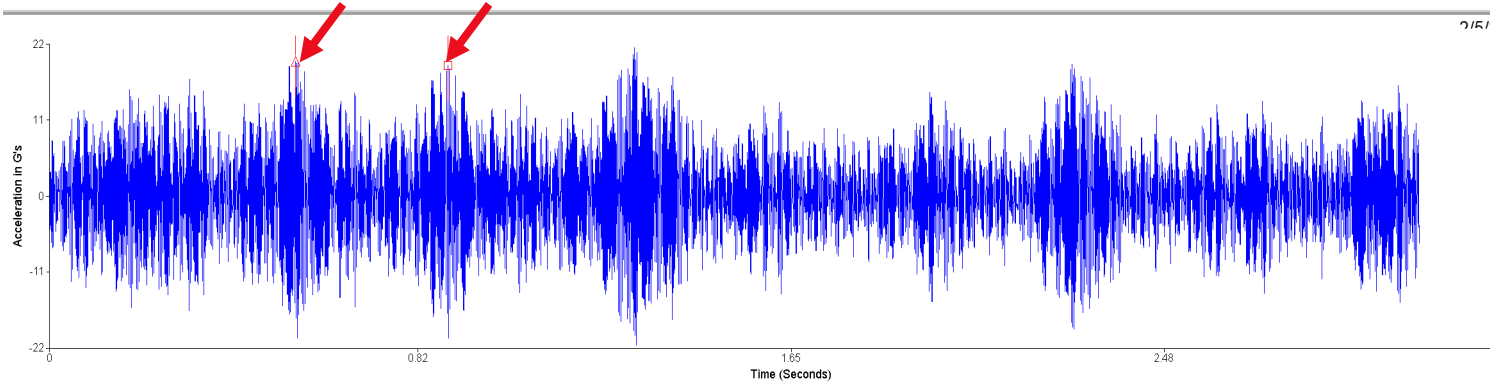
The **impact spikes** (red arrows) in the data are 1 times turning speed (Frequency in CPM).

This confirms the bearing fault in the spectral data

The analyst findings is that this motor has developed the bearing fault.

Vibration Analysis

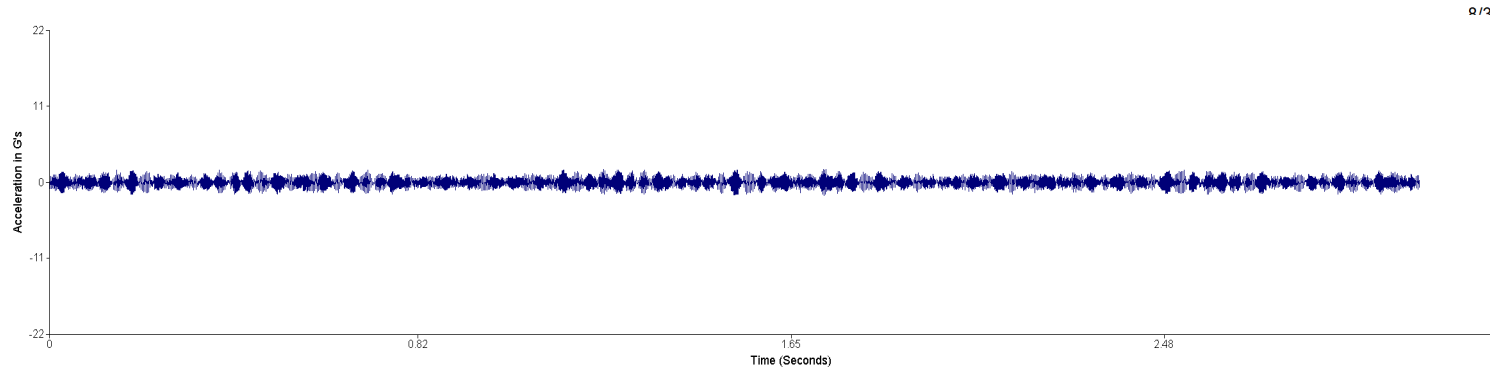
ta16.rbm / 205 / FE-4 Fan / MIA - Motor Inboard Axial



2/27

Analyze
RPM = 1785.3
(29.76 Hz)
LOAD = 100.00
RMS = 6.294
Pk(+) = 21.53
Pk(-) = 21.56
Crest = 3.426

Reference:
Time: 0.547
Rev: 16.29
Amp: 19.55



2/27

Primary:
Time: 0.887
Rev: 26.38
Amp: 18.89

Dtim: 0.339
Freq: 176.94
Drev: 10.09

8-27-06 AM

Route
RPM = 1765.0
(29.42 Hz)
LOAD = 100.00
RMS = 0.712
Pk(+) = 1.933
Pk(-) = 1.867
Crest = 2.713

FE - 004 - Motor - Drive end Axial Waveform data.

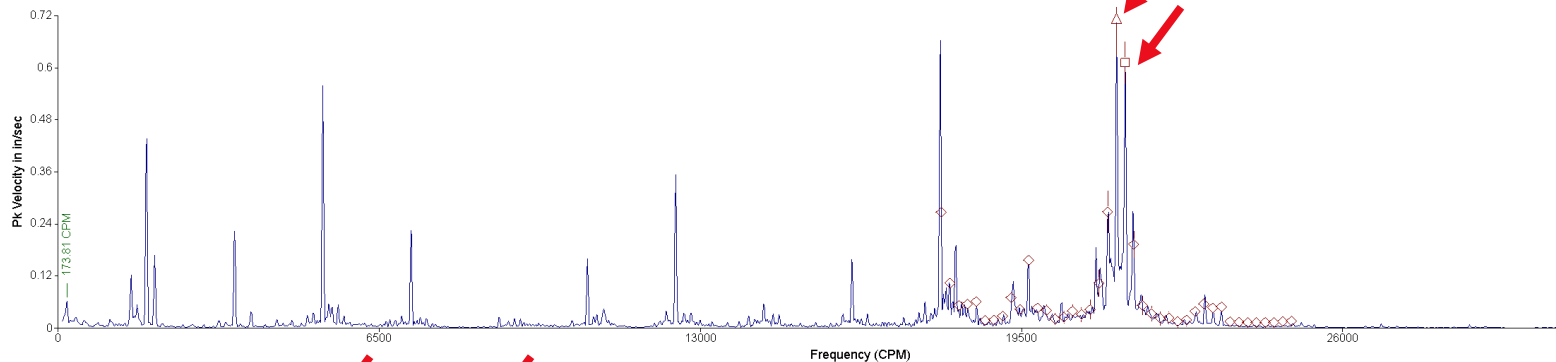
Vibration Waveform (Raw Data) before and after fault developed.

The **impact spikes** (red arrows) in the data are 1 times **belt** turning speed (Frequency in CPM).

This data is highlighting a belt fault frequency - we knew that the belt was in bad shape.

Vibration Analysis

ta16.rbm / 205 / FE-4 Fan / MIA - Motor Inboard Axial

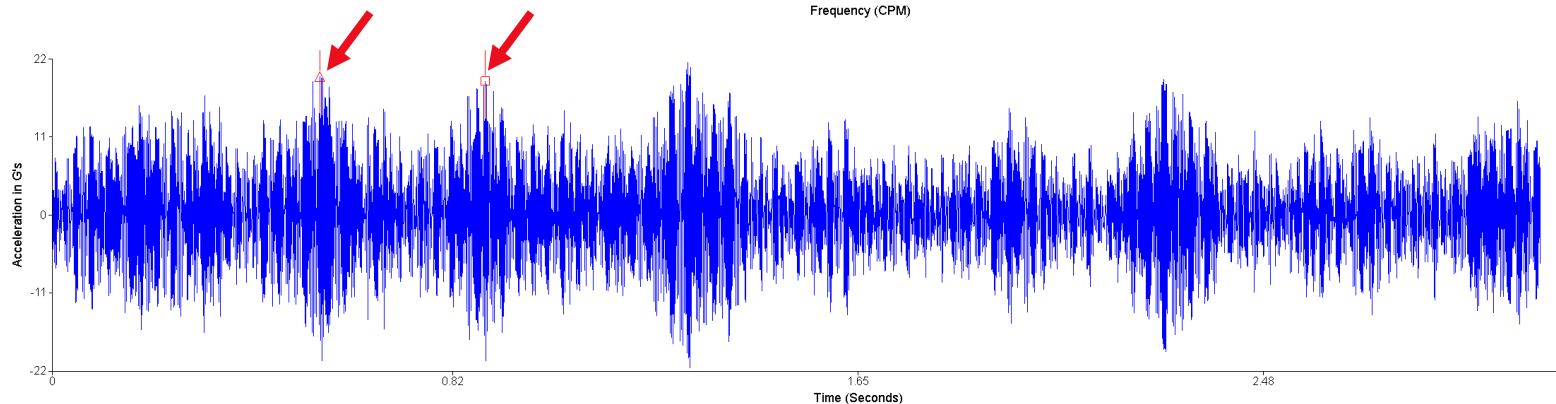


Analyze
1,766 V -DG
Pk = 1,766
LOAD = 100.00
RPM = 1785.3
(29.76 Hz)

Reference:
Freq:21420.0
Ord:12.00
Amp: 0.704

Primary:
Freq:21597.2
Ord:12.10
Amp: 0.602

Dfrq:177.19



11:00:02 AM

Analyze
RPM = 1785.3
(29.76 Hz)
LOAD = 100.00
RMS = 6.294
Pk(+) = 21.53
Pk(-) = 21.56
Crest = 3.426

Reference:
Time:0.547
Rev:16.29
Amp: 19.55

Primary:
Time:0.887
Rev:26.38
Amp: 18.89

Dtm:0.339
Freq:176.94
Drev:10.09

FE - 004 - Motor - Drive end Axial Spectral and Waveform data.

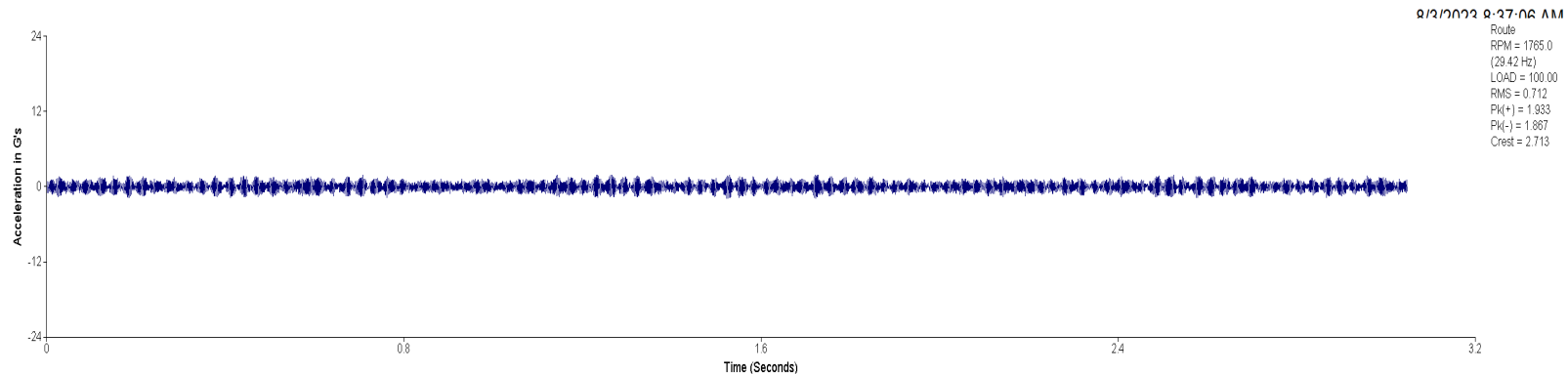
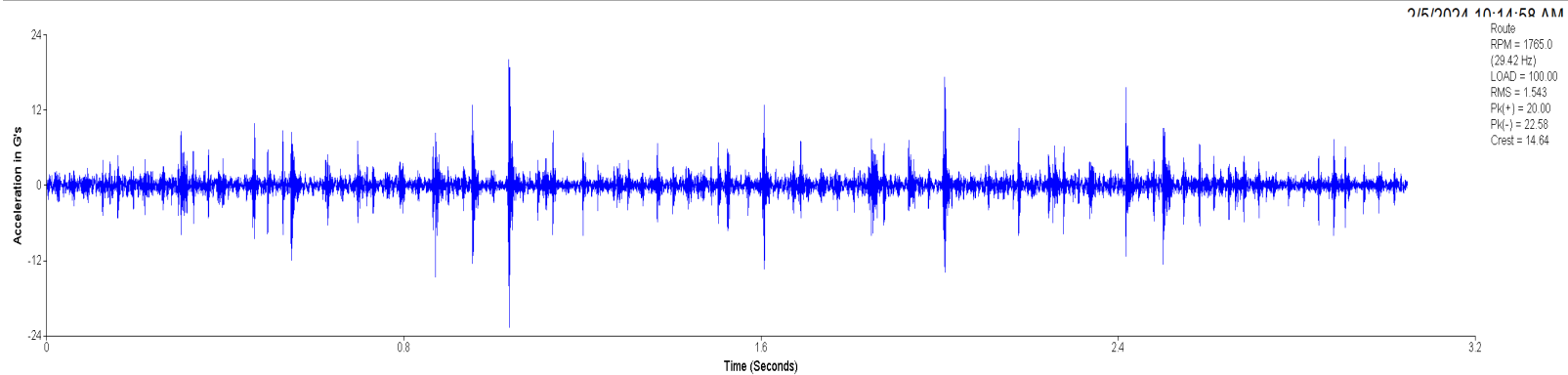
Spectra shows belt frequency sidebands (red arrows) that are highlighted in the waveform data.

The impact spikes (red arrows) in the waveform data are 1 times belt turning speed (Frequency in CPM).

This data is highlighting a belt fault frequency.

Vibration Analysis

ta16.rbm / 205 / FE-4 Fan / MIA - Motor Inboard Axial



FE – 004 - Motor – Drive end Axial Waveform data

Vibration Waveform (Raw Data) before and after fault developed.

The **impact spikes** in the data **confirms the bearing fault in the spectral data**

The analyst findings is that this motor has developed the bearing fault.

Vibration Analysis

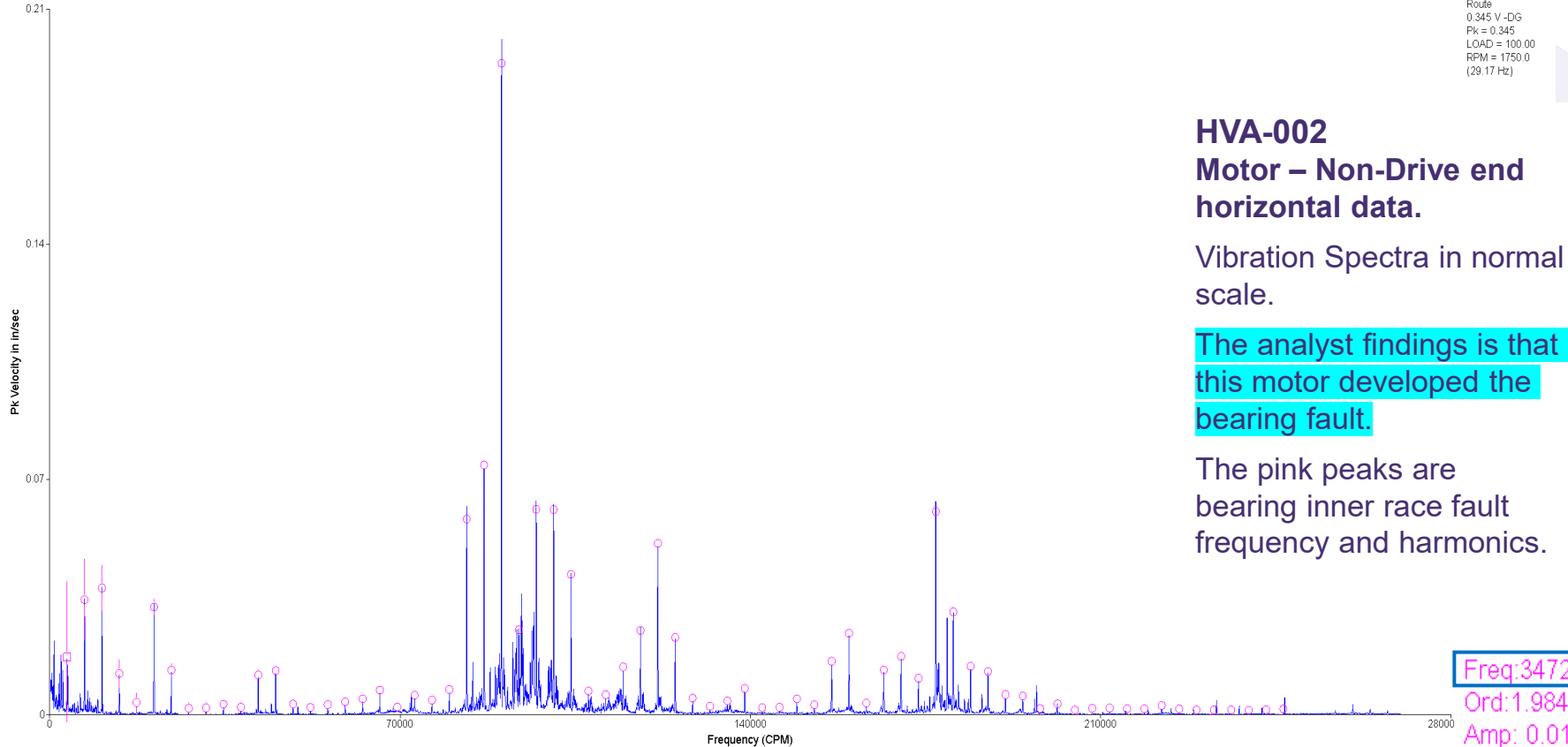
Case History #4

HVA-002

Motor and Fan bearing faults

Vibration Analysis

2/14/2024 9:00:21 AM
Route
0.345 V-DG
Pk = 0.345
LOAD = 100.00
RPM = 1750.0
(29.17 Hz)



HVA-002 Motor – Non-Drive end horizontal data.

Vibration Spectra in normal
scale.

The analyst findings is that
this motor developed the
bearing fault.

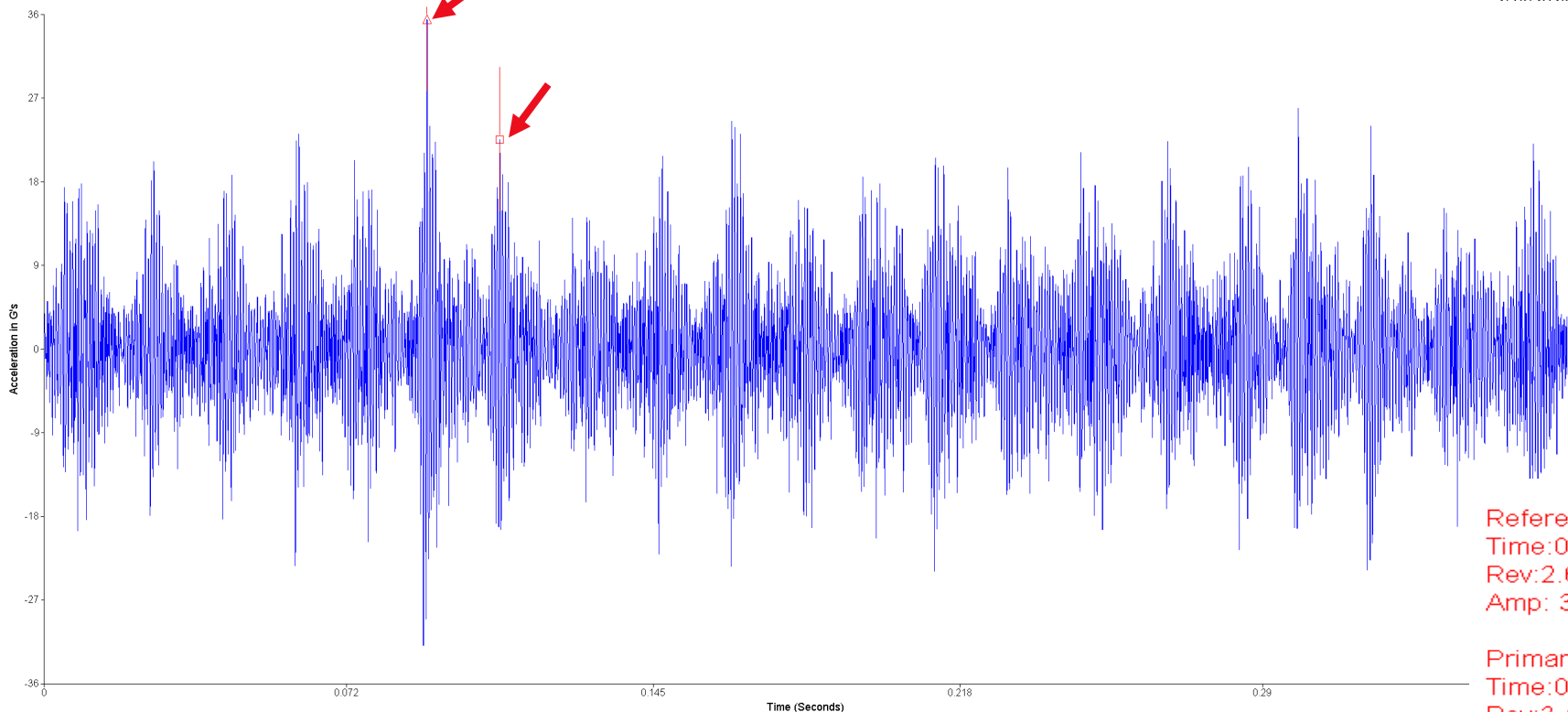
The pink peaks are
bearing inner race fault
frequency and harmonics.

Freq:3472.1
Ord:1.984
Amp: 0.0159

Vibration Analysis

ta-22 rbm / 91 / HVA-2 RM C-102 / MIH - Motor Inboard Horizontal

2/11/2024 0:00:24 AM



Route
RPM = 1750.0
(29.17 Hz)
LOAD = 100.00
RMS = 7.061
Pk(+) = 35.48
Pk(-) = 31.89
Crest = 5.109

Reference:
Time:0.0911
Rev:2.658
Amp: 35.48

Primary:
Time:0.108
Rev:3.162
Amp: 22.57

Dtim:0.0173
Freq:3473.4
Drev:0.504

HVA-002 Motor – Drive end horizontal data. Vibration Waveform (Raw Data)

The **impact spikes** (red arrows) in the data are inner race fault frequency (Frequency in CPM).

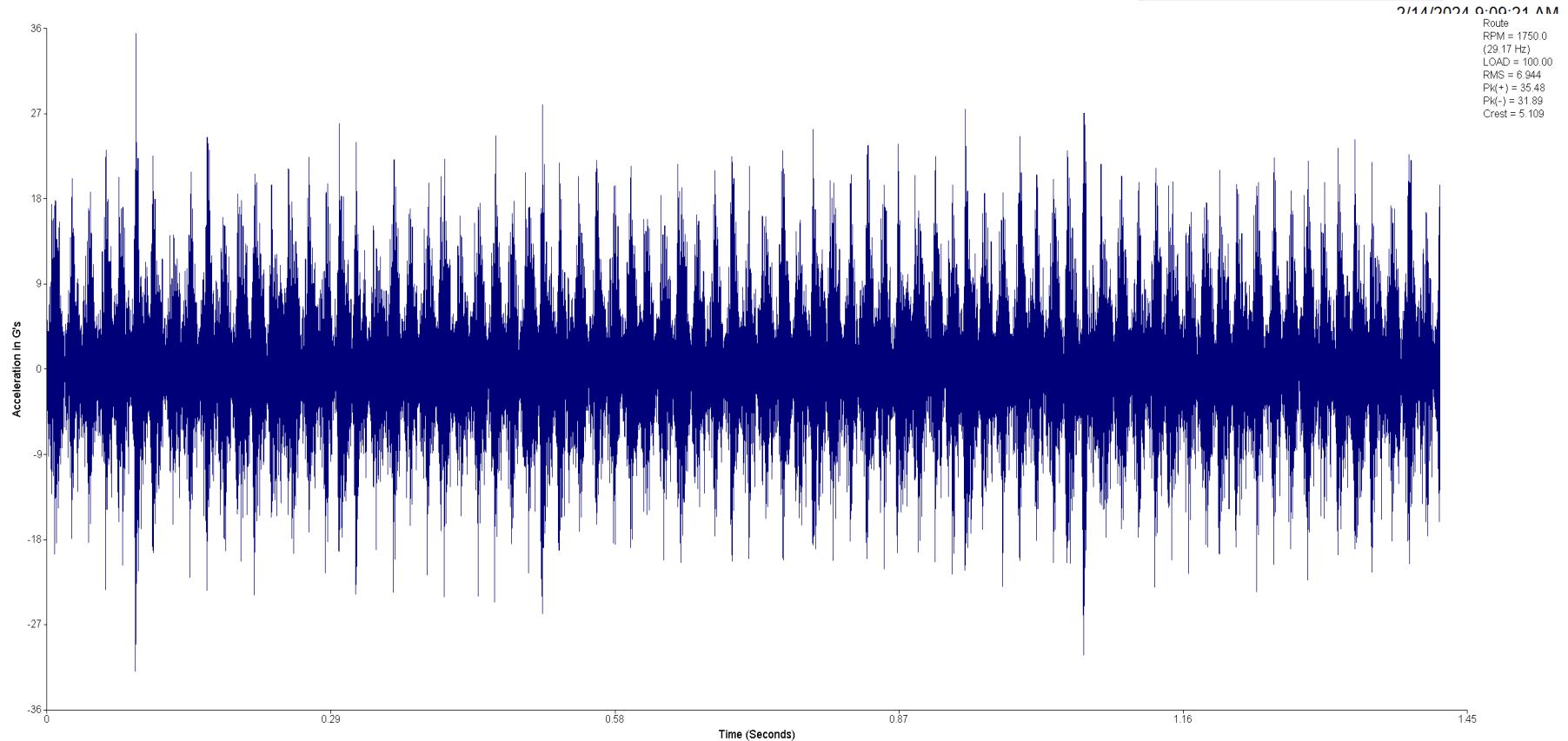
This confirms the bearing fault in the spectral data

The analyst findings is that this motor developed the bearing fault.

Vibration Analysis

Questions

Vibration Analysis



Vibration Analysis

Freq: 3472.1
Ord: 1.984
Amp: 0.0159

Vibration Analysis