

Course Objectives

1. Provide you with a general understanding of how vibration analysis is done, it's advantages and disadvantages.
2. Reinforce the basic information you need to understand when looking at the vibration spectrum.
 - Measurement units: Mils Vs IPS Vs G's,
 - Frequency units: Hz Vs CPM Vs Orders
 - How to locate primary forcing frequencies
3. How to operate the Microlog.
 - Navigating the menus
 - Performing various setups for data collection
 - Transferring Data to and from the Microlog
 - Transferring data to and from their computers to MKE
 - How to navigate through the Routes

Course Objectives

3. How to operate the Microlog.
 - Understanding the route setup
 - How to collect accurate vibration data
 - How to collect Amplitude and Phase data
 - New wizards
 - Using coded Notes
4. How to perform single and dual plane balancing.
5. How to perform both laser and dual dial indicator alignments for coupled shafts and belt driven machines.
6. How to communicate results to the customer.
7. Reviewing reports and understanding the content.

Maintenance Strategies

“Learning vibration analysis has made me a better mechanic.”

“I’ve learned that its not the big things that matter, but the hundreds of little things that make the difference.”

Tim Sorensen
Lead Mechanic
GSA Commonwealth of Virginia
1991

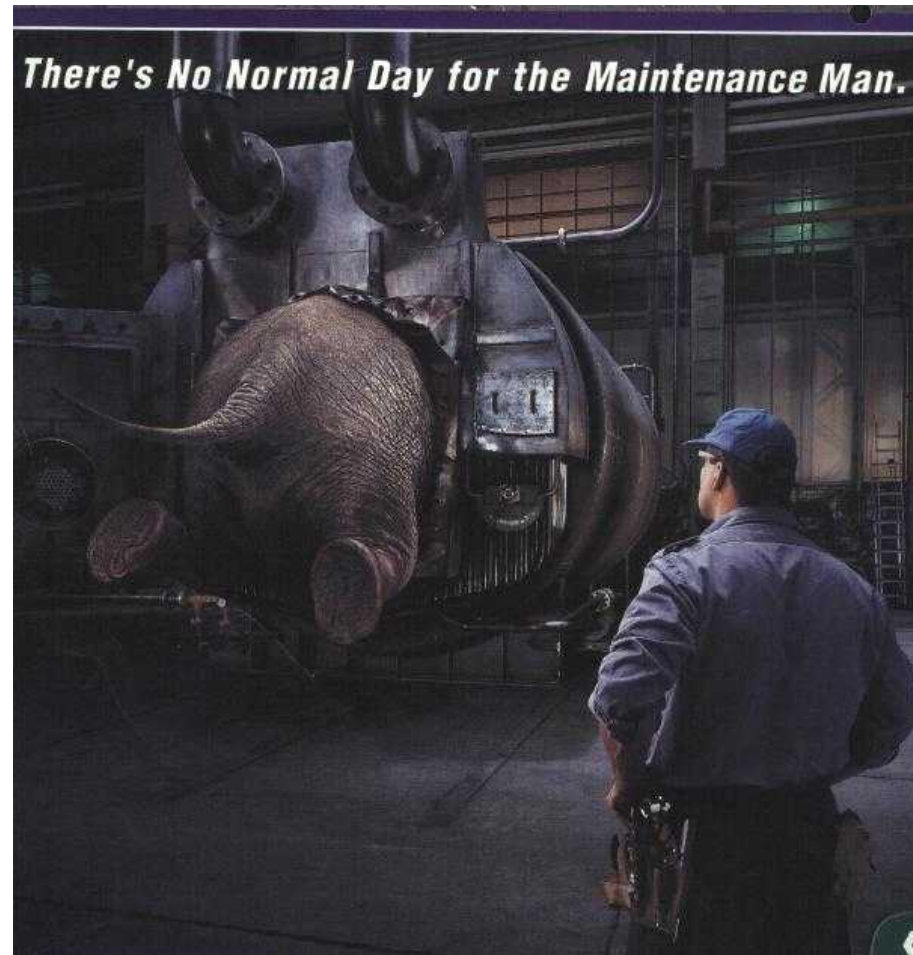
Maintenance Strategies

- Reactive Maintenance
- Preventive Maintenance
- Predictive Maintenance
- Pro-active Maintenance
- Practical Maintenance

Maintenance Strategies

Reactive Maintenance

Run it until it dies!



Maintenance Strategies

Reactive Maintenance

Advantages

- Low *apparent* cost.
- Low training costs.

Disadvantages

- Increased cost due to unplanned downtime of equipment.
- Increased labor cost, especially if overtime is needed.
- Possible secondary equipment or process damage from equipment failure.
- Inefficient use of staff resources.

Maintenance Strategies

Preventive (time based) Maintenance

Advantages

- Estimated 12% to 18% cost savings over reactive maintenance program.
- Flexibility allows for the adjustment of maintenance periodicity.
- Increased component life cycle.
- Energy savings.
- Reduced equipment or process failure.

Disadvantages

- Catastrophic failures still likely to occur.
- Labor intensive.
- Includes performance of unneeded maintenance.
- Potential for incidental damage to components in conducting unneeded maintenance.

Maintenance Strategies

Predictive Maintenance

- Machine condition determines when maintenance is scheduled.
- Plant management in control of maintenance programs. Overall condition of plant equipment is a known.
- Plant has better control of schedule.

Maintenance Strategies

Pro-active Maintenance

- Looks at equipment failures to determine the exact (root) cause of failure
- Gradually design problems out of plant
- Natural extension of predictive maintenance

Maintenance Strategies

Where are we today?

- Greater than 50% of maintenance hours are spent in reactive mode
- Less than 40% spent in preventive maintenance
- Less than 10% in predictive Maintenance
- Less than 1% in Pro-active maintenance

Maintenance Strategies

Repair Cost Estimates

Repair Description	< 30 HP	30- 60 HP	> 60HP
Replace motor	\$2000	\$4000	\$6000
Replace motor bearings	\$1050	\$1850	\$2950
Replace fan bearings & balance & align	\$1800	\$2500	\$3200
Balance & align	\$1000	\$1000	\$1000
Replace fan bearings, fan shaft & balance	\$5400	\$7500	\$9600
Replace fan bearings & balance & align	\$1800	\$2500	\$3200

Maintenance Strategies

Bearing Life Equation

- When bearings fail, secondary damage is eminent.

$$L_{10} = \frac{16700}{\text{rpm}} \left[\frac{\text{dynamic capacity x load rating}}{\text{force}} \right]^3 = \text{Hours of life}$$

Maintenance Strategies

Practical Maintenance

- Constantly gather information
- Identify that equipment that contributes to the majority of reactive maintenance calls.
- Target basic maintenance practices that:
 - Extend potential machinery life cycles
 - Contribute to reductions in vibrations
 - Require only small investments in tools and equipment
- Train personnel in performing those practices.
- Expose personnel to technologies that will enhance those practices.

Maintenance Strategies

Practical Maintenance

Common machinery problems we *easily* can control

- Improper lubrication
- Worn pulleys & belts
- Misalignment of pulleys to shafts
- Misalignment of direct coupled machines
- Imbalance
- Structural looseness

Activity 1: HACCC Report

The JCI Predictive Offering

- Read the HACCC Report
- You will find the report in the Activities Folder

HACC Report

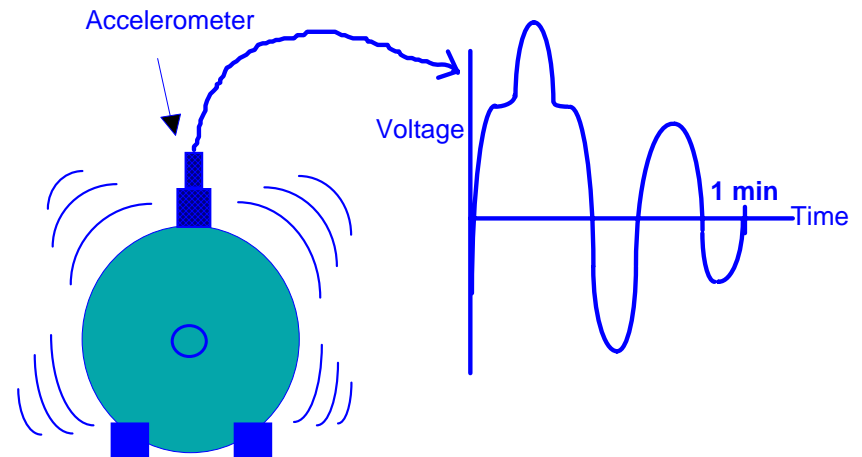
The JCI Predictive Offering

- After reading the report, can you name any service opportunities?
(list three)
- Which machines would you say are in good condition?
- In your opinion, which 5 machines are in the most need of repair?
(List them with from worst to better)
- List 5 machinery faults that can be determined using vibration predictive services.
- If you were to repair the two worst machines, approximate the service revenue you would generate.

Vibration Basics

What is Vibration?

- Any physical process characterized by cyclic variations in amplitude, intensity, or frequency
- Vibration is usually ***not*** the direct cause of a problem, rather it is the ***symptom*** of the problem.



Vibration Basics

Vibration Causes

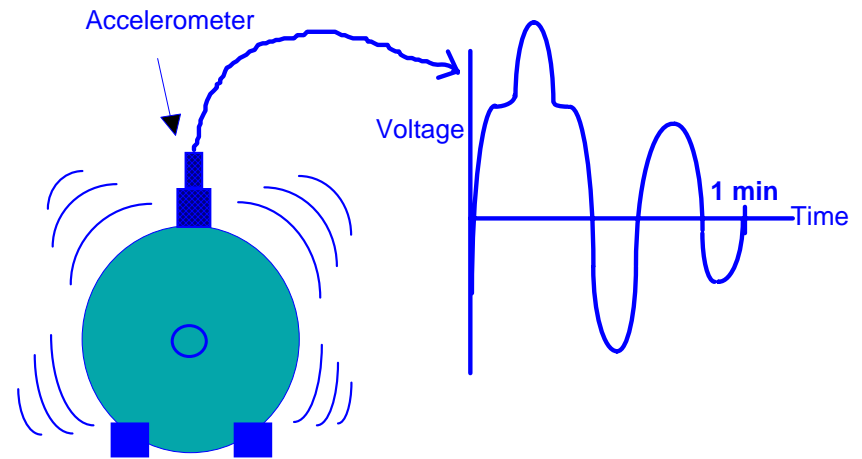
Common machinery problems that cause vibration

- Imbalance
- Worn pulleys and belts
- Misalignment of pulleys to shafts
- Misalignment of pulleys to one another
- Looseness
- Improper fit between races and shafts (internal looseness)
- Bearing Damage
- Improper lubrication
- Aerodynamic forces
- Hydraulic forces
- Improper loading of resilient mounts
- Inadequate motor mount support
- Resonance
- VFD's: operating at or near a natural frequency

Vibration Basics

The Vibration Signal

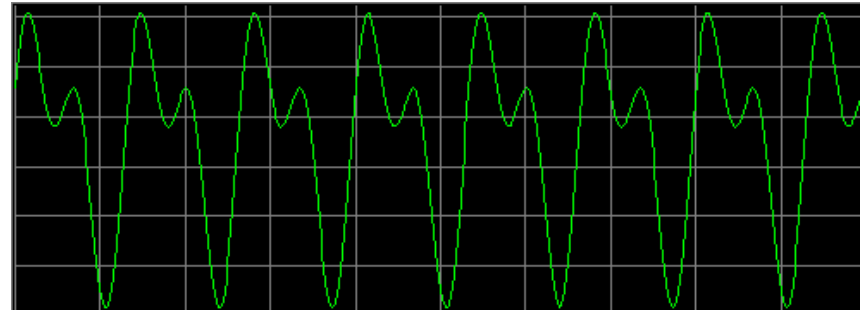
- A vibration sensor is mounted at or near a machine bearing support.
- Mounting methods include magnets, extension probes, and hard mounts.
- If the mount is good the sensor is “coupled” to the bearing support, and therefore vibrates just as the machine does.
- The sensor produces voltage that is proportional to the vibration.



Vibration Basics

The Vibration Signal

Periodic Motion – Motion which repeats itself in a given time interval

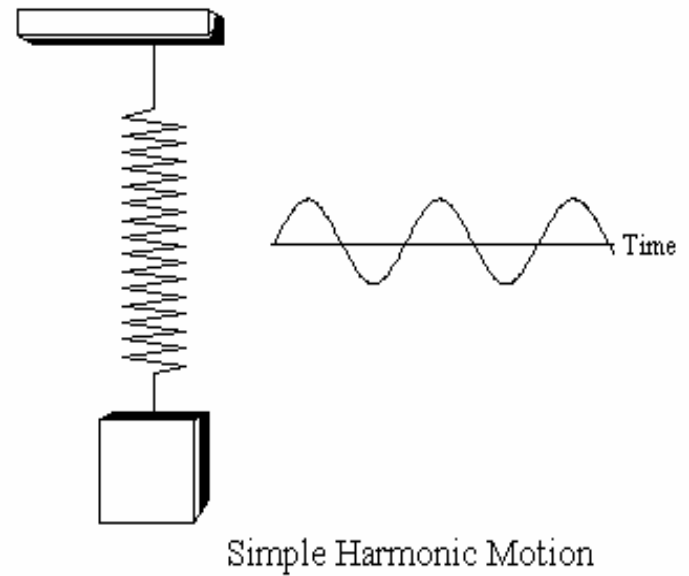
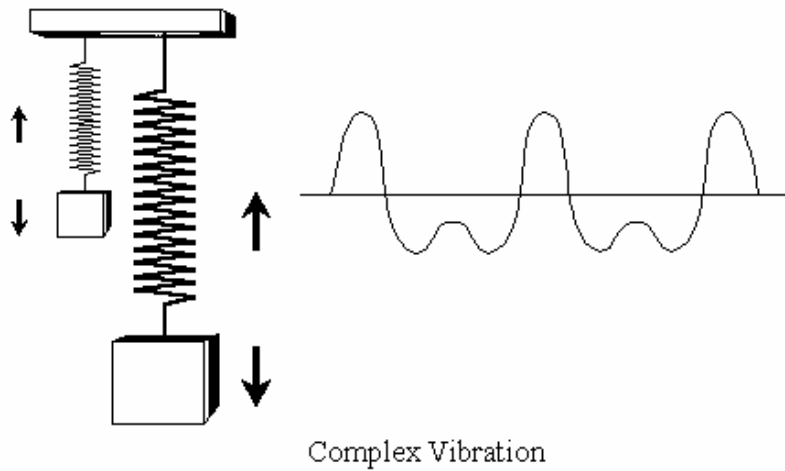


Harmonic Motion – A single frequency of vibratory motion which repeats itself in a given time interval.



Vibration Basics

The Vibration Signal

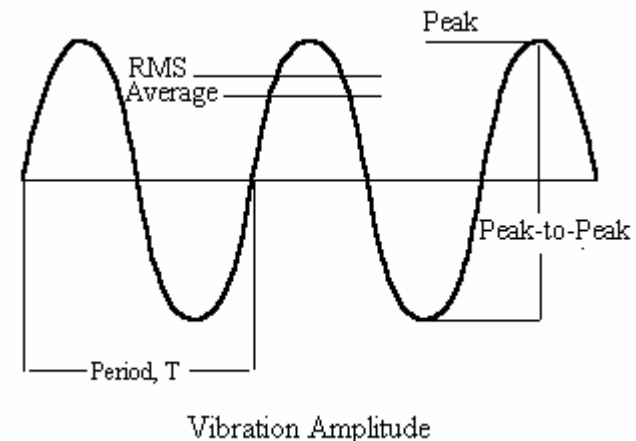


Vibration Basics

The Vibration Signal

- Vibration amplitude is the amount of vibration and indicates the severity of combined problems.

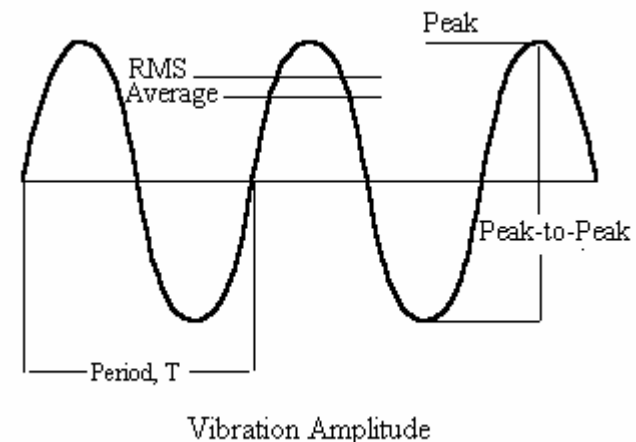
- 0-Pk maximum motion in either positive or negative direction. Expressed as an absolute value
- PK-PK maximum positive plus maximum negative motion
- RMS used to express power or energy in a waveform.



Vibration Basics

The Vibration Signal

- Vibration frequency indicates how often the vibration event occurs.
- Vibration frequency is used to determine specific problems.



Vibration Basics

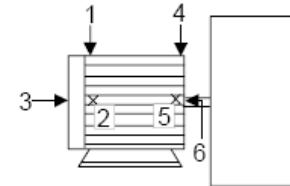
Collecting Vibration Data

- Data is collected by mounting at machinery bearing positions and then moving the sensor to subsequent positions.
- A vibration analyzer or data collector stores the data from the sensor.
- The collection process is broken into “routes” which can be collected in 1-2 hours.
- The data is permanently stored in a computer database.
- The software is also used in diagnosing specific machinery problems.

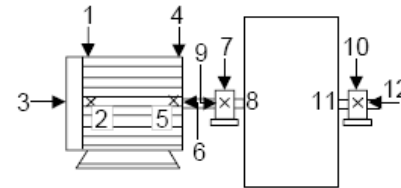
Vibration Basics

Collecting Vibration Data

- Vibration data is collected in three axis at each bearing position (if possible).
- The sensor is moved to each position as the route is collected.
- Some vibration equipment manufacturers use a 3-axis sensor, so three data points are collected simultaneously.
- The data for one machine can be collected in 5-15 minutes.



NOTE: Positions 7-12 do not apply to overhung conditions

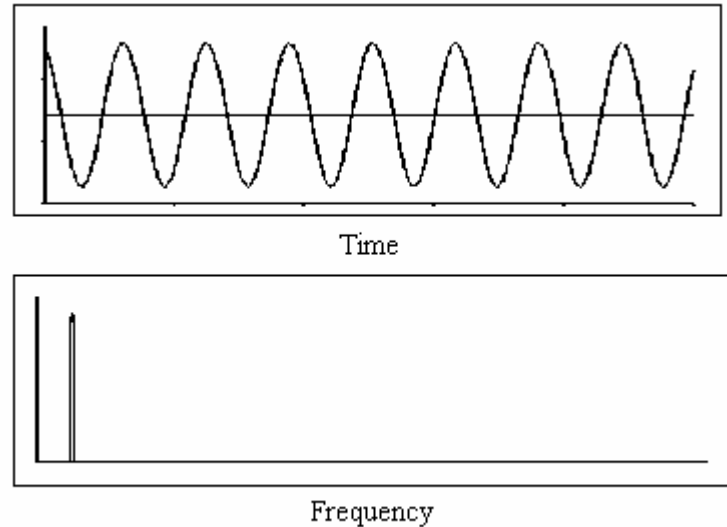


1. MOV Motor off end vertical
2. MOH Motor off end horizontal
3. MOA Motor off end axial
4. MDV Motor drive end vertical
5. MDH Motor drive end horizontal
6. MDA Motor drive end axial
7. FIV Fan inboard vertical
8. FIH Fan inboard horizontal
9. FIA Fan inboard axial
10. FOV Fan outboard vertical
11. FOH Fan outboard horizontal
12. FIA Fan outboard axial

Vibration Basics

The Vibration Spectrum

- The raw time waveform (Amplitude VS Time) is processed using FFT analysis.
- The waveform is converted and presented as a spectrum (Amplitude VS Frequency).

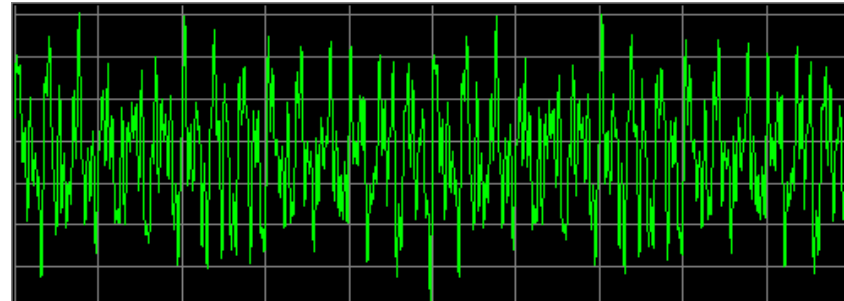


The Spectrum of a Sine Wave

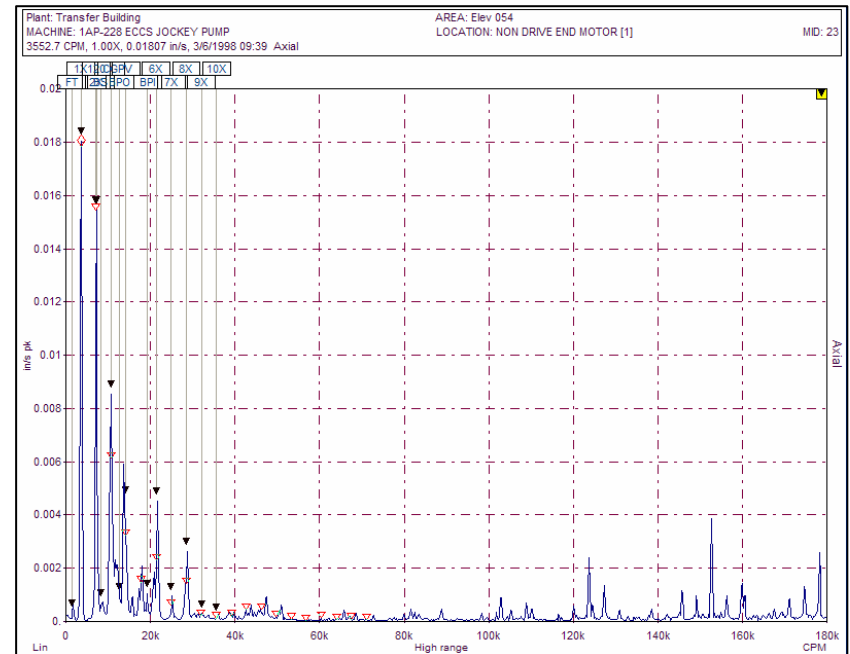
Vibration Basics

The Vibration Spectrum

- The waveform



- The Spectrum



Vibration Basics

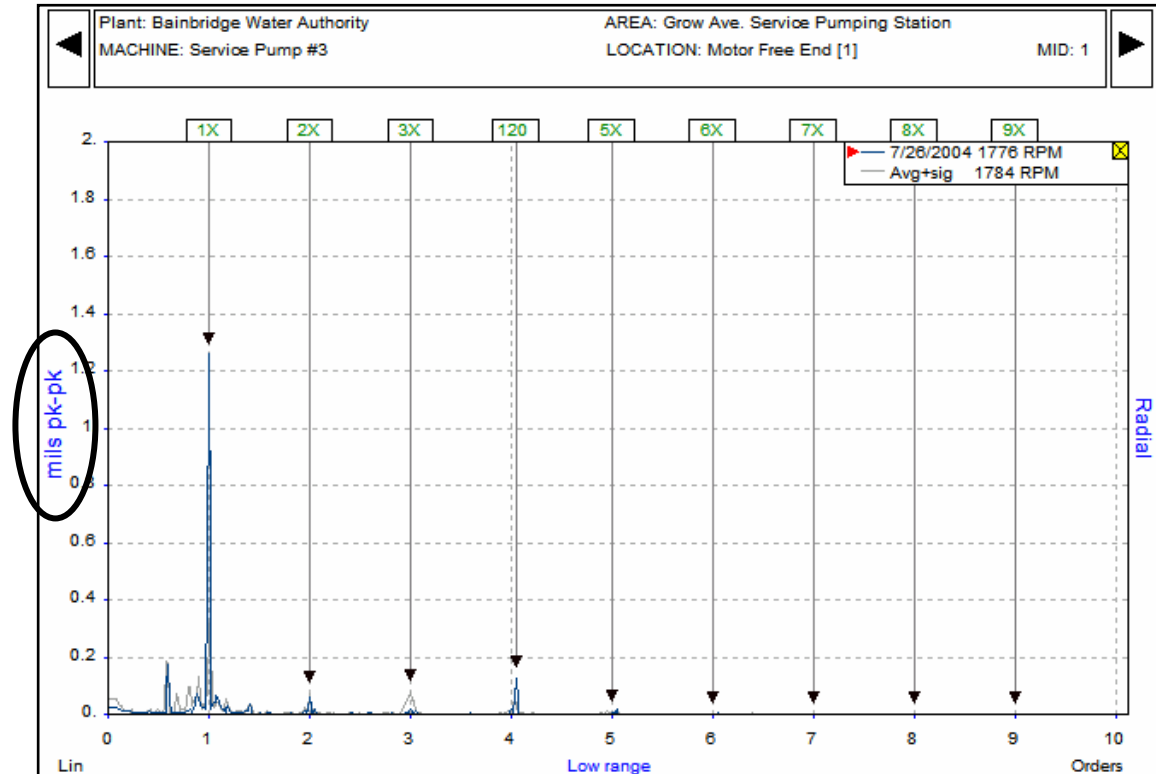
Units of Amplitude

Measure	Units	Description
Displacement	Mil (.001") Pk-Pk	Motion of equipment or rotor, relates to stress
Velocity	inches/second (IPS) 0-Pk	Time rate of motion, relates to component fatigue
Acceleration	G's (386.4 in/sec ²) 0-Pk	Relates to forces present in components

Vibration Basics

Units of Amplitude

- Displacement
Mils (PK to PK)

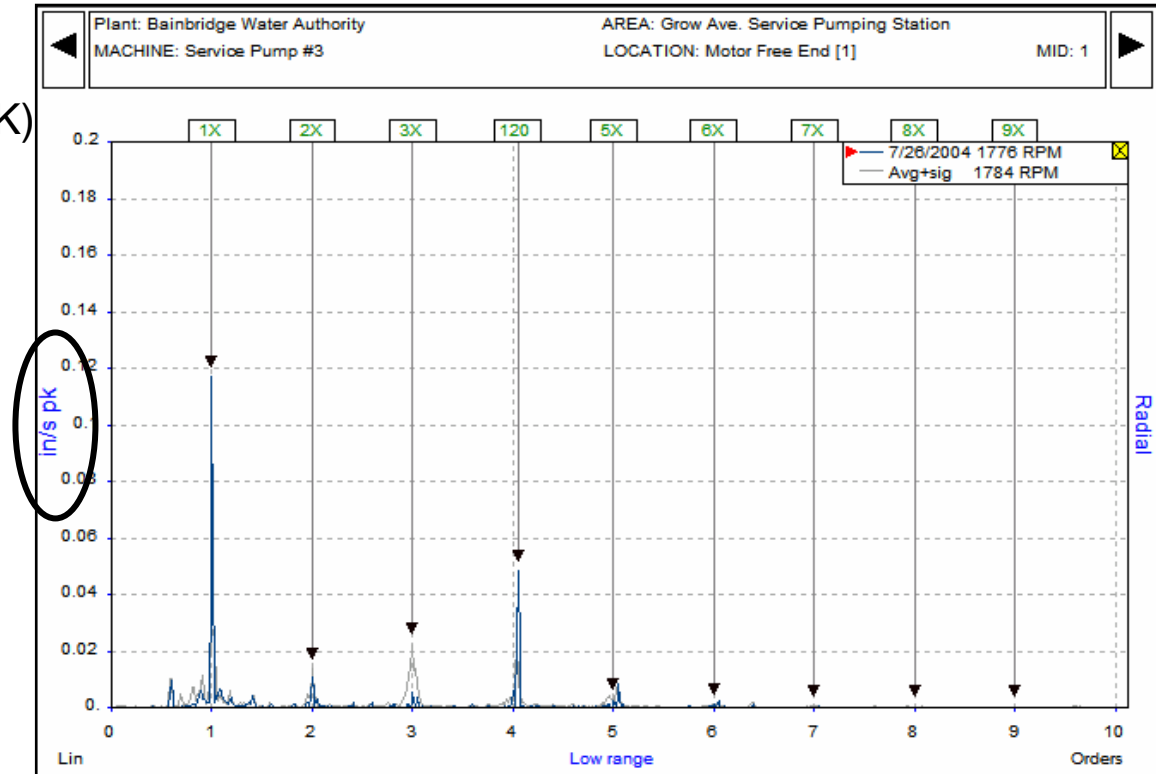


Vibration Basics

Units of Amplitude

- Velocity

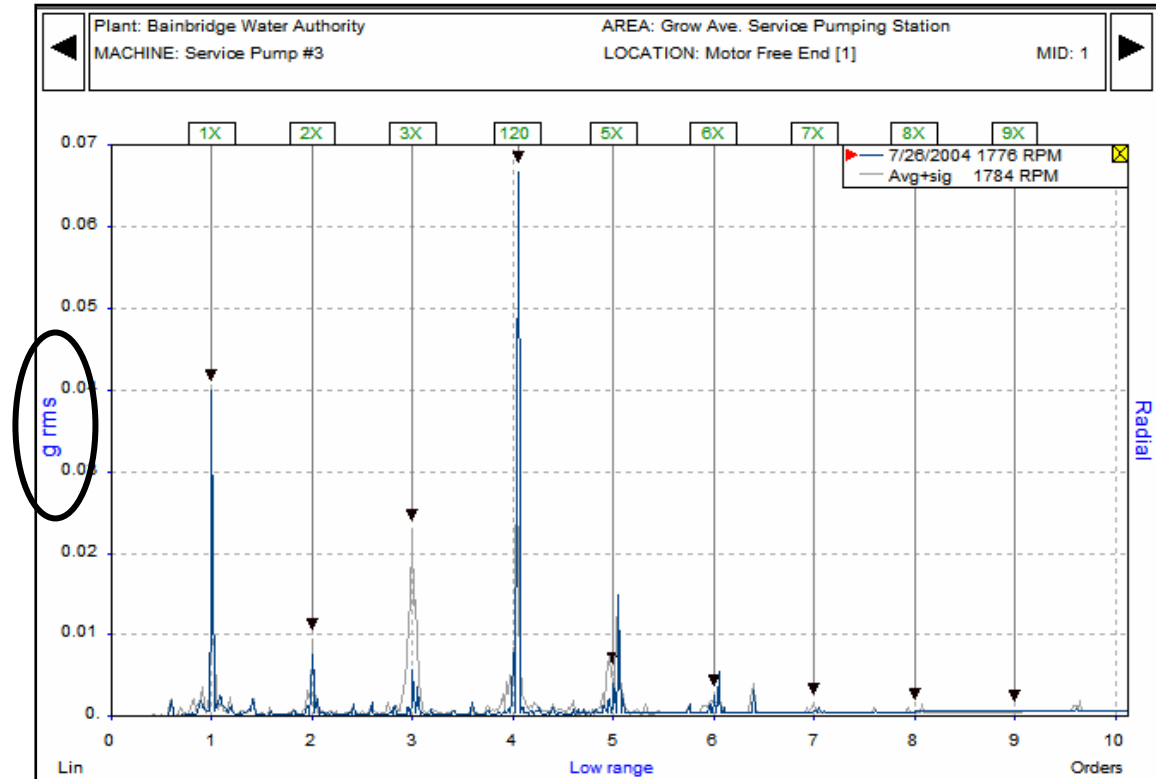
Inches/second (PK)



Vibration Basics

Units of Amplitude

- Acceleration
G's (RMS)

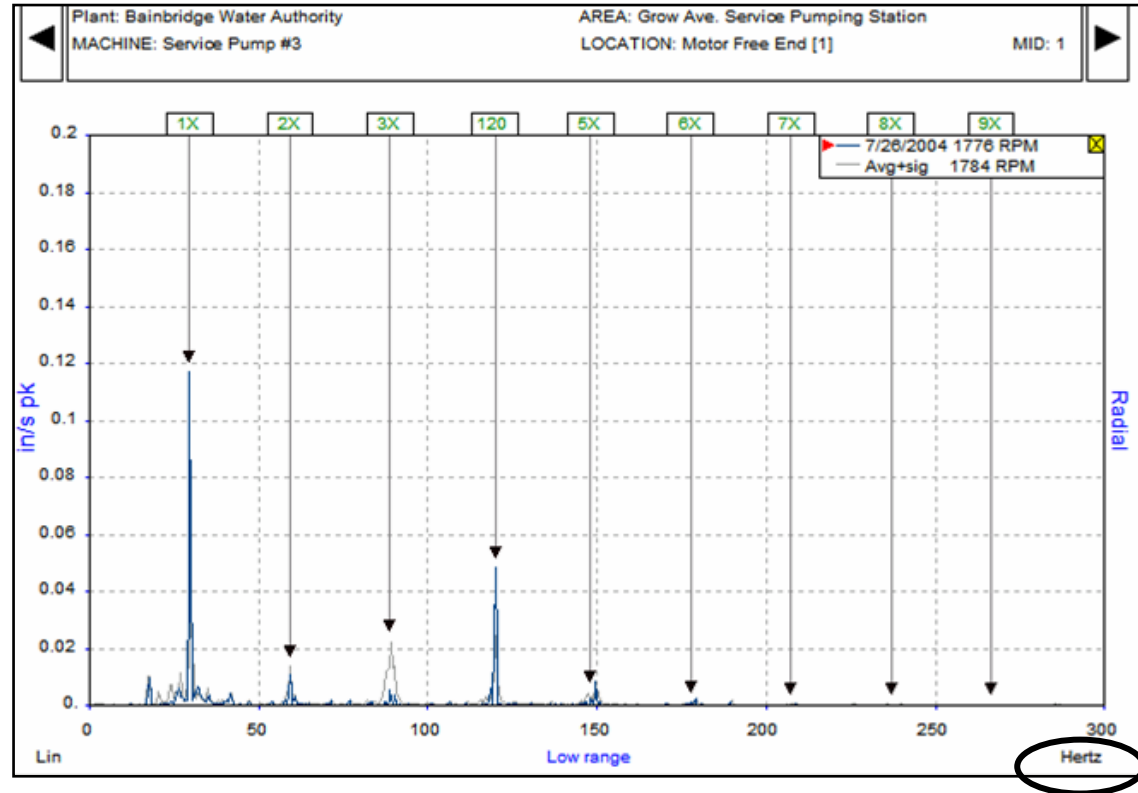


Vibration Basics

Units of Frequency

- Hertz

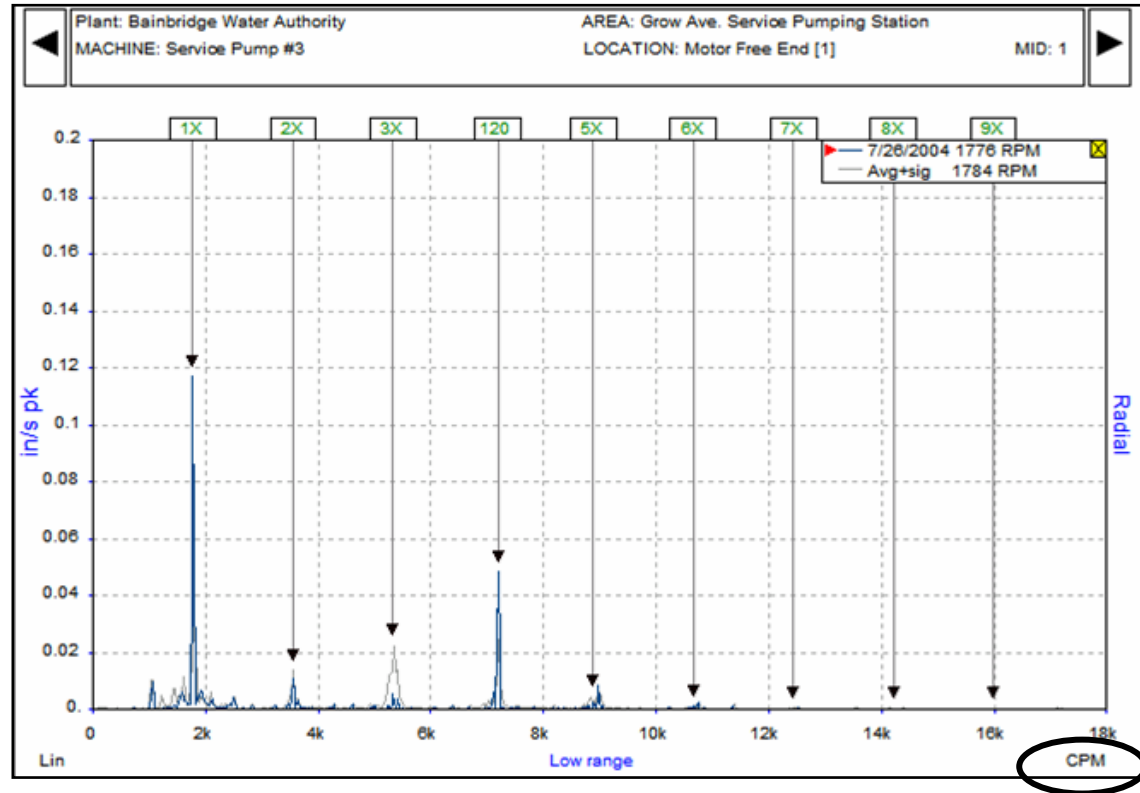
Cycles per Second



Vibration Basics

Units of Frequency

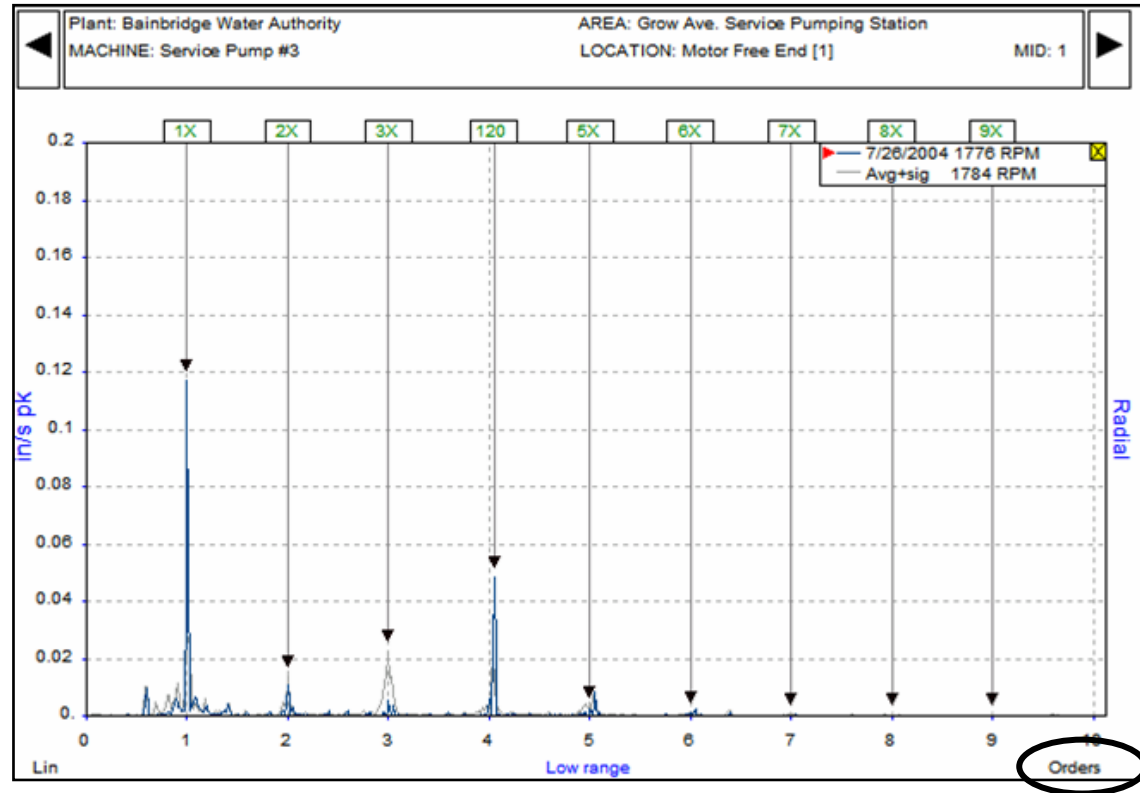
- CPM
Cycles per Minute



Vibration Basics

Units of Frequency

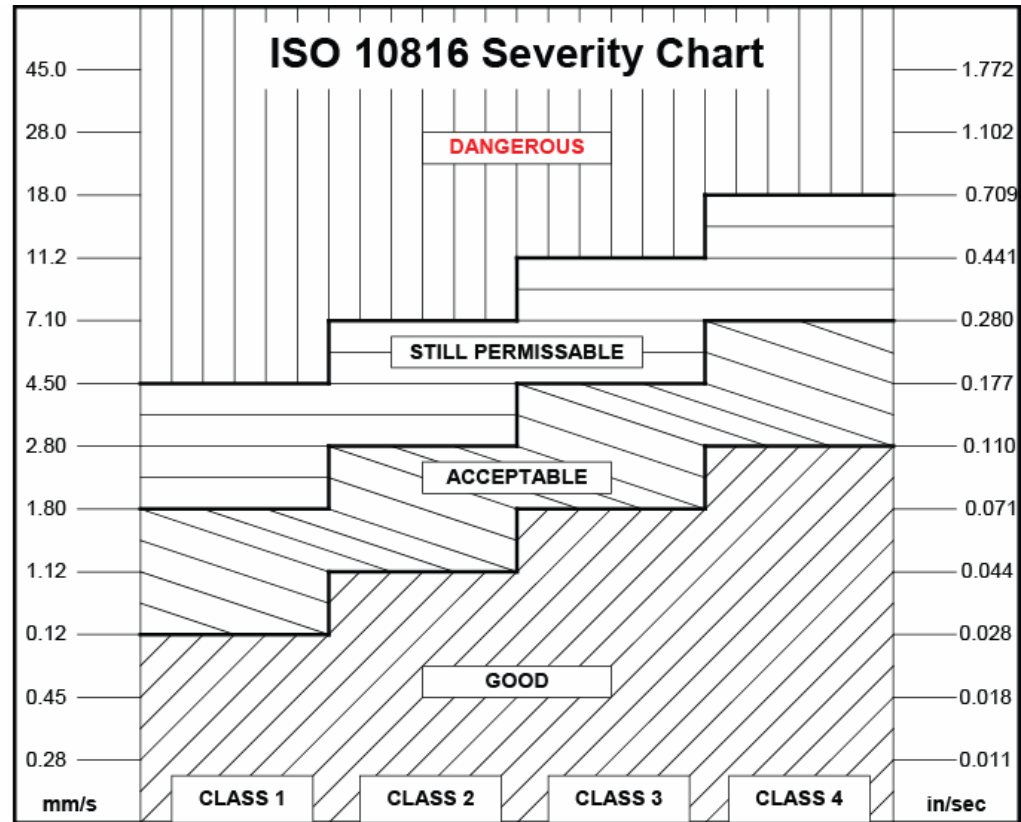
- Orders
CPM/RPM



Vibration Basics

Overall Amplitude Severity Guides

- Overall Amplitude to determine severity.



CLASS 1 - Small machines, especially production electrical motors up to 15kW (20 HP)
CLASS 2 - Medium sized machines, especially electrical motors >15Kw to 75KW (20-100 HP) without special foundations
CLASS 3 - Large machines on heavy foundations
CLASS 4 - Largest machines and turbo machines with special foundations

Vibration Basics

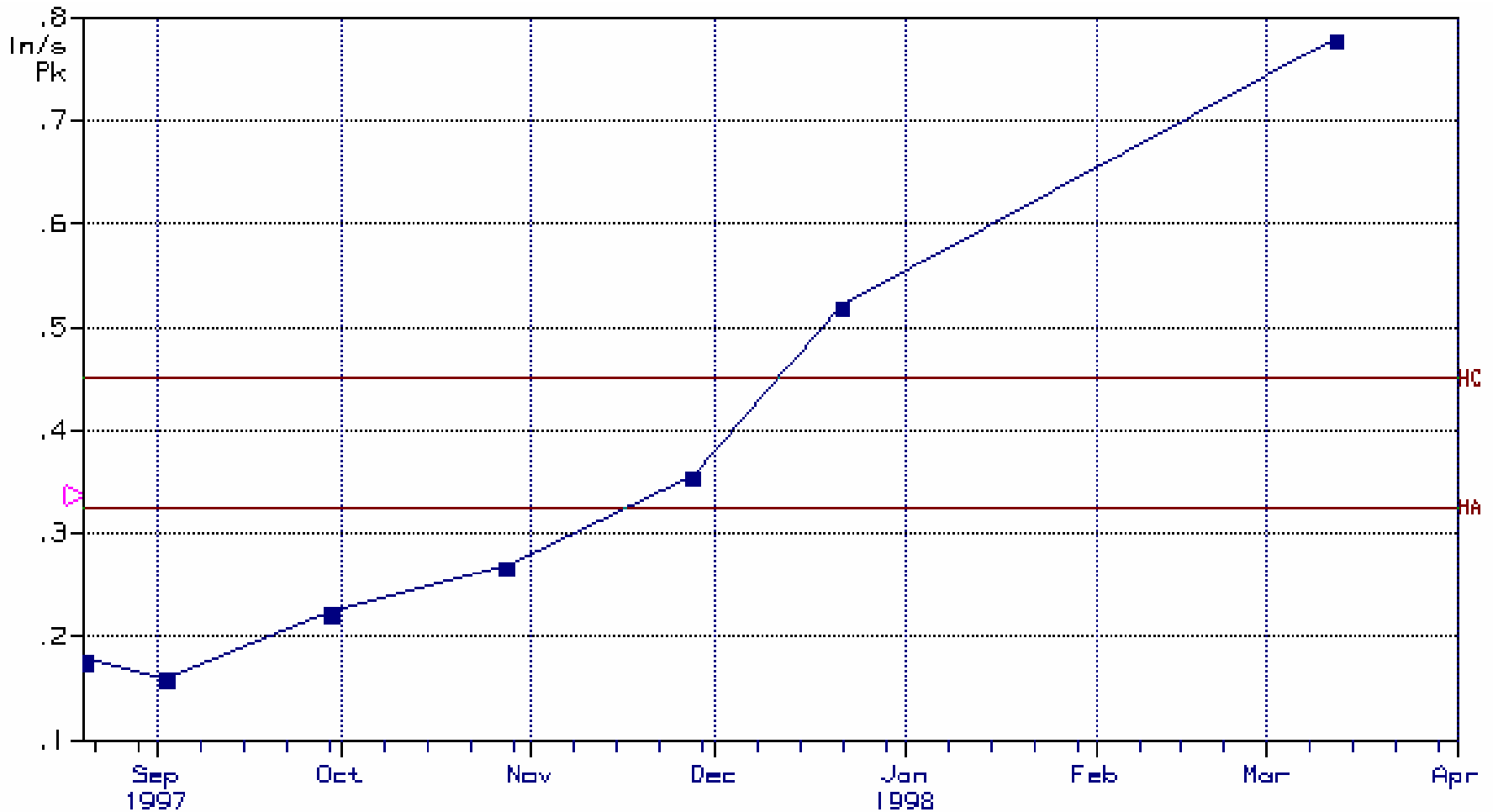
Overall Amplitude Severity Guides

- ISO 10816 Simplified
- Large machines
- Small machines on isolation

Acceptable Less than .20 IPS	No Alarms
Alert .20 IPS -.45	Alarm 1
Danger .45 IPS and greater	Alarm 2

Vibration Basics

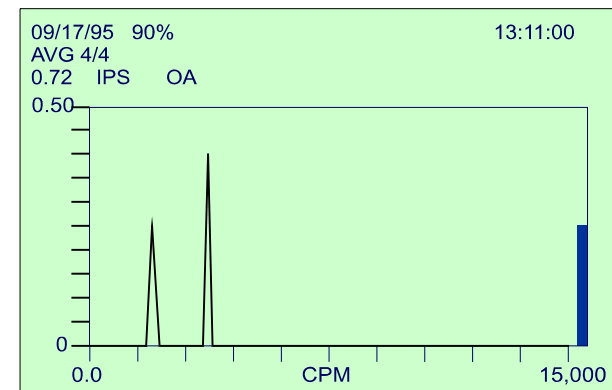
Trending Overall Amplitude



Activity 2

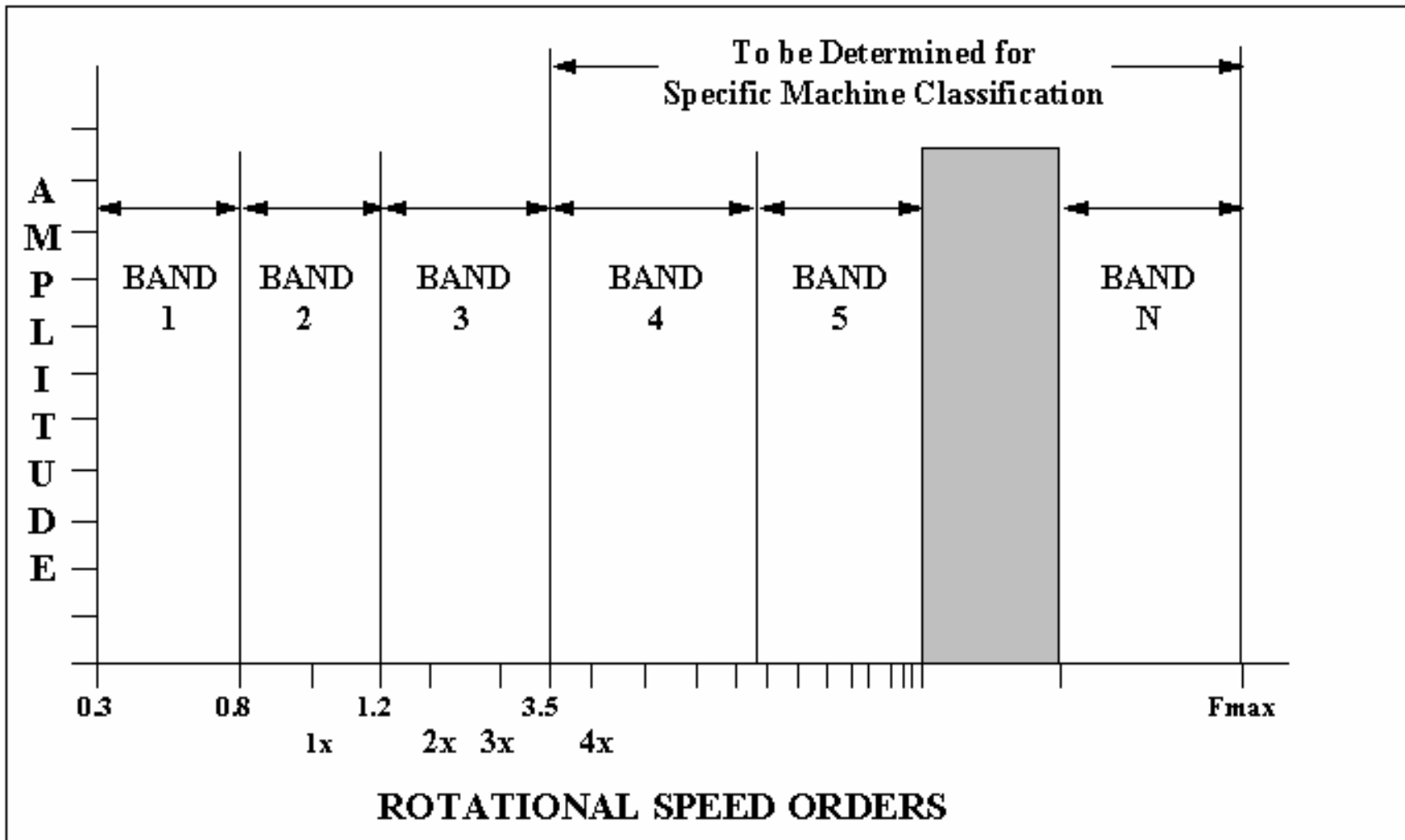
The vibration spectrum

- Go to Activity 2 in the Activities Folder.
- After reviewing page 1, go to the second slide:
 - What is the full scale amplitude?
 - Approximate the amplitude of the vibration spike.
 - What is the overall amplitude?
 - Name the units of amplitude.
 - Approximate the frequency of the vibration spike.



Vibration Analysis Techniques

Banded Vibration Levels



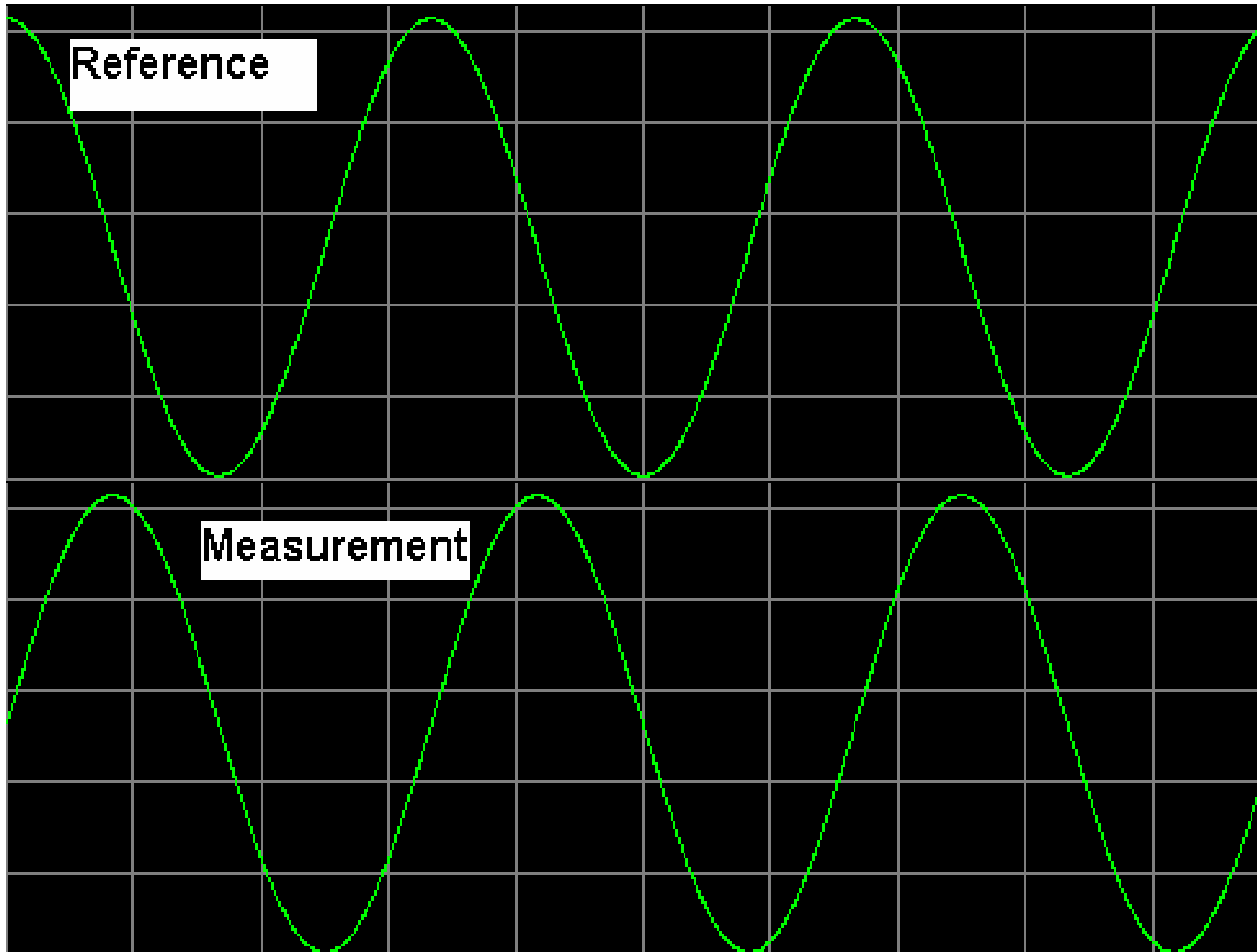
Vibration Analysis Techniques

Phase Analysis

- Time relationship between a fixed reference signal and a measurement signal.
- The reference signal can be a once-per-revolution tachometer pulse or it can be a fixed transducer location.

Vibration Analysis Techniques

Phase between 2 signals



Common Machinery Faults

Imbalance

Misalignment

Rolling Element Bearing

Common Machinery Faults

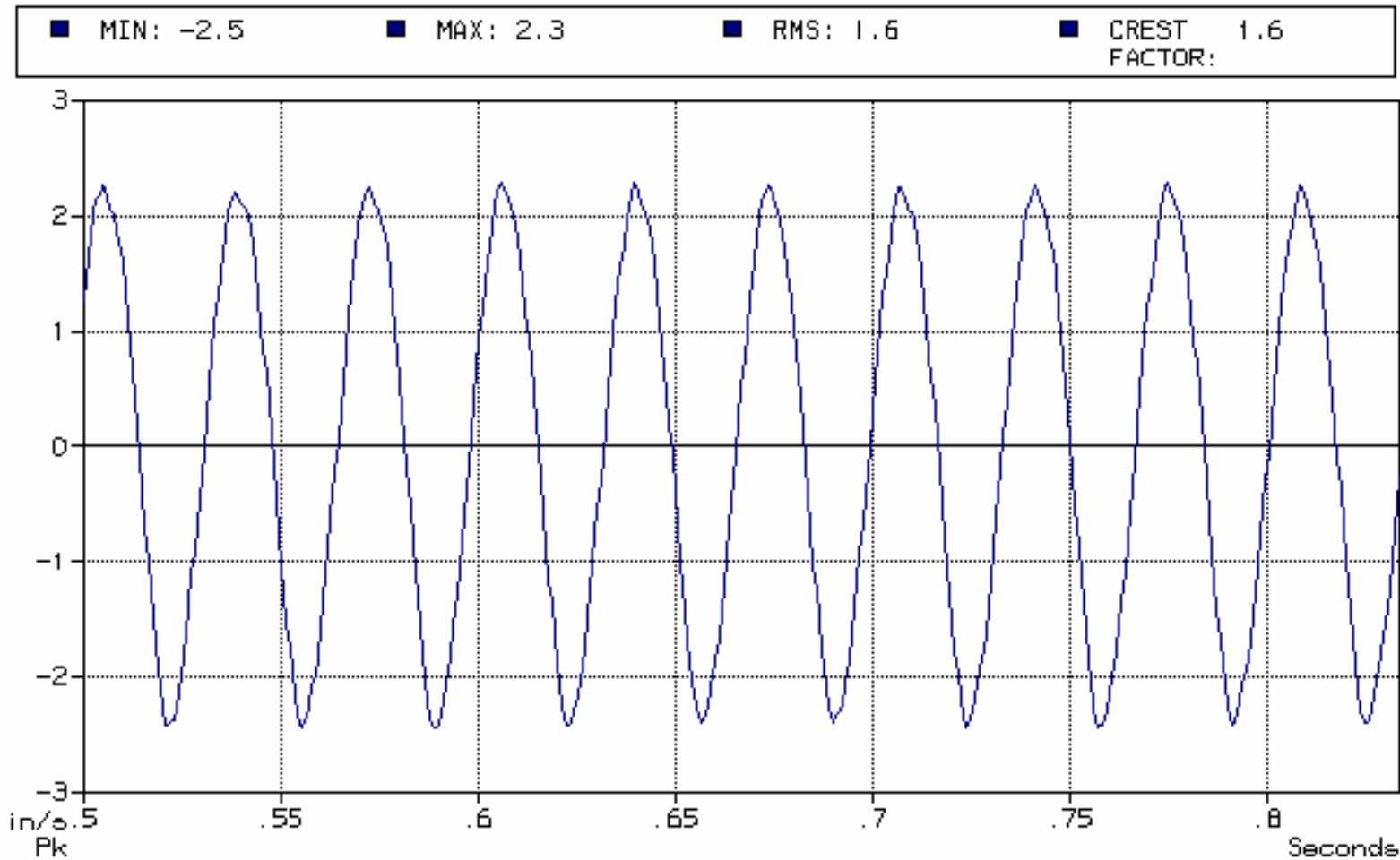
Imbalance

Unbalance occurs when the Mass Center and the Geometric Center of a rotor do not coincide.

Unbalance always occurs at running speed (1X) of the rotor.

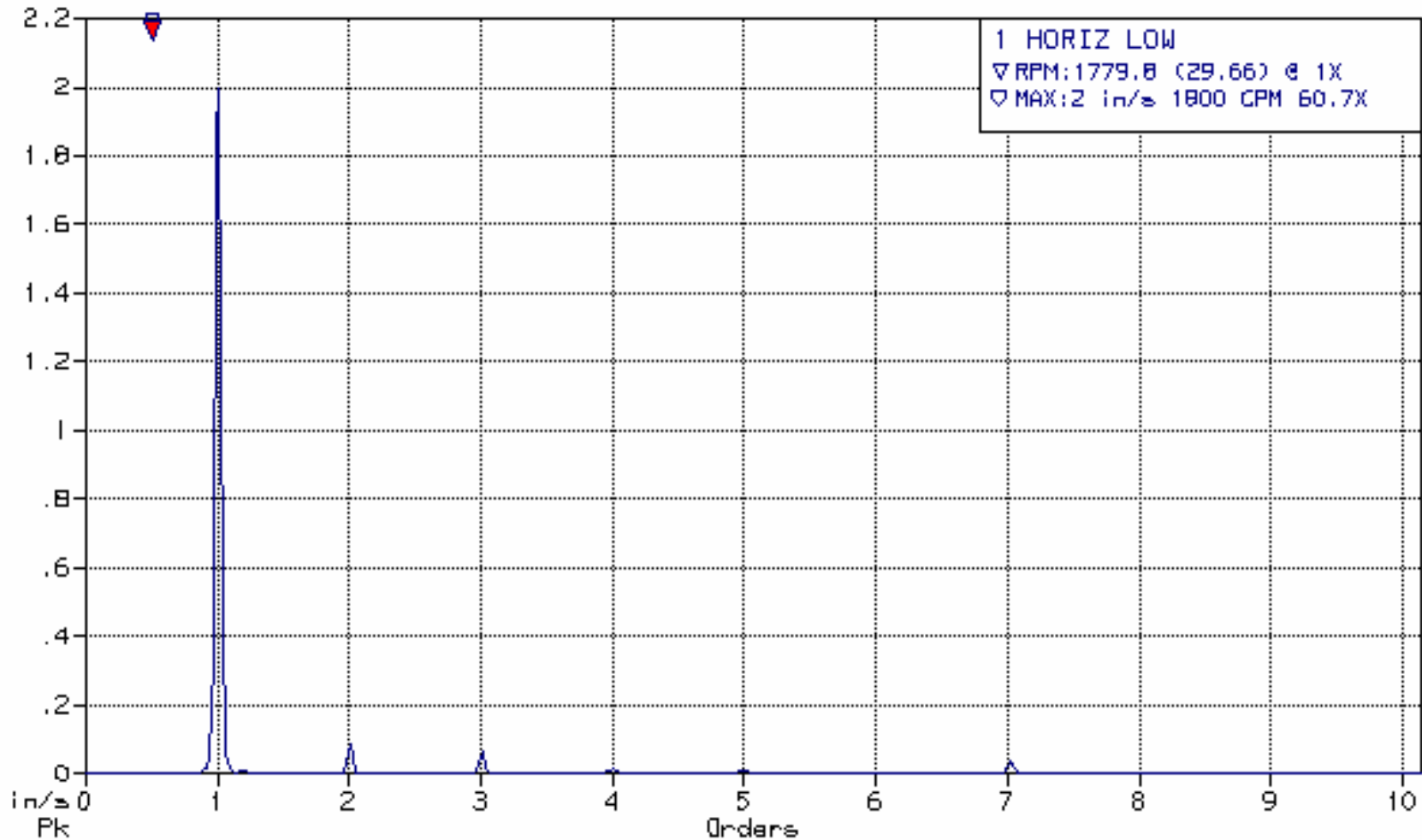
Common Machinery Faults

Imbalance Waveform



Common Machinery Faults

Imbalance Spectrum



Common Machinery Faults

Causes of Imbalance

Rotor improperly or not balance checked prior to assembly

Shaft Key not properly sized

Loose rotor to shaft fits

Uneven dirt accumulation on rotor

Lack of homogeneity on cast parts, such as bubbles, blow holes, porous sections

Causes of Imbalance

Rotor Eccentricity

Roller Deflection – Paper Machines

Machining Errors

Uneven mass distribution in electric motor rotor bars or winding.

Erosion or corrosion of rotor

Bowed or bent shaft

Common Machinery Faults

Imbalance Severity

1X Vibration Level	Diagnosis	Repair Priority
Less than 0.13 IPS	Slight Imbalance	No Action
0.13 IPS - 0.25 IPS	Moderate Imbalance	Desirable
0.25 IPS - 0.70 IPS	Severe Imbalance	Important
Greater than 0.70 IPS	Extreme Imbalance	Mandatory

Common Machinery Faults

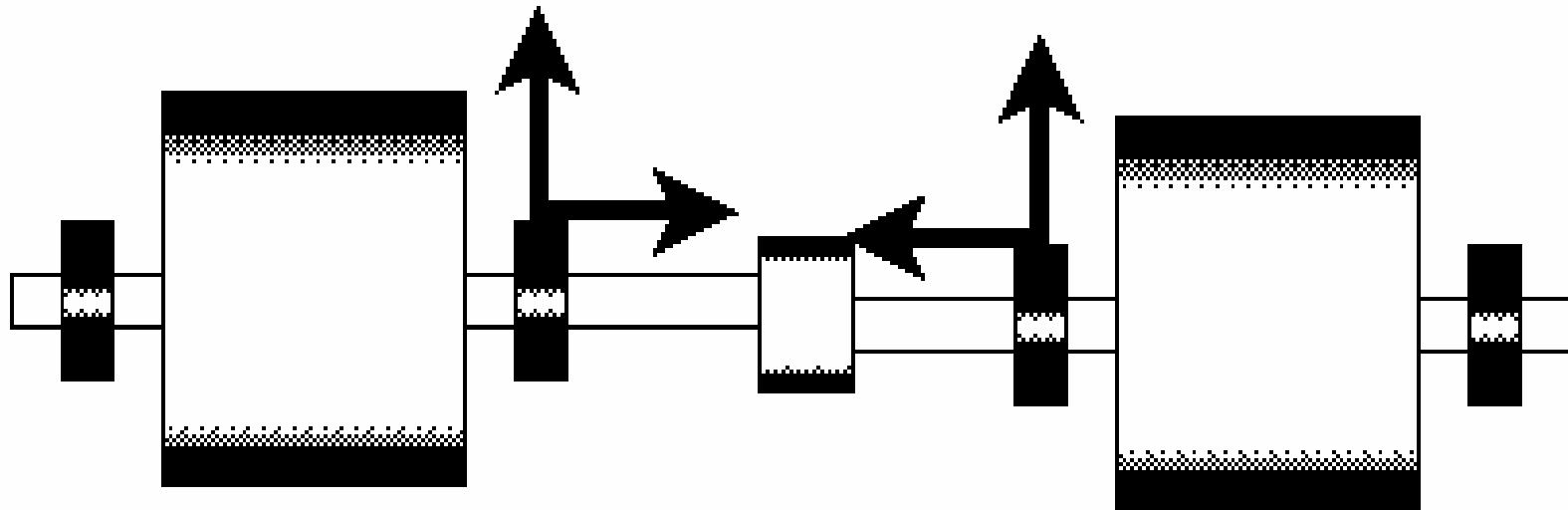
Misalignment

Can occur between any 2 bearings when the centerlines are not co-linear.

In belt drive machines when the sheaves are parallel offset or have vertical or horizontal angle.

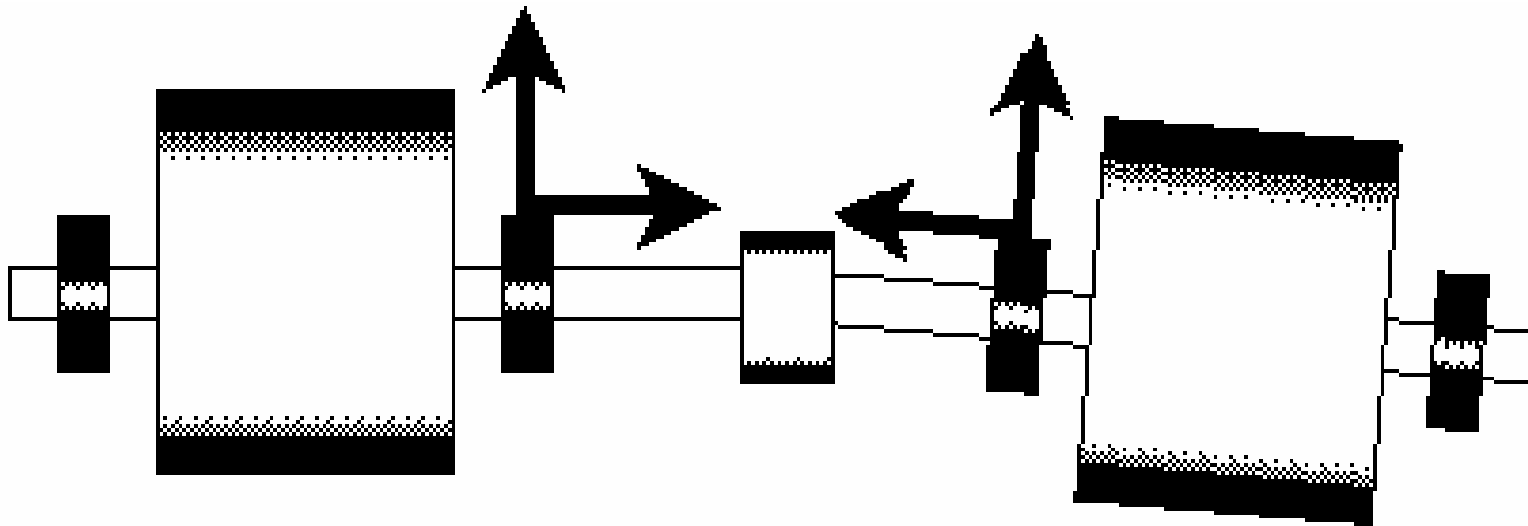
Common Machinery Faults

Parallel Misalignment



Common Machinery Faults

Angular Misalignment



Common Machinery Faults

Causes of misalignment

Inaccurate assembly of components

Cocked bearings

High radial or axial coupling runouts

Relative position of components shifting after assembly

Distortion due to forces exerted by piping

Distortion of flexible supports due to torque

Temperature induced growth of machine structure

Coupling face not perpendicular to the shaft axis

Soft foot, where the machine frame distorts when hold down bolts are tightened

Common Machinery Faults

Effects of Misalignment

High level of coupling wear, and heating of the coupling

Thrust transmission through the coupling when the coupling becomes locked

Cracked shafts due to fatigue caused by bending.

Excessive loading of the bearings.

Premature bearing failure

Misalignment Direct Drive

Misalignment shows up as 1X and 2X in spectrum

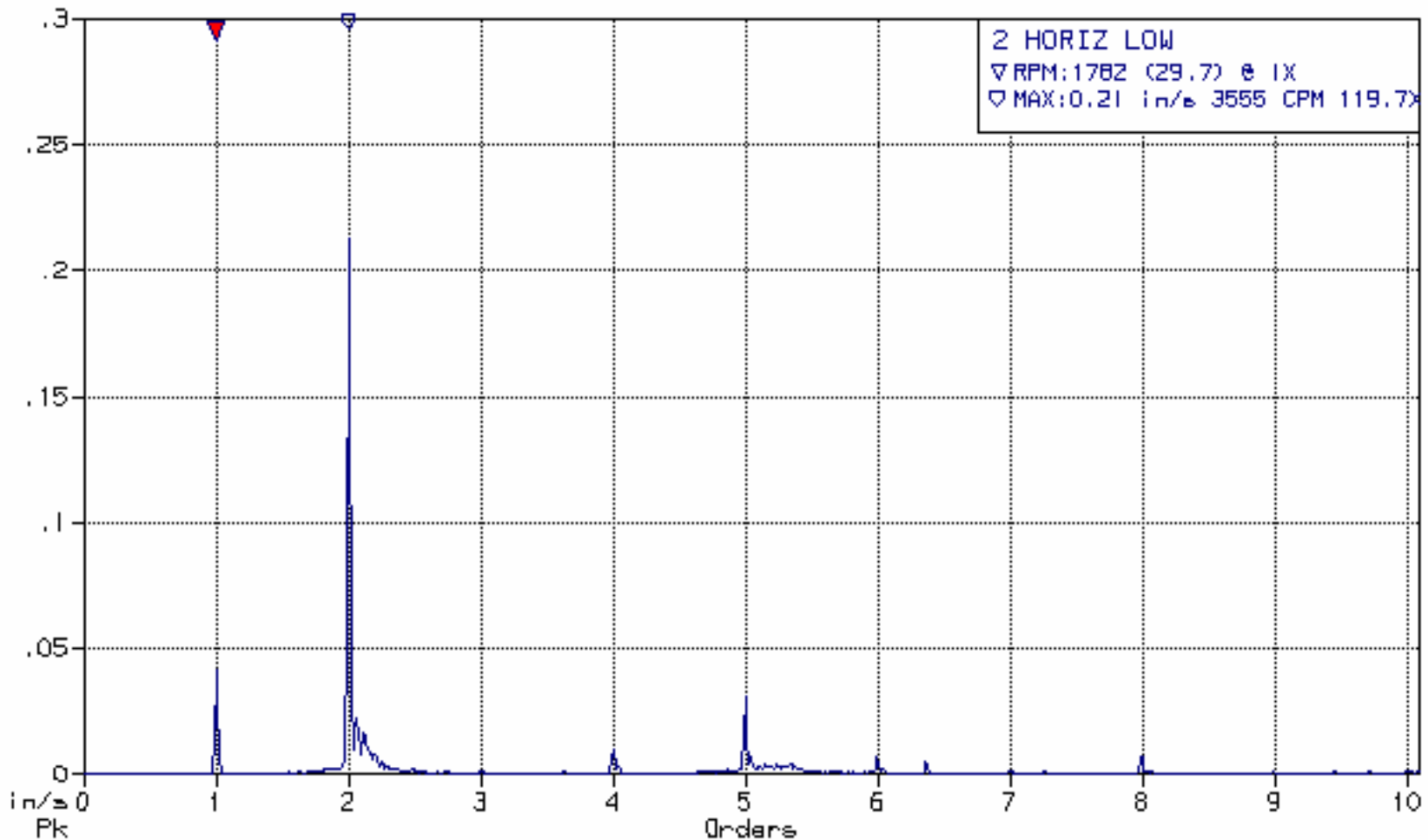
The dominant direction will be radial if the misalignment is parallel and axial if the misalignment is angular.

The 1X response is due to increased bending

The 2X response is due to crankshaft effect

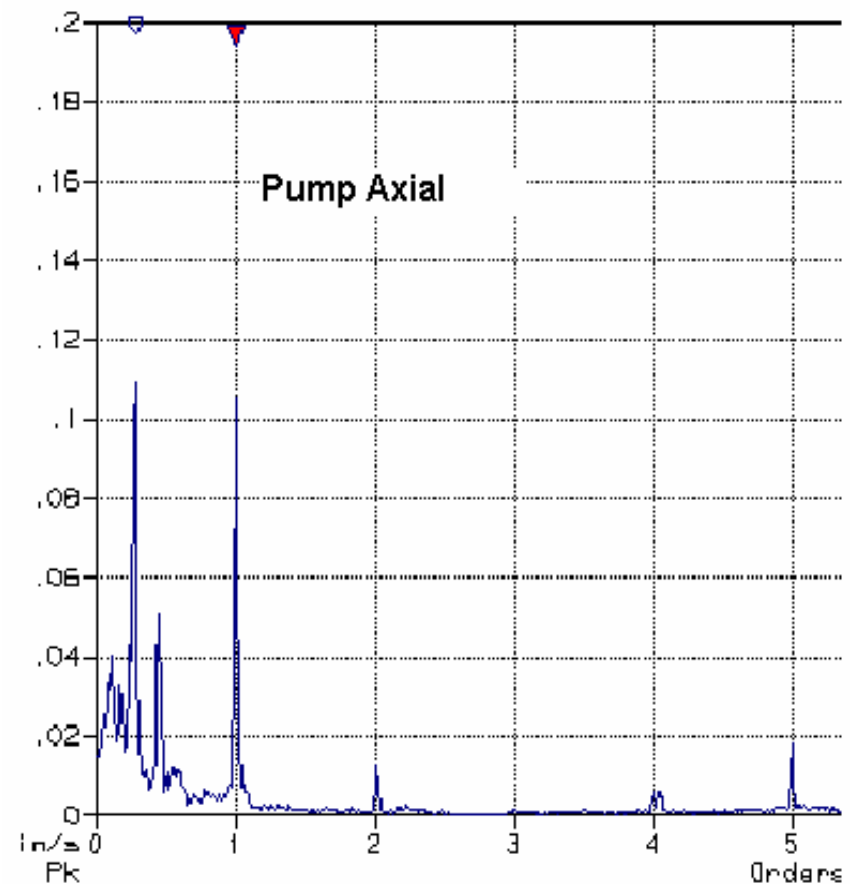
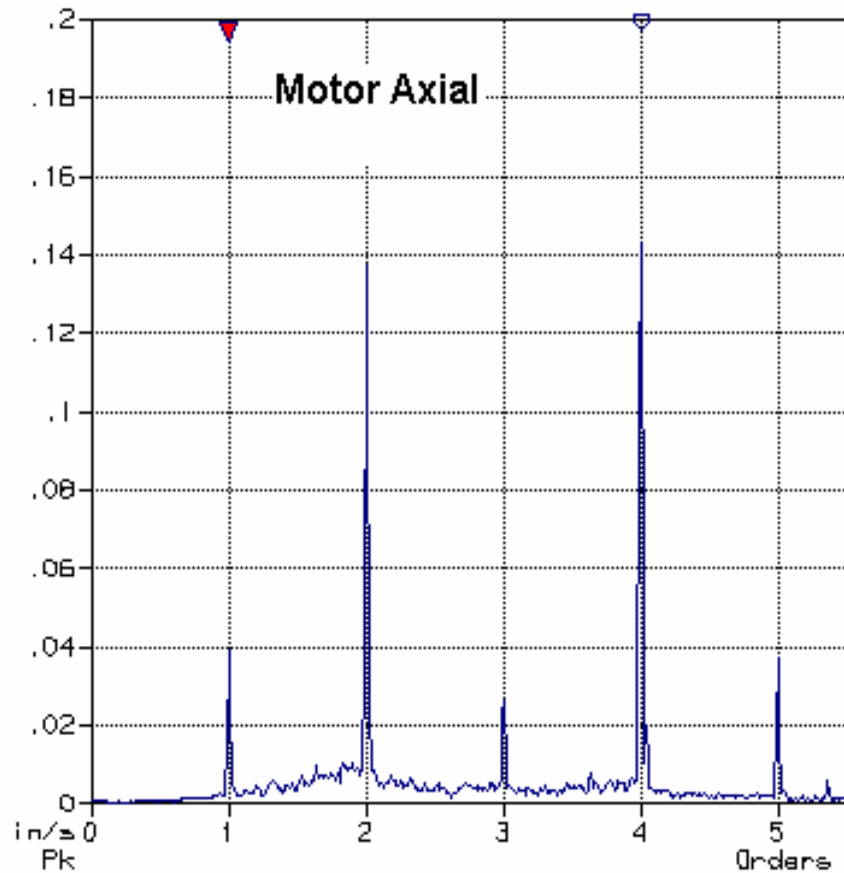
Common Machinery Faults

Example of Parallel Misalignment



Common Machinery Faults

Example of Complex Misalignment



Common Machinery Faults

Rolling Element Bearing Faults

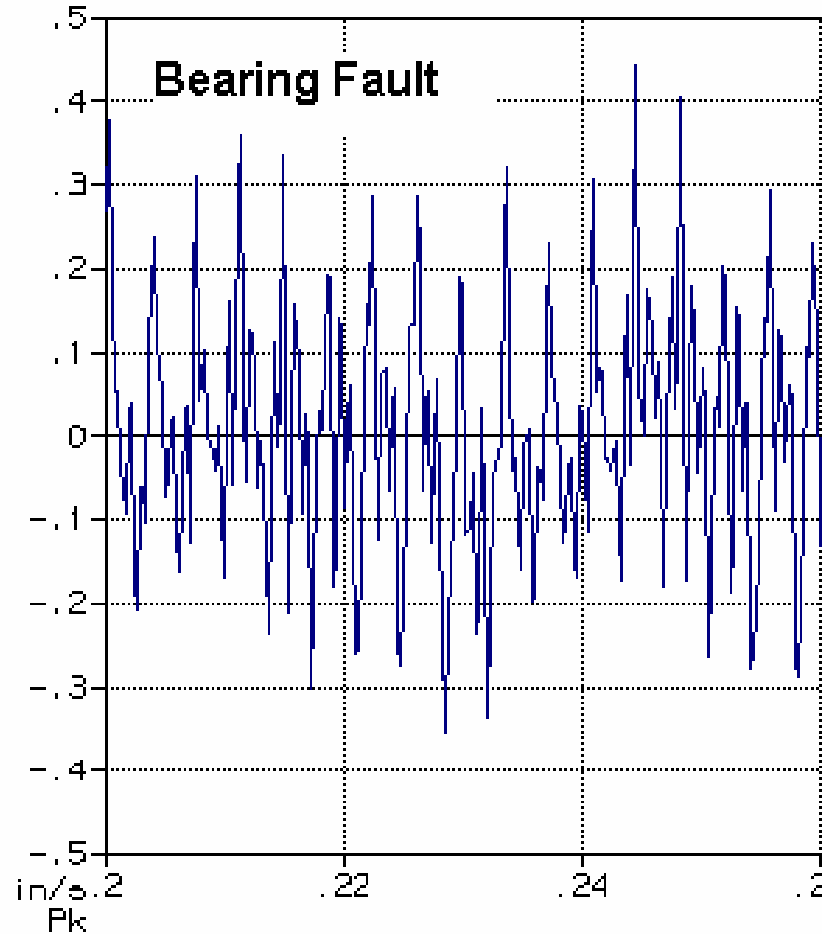
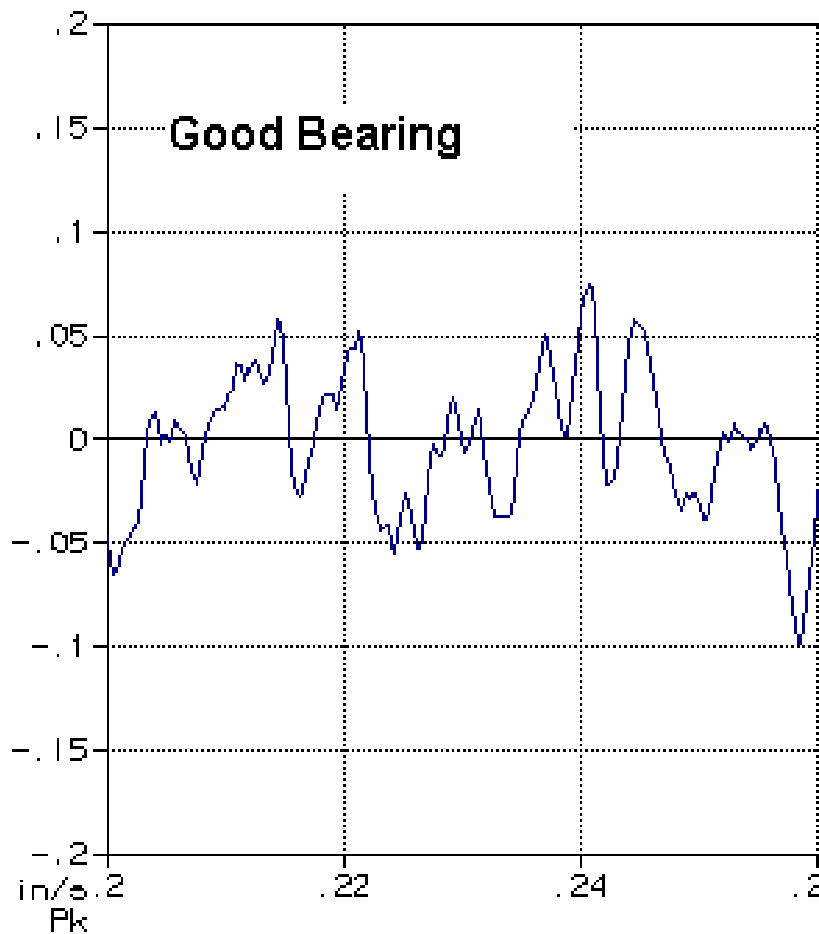
Always produce frequencies which are asynchronous to operating speed of rotor.

There are 4 fundamental frequencies which are produced – Ball Pass Outer Race, Ball Pass Inner Race, Ball Spin, and Fundamental Train Frequency.

These frequencies produced are a function of the pitch diameter, element diameter, number of elements, and contact angle.

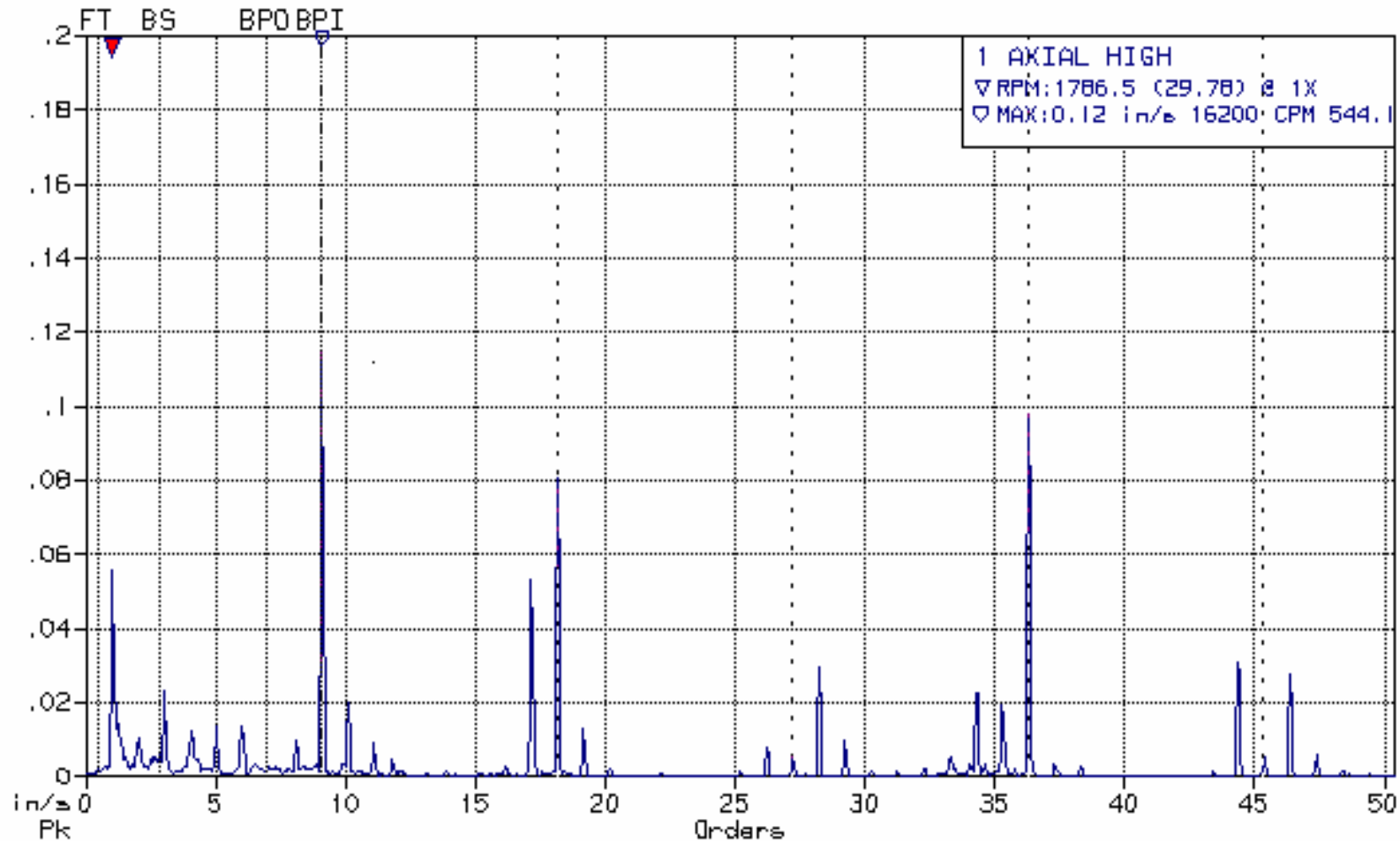
Common Machinery Faults

Bearing Defects-Waveform Analysis



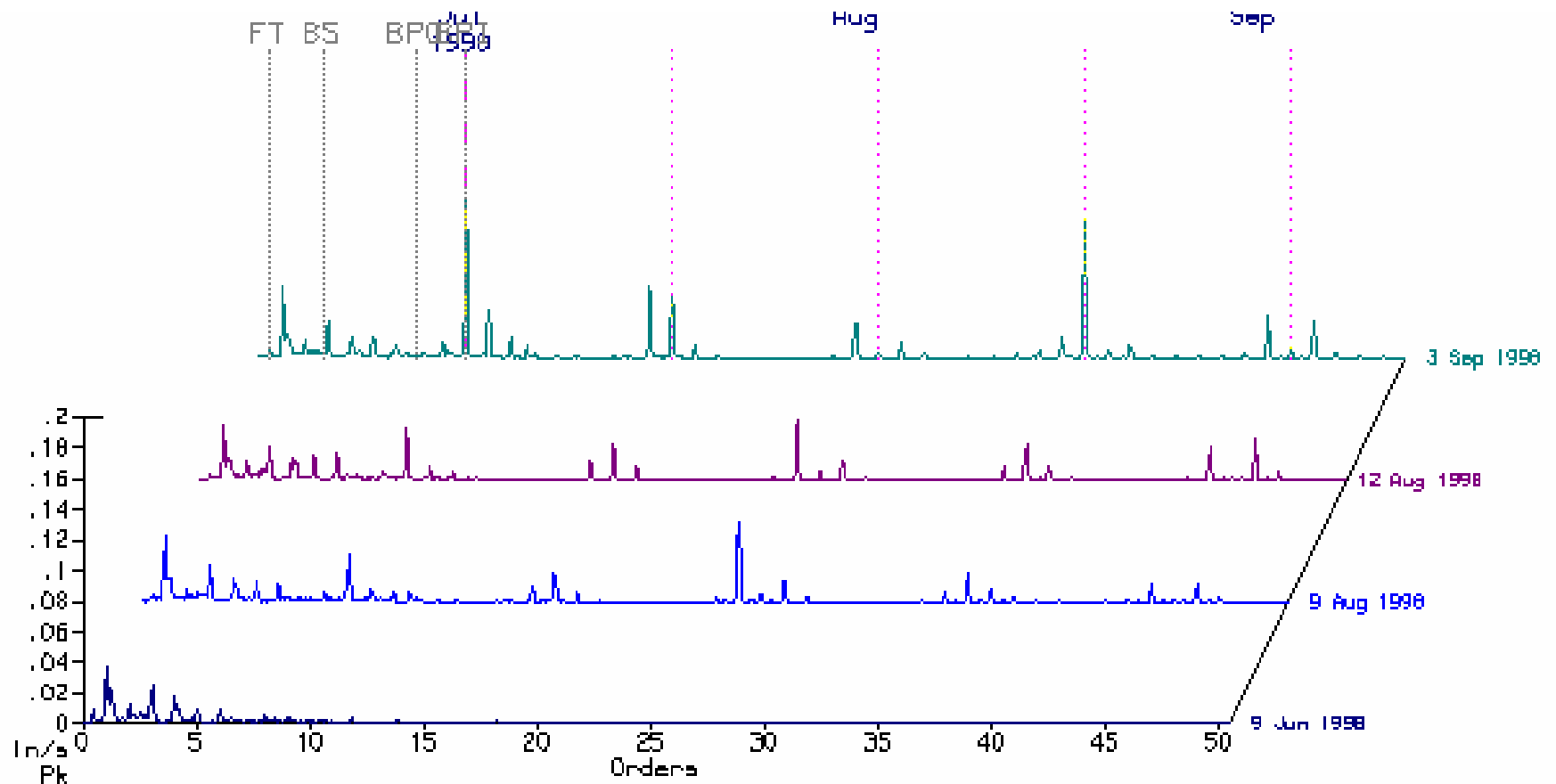
Common Machinery Faults

Bearing Defects - Spectrum Analysis

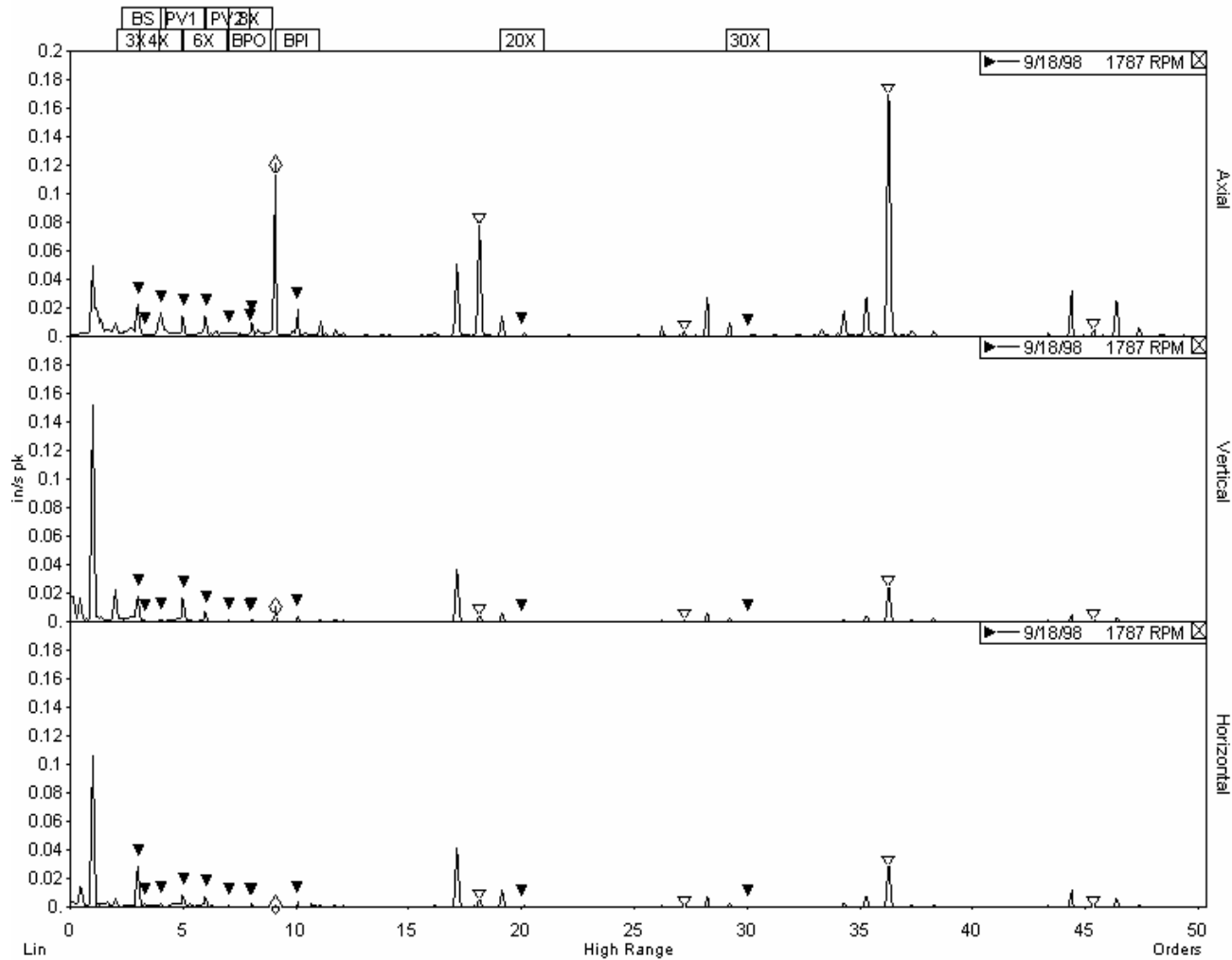


Common Machinery Faults

Bearing Defects – Spectral Trend



3 Axis View of Bearing Fault



Activity 3:


Remote Route

- Load remote route on your computer
- Instructions are found in the Activities Folder.

Preparing to Take Data

Nameplate Data

1. You collect Nameplate Data and Fax it to the Predictive Diagnostics Team.
2. The Predictive Diagnostic Team will create a database for your machines.
3. Allow 1 week for the databases to be completed.
4. Your routes will be downloaded into the Microlog.


Pump Nameplate Information Form
Exceeding Your Expectations!

Branch _____ Branch # _____ Date needed _____
 Branch Contact _____ FLSP _____
 Customer Name _____ Customer Site _____
 Cust Address _____ Cust City, State _____

Equipment ID: _____ CMMS Equipment ID: _____

Motor				Pump	
Make				Make	
Model				Model	
Serial number				Serial Number	
Speed	<input type="checkbox"/> VFD	Frame		Speed	Frame
HP	Volts	FLA		# of Vanes	
Off End Bearing				Inboard Bearing	
Drive End Bearing				Outboard Bearing	
Configuration		<input type="checkbox"/> Horizontal	<input type="checkbox"/> Vertical	___ # of Stages	
Impellers		<input type="checkbox"/> Overhung	<input type="checkbox"/> Centerhung		
# of pump bearings: _____					

Equipment ID _____ CMMS Equipment ID: _____

Motor				Pump	
Make				Make	
Model				Model	
Serial number				Serial Number	
Speed	<input type="checkbox"/> VFD	Frame		Speed	Frame
HP	Volts	FLA		# of Vanes	
Off End Bearing				Inboard Bearing	
Drive End Bearing				Outboard Bearing	
Configuration		<input type="checkbox"/> Horizontal	<input type="checkbox"/> Vertical	___ # of Stages	
Impellers		<input type="checkbox"/> Overhung	<input type="checkbox"/> Centerhung		
# of pump bearings: _____					

Preparing to Take Data

Nameplate Data - Machine Speed

Accurate machinery speed is very important to good data analysis.

1. You can use a tachometer.
 - Contact
 - Photo
 - Strobe
2. Or, you can calculate the fan speed.

Fan RPM

$$\frac{\text{Motor pulley diameter}}{\text{Fan pulley diameter}} \times \text{Motor RPM}$$

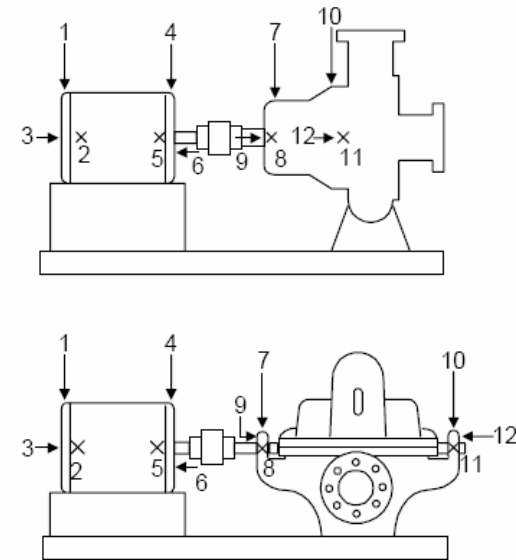
Activity 4:

Using a strobe to determine machinery RPM

- Your Instructor will demonstrate the use of the strobe as a tachometer.
- You will be asked to determine the RPM of a machine simulator.

Where You Take Measurements: Pumps

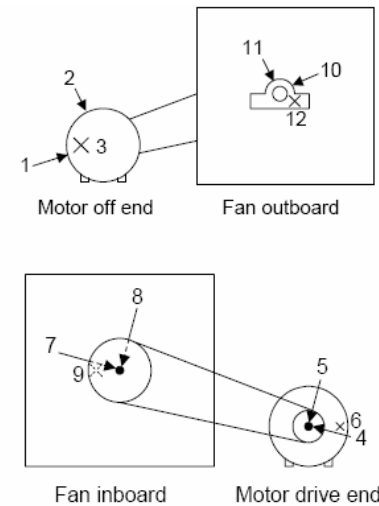
- At each bearing
 - MO
 - MD
 - PI
 - PO
- Three directions at each bearing
 - V- vertical
 - H- horizontal
 - A- Axial



1. MOV Motor off end vertical
2. MOH Motor off end horizontal
3. MOA Motor off end axial
4. MDV Motor drive end vertical
5. MDH Motor drive end horizontal
6. MDA Motor drive end axial
7. PIV Pump inboard vertical
8. PIH Pump inboard horizontal
9. PIA Pump inboard axial

Where You Take Measurements: Fans

- At each bearing
 - MO
 - MD
 - FI
 - FO
- Three directions at each bearing
 - IL- In line with belts
 - P- Perpendicular to belts
 - A- Axial



1. MOIL Motor off end in line
2. MOP Motor off end perpendicular
3. MOA Motor off end axial
4. MDIL Motor drive end in line
5. MDP Motor drive end perpendicular
6. MDA Motor drive end axial
7. FIIL Fan inboard in line
8. FIP Fan inboard perpendicular
9. FIA Fan inboard axial
10. FOIL Fan outboard in line
11. FOP Fan outboard perpendicular
12. FOA Fan outboard axial

Activity 6:

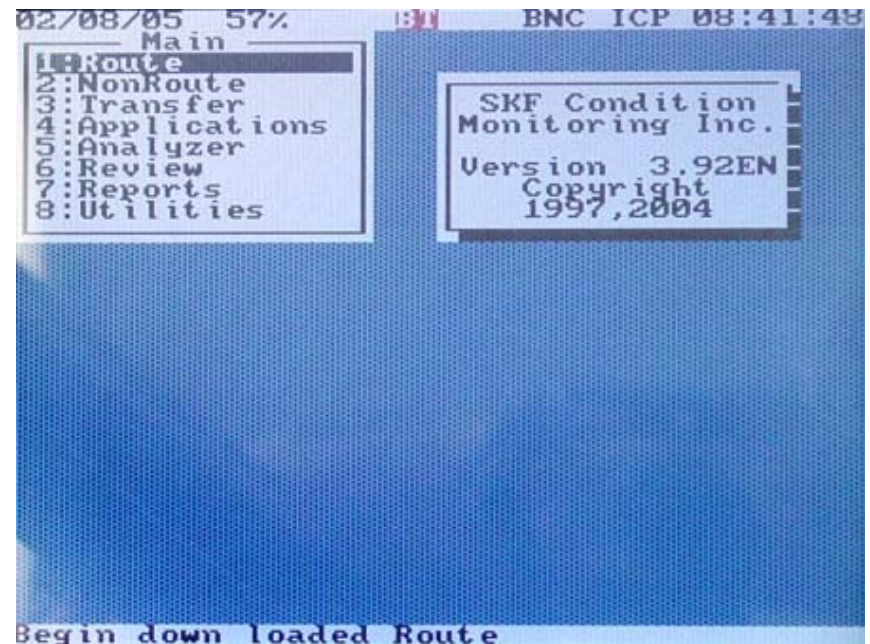
Nameplate Data

- You will be asked to collect nameplate data for assigned machine simulators.

How to Operate the Microlog

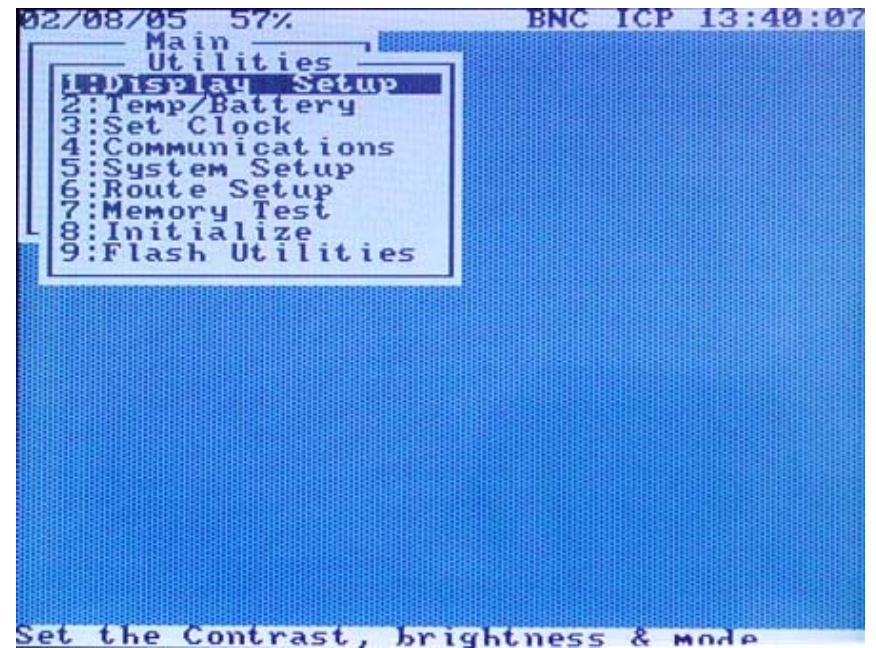
Navigating the Menus

- The Main menu is navigated with the Arrows.
- The Enter Key selects an item.
- The Menu Key offers “pull down” selections.



How to Operate the Microlog

Navigating the Menus



How to Operate the Microlog

Configuring the Microlog

System Setup

- Set to the Microlog to these settings.

```
02/08/05 57% BNC ICP 13:40:35
Main
Utilities
System Setup
FFT Hz/CPM:0.00
FFT Lin/Log:Linear
System:English
Auto Range:On
User Mode:Normal
Data Storage:Normal
Sensor Mode:Normal
Connector:BNC
Sensor Power:ICP
Settling Mode:Aggressive
Sensor/Cable Check:No
Calibration Reminder:Enabled

Use MENU KEY for selections
```

How to Operate the Microlog

Configuring the Microlog

Route Setup

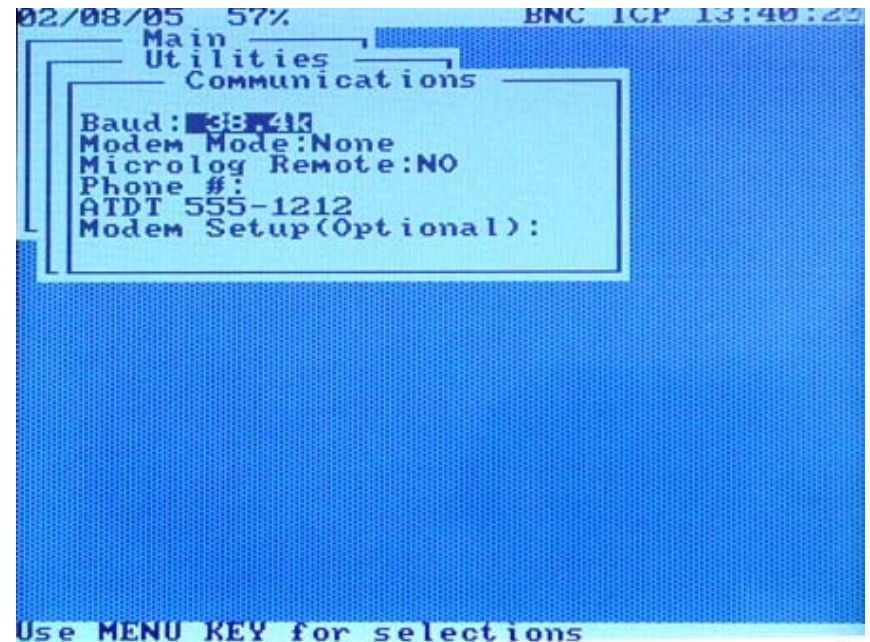
```
02/08/05 57% BNC TCP 13:40:43
Main
Utilities
Route Setup
Route Mode: Normal
Route Spectrum: Show
Route Trigger Slope: +
Route Collection: Normal
Average Overlap: 75%
Operator ID Tagging: No
Route Display: Hierarchy
View MPA spectrum: No
HAL Enable: Disabled

Use MENU KEY for selections
```

How to Operate the Microlog

Configuring the Microlog

Communications Setup



Activity 6:

Configure the Microlog

- System Setup
- Route Setup
- Communications Setup

Collecting Data

Microlog Operational Checks

Cable Integrity

- **Keep the sensor idle.**
- **Collect vibration data on any route point (ips).**
- **The spectrum should have less than .01 ips, overall.**

Collecting Data

Microlog Operational Checks

Accelerometer

- **Lightly tap the sensor.**
- **Collect vibration data on any route point (ips).**
- **The spectrum should have more than .03 ips, overall.**

Activity 7:

Microlog Operational Checks

Check the Cable

- Route Mode
- Training Route
- Fump#1
- Lay the sensor on the table
- ***Be Very Still***
- Enter to take measurement
- Record the Overall Amplitude

Activity 8:

Collecting Vibration Data

- Collect vibration data for assigned machine simulators.

Activity 7:

Microlog Operational Checks

Check the Accelerometer

- Reset measurement
- Hold the sensor
- ***Lightly tap the table***
- Enter to take measurement
- Record the Overall Amplitude

Activity 8:

Collecting Vibration Data 1

- Collect vibration data for assigned machine simulators.
- Be sure that the sensor is “seated” properly before saving the data.

Collecting Data

Verifying that the data is accurate

Review Options

- Data can be viewed in route mode **before it has been saved.**
- Data can be viewed in the review mode after it has been saved.

Collecting Data

Verifying that the data is accurate

Expanding the Display

- F_{\max} is established when the route is created.
- The F_{\max} That you see can be minimized so that the data appears to be expanded.
- Touch the Expand Display Button (to turn the function on).
- Press the right arrow the reduce the F_{\max} .
- Touch the Expand Display Button (to turn the function off).



Collecting Data

Verifying that the data is accurate

Lines of resolution

- Every spectrum is made up of a series digital values.
- Resolution choices may include: 100,200,400,800,1600,3200, etc.
- The resolution is set when the route is created.
- The cursor movement is determined by the resolution of the spectrum.

Collecting Data

Verifying that the data is accurate

The Cursor

- The cursor move to the right when you touch the right arrow..
- When the cursor is being used the overall amplitude is no longer displayed.
- The amplitude that is displayed is that digital value for the line of resolution of the cursor location.
- In other words, you will see a frequency value and an amplitude value.

Collecting Data

Verifying that the data is accurate

Data Inaccuracies

- Bad data usually appears in the first 3 lines.
- Looks like a “ski slope”.
- Other data inaccuracies.

Activity 9:

Checking Data Accuracy

- Review Mode
- Select Fump #1, MDV.
- Expand the display until the F_{\max} is approximately 15,000cpm.
- Move the cursor ONE position by touching the right arrow once.
- Record the amplitude at that cursor frequency.
- Move to the second line by touching the right arrow again.
- Record the amplitude at that cursor frequency.

frequency	amplitude
frequency	amplitude
frequency	amplitude

Activity 10:

Collecting & Reviewing Route Data

1. Collect data for the three Fumps in your Training Route.
2. Be sure to determine the RPM (before collecting data).
3. Manually enter the RPM information.

Activity 11:

Collecting & Reviewing Route Data

Review the data.

- Expand the display.
- Move the cursor to 1X.
- The “right” frequency is determined by finding maximum amplitude near that frequency.
- Record the frequency and amplitude for each Fump.

Fump #1 1 X frequency	amplitude
Fump #2 1 X frequency	amplitude
Fump #3 1 X frequency	amplitude

Reviewing Data

More about the vibration spectrum.

1X

- Spectral analysis always requires the determination of 1X .
- 1X will NOT always be the highest or the first significant peak in the spectrum.
- 1X frequency in the spectrum will not be exactly the same as the tachometer speed.

Reviewing Data

More about the vibration spectrum.

Synchronous Peaks

- Any peak which is a even order integer or fraction of a fundamental frequency is synchronous.
- Even multiples are often called “harmonics”.
- Even fractions are called “sub-harmonic”.
- The marker button will identify multiples of whatever frequency the cursor is tuned.
- If the cursor is tuned to 1X, the marker button will highlight harmonics of running speed.

Reviewing Data

More about the vibration spectrum.

High Harmonics

- For radial measurements only.
- If any harmonic amplitude is $\frac{1}{2}$ of the 1X amplitude (or greater), it is considered high.

Activity 10: Reviewing Route Data

1. Use this format to tabulate the vibration data for Fump #3.

	1x	High harmonics	Non-synchronous
MOV			
MOH			
MOA		-----	
MDV			
MDH			
MDA		-----	
PIV			
PIH			
PIA		-----	
POV			
POH			
POA		-----	

Reviewing Data

More about the vibration spectrum.

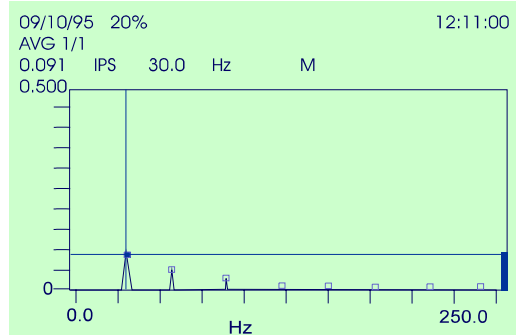
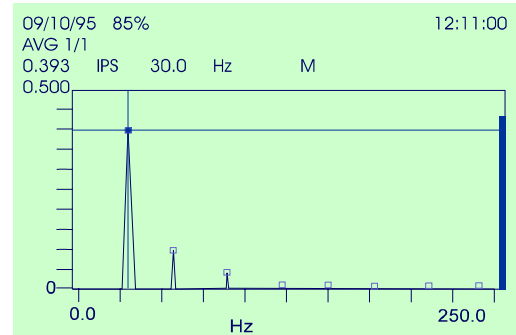
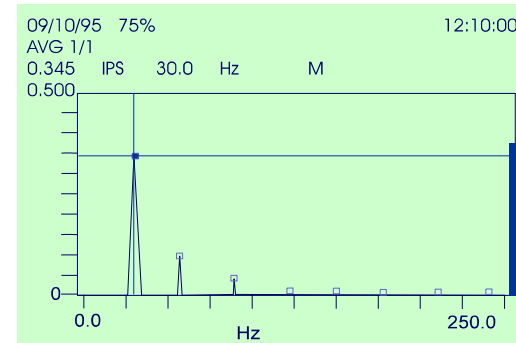
High Axial

- If at any bearing, the axial1X is greater than $\frac{1}{2}$ of the lowest radial amplitude, it is considered high.

Analysis Rules

Imbalance

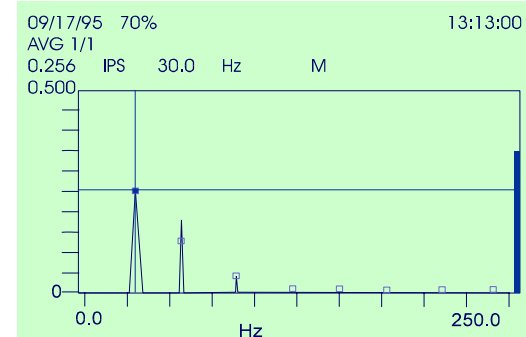
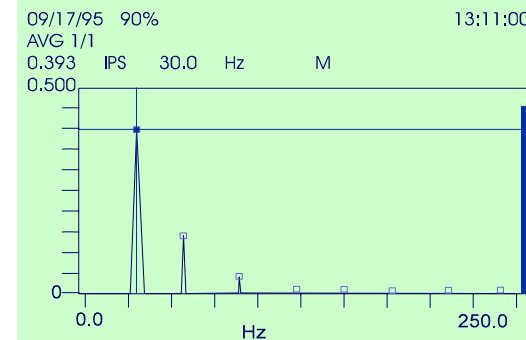
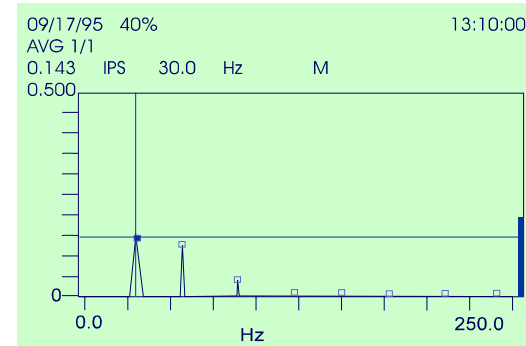
- Always at 1X RPM
- Similar radial amplitude
- Low axial
- Low harmonics



Analysis Rules

Misalignment

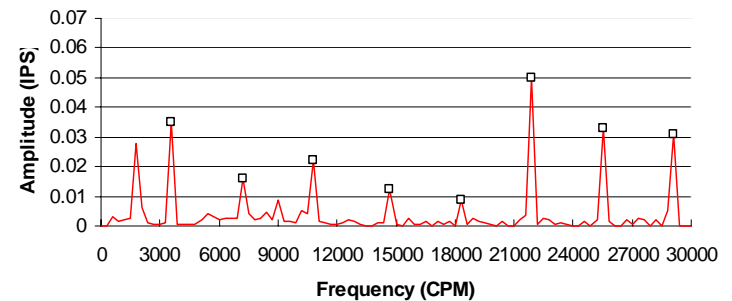
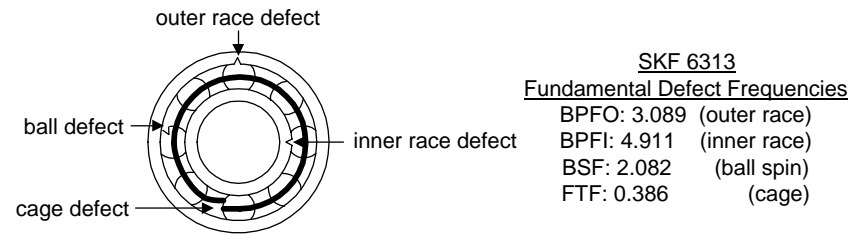
- Dissimilar radial amplitude
- High axial
- High harmonics



Analysis Rules

Bearing Damage

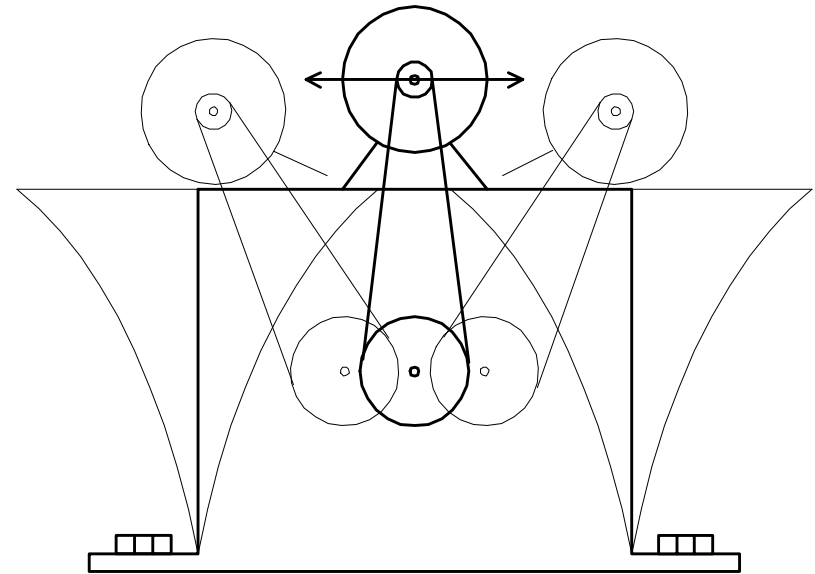
- Low amplitude can be serious
- Many possible frequencies
- Non-harmonic frequencies
- Unrelated to 1X RPM
- “Broad band”



Analysis Rules

Resonance

- A radial or axial 1x shaft RPM amplitude is in alarm.
- The larger radial 1x amplitude is greater than five times the smaller radial 1x amplitude at any bearing.
- Or...the axial 1x shaft RPM amplitude is greater than two and one half times the larger radial 1x shaft RPM amplitude at the same end of the machine.
- The PAD between the two radial 1x shaft RPM phase angles at the resonant end of the machine is 0° or 180° ($\pm 30^\circ$).

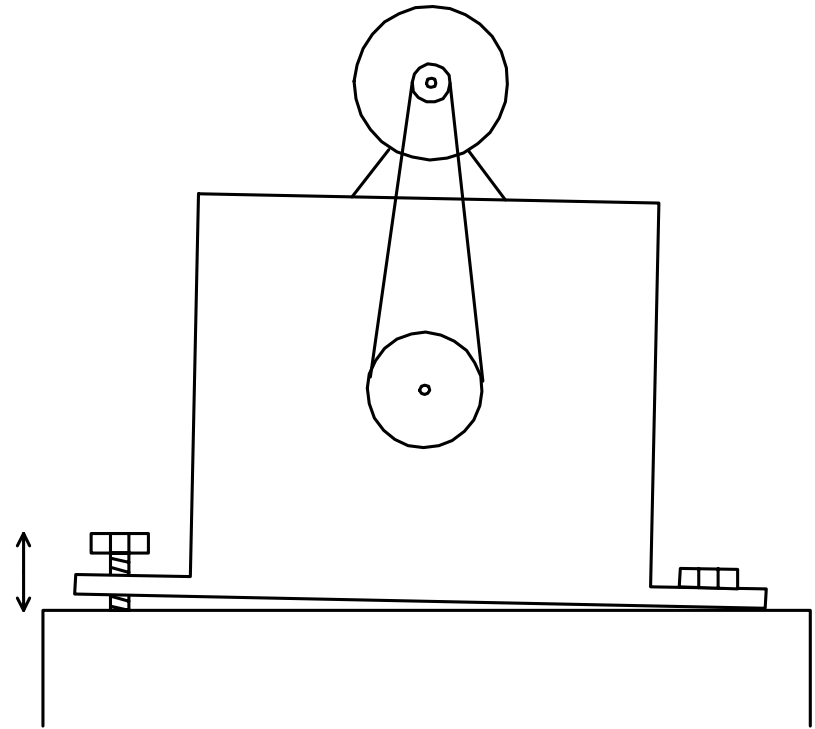


Analysis Rules

Looseness

- A radial or axial 1x amplitude is in alarm.
- Radial harmonics of 1x amplitude are greater than half the 1x.
- $\frac{1}{2}$ x shaft RPM harmonics are present.
- The PAD between the two radial 1x shaft RPM phase angles at the end of the machine that is loose is 0° or 180° ($\pm 30^\circ$)

▪ *Alarm limits:* Radial 1x shaft RPM amplitude greater than 0.15 IPS. Axial 1x amplitude and radial 2x shaft RPM amplitude greater than 0.075 IPS.

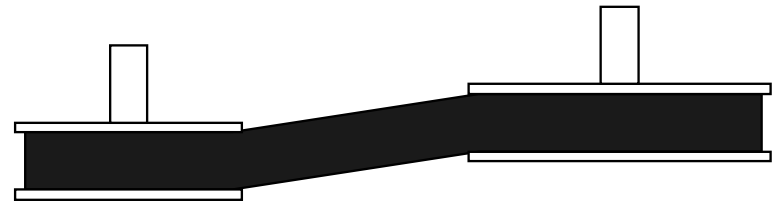


Analysis Rules

Pulley Misalignment

- A radial or axial 1x shaft RPM amplitude is in alarm.
- The axial 1x shaft RPM amplitude is greater than half the smallest radial 1x shaft RPM amplitude at the same end of the machine.
- The driver (1x motor shaft RPM amplitude) vibration is usually the dominant vibration.
- Often the highest amplitude on the motor is at 1x fan shaft RPM and the highest amplitude on the fan is at 1x motor .
- The 2x amplitude is greater than half the 1x amplitude at any bearing.

Alarm limits: Radial 1x shaft RPM amplitude greater than 0.15 IPS. Axial 1x shaft RPM amplitude greater than 0.075 IPS.



Course Objectives

1. Provide you with a general understanding of how vibration analysis is done, it's advantages and disadvantages.
2. Reinforce the basic information you need to understand when looking at the vibration spectrum.
 - Measurement units: Mils Vs IPS Vs G's,
 - Frequency units: Hz Vs CPM Vs Orders
 - How to locate primary forcing frequencies
3. How to operate the Microlog.
 - Navigating the menus
 - Performing various setups for data collection
 - Transferring Data to and from the Microlog
 - Transferring data to and from their computers to MKE
 - How to navigate through the Routes

Course Objectives

3. How to operate the Microlog.
 - Understanding the route setup
 - How to collect accurate vibration data
 - How to collect Amplitude and Phase data
 - New wizards
 - Using coded Notes
4. How to perform single and dual plane balancing.
5. How to perform both laser and dual dial indicator alignments for coupled shafts and belt driven machines.
6. How to communicate results to the customer.
7. Reviewing reports and understanding the content.

Maintenance Strategies

“Learning vibration analysis has made me a better mechanic.”

“I’ve learned that its not the big things that matter, but the hundreds of little things that make the difference.”

Tim Sorensen
Lead Mechanic
GSA Commonwealth of Virginia
1991

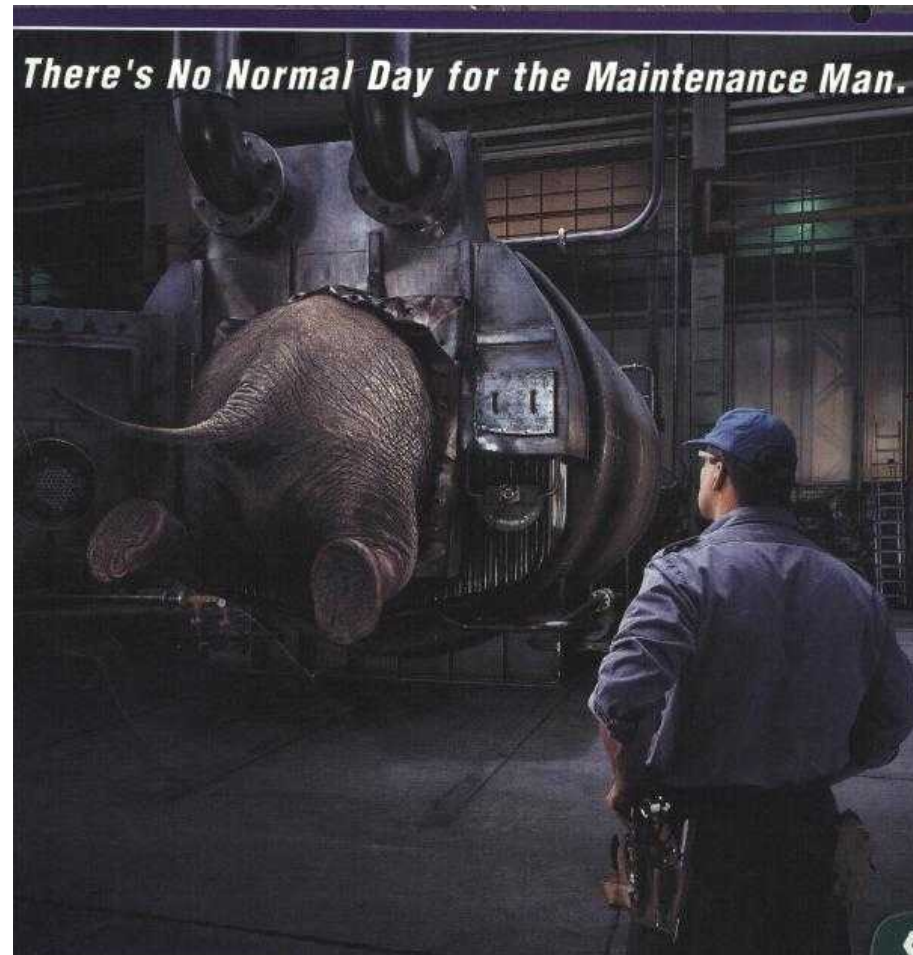
Maintenance Strategies

- Reactive Maintenance
- Preventive Maintenance
- Predictive Maintenance
- Pro-active Maintenance
- Practical Maintenance

Maintenance Strategies

Reactive Maintenance

Run it until it dies!



Maintenance Strategies

Reactive Maintenance

Advantages

- Low *apparent* cost.
- Low training costs.

Disadvantages

- Increased cost due to unplanned downtime of equipment.
- Increased labor cost, especially if overtime is needed.
- Possible secondary equipment or process damage from equipment failure.
- Inefficient use of staff resources.

Maintenance Strategies

Preventive (time based) Maintenance

Advantages

- Estimated 12% to 18% cost savings over reactive maintenance program.
- Flexibility allows for the adjustment of maintenance periodicity.
- Increased component life cycle.
- Energy savings.
- Reduced equipment or process failure.

Disadvantages

- Catastrophic failures still likely to occur.
- Labor intensive.
- Includes performance of unneeded maintenance.
- Potential for incidental damage to components in conducting unneeded maintenance.

Maintenance Strategies

Predictive Maintenance

- Machine condition determines when maintenance is scheduled.
- Plant management in control of maintenance programs. Overall condition of plant equipment is a known.
- Plant has better control of schedule.

Maintenance Strategies

Pro-active Maintenance

- Looks at equipment failures to determine the exact (root) cause of failure
- Gradually design problems out of plant
- Natural extension of predictive maintenance

Maintenance Strategies

Where are we today?

- Greater than 50% of maintenance hours are spent in reactive mode
- Less than 40% spent in preventive maintenance
- Less than 10% in predictive Maintenance
- Less than 1% in Pro-active maintenance

Maintenance Strategies

Repair Cost Estimates

Repair Description	< 30 HP	30- 60 HP	> 60HP
Replace motor	\$2000	\$4000	\$6000
Replace motor bearings	\$1050	\$1850	\$2950
Replace fan bearings & balance & align	\$1800	\$2500	\$3200
Balance & align	\$1000	\$1000	\$1000
Replace fan bearings, fan shaft & balance	\$5400	\$7500	\$9600
Replace fan bearings & balance & align	\$1800	\$2500	\$3200

Maintenance Strategies

Bearing Life Equation

- When bearings fail, secondary damage is eminent.

$$L_{10} = \frac{16700}{\text{rpm}} \left[\frac{\text{dynamic capacity x load rating}}{\text{force}} \right]^3 = \text{Hours of life}$$

Maintenance Strategies

Practical Maintenance

- Constantly gather information
- Identify that equipment that contributes to the majority of reactive maintenance calls.
- Target basic maintenance practices that:
 - Extend potential machinery life cycles
 - Contribute to reductions in vibrations
 - Require only small investments in tools and equipment
- Train personnel in performing those practices.
- Expose personnel to technologies that will enhance those practices.

Maintenance Strategies

Practical Maintenance

Common machinery problems we *easily* can control

- Improper lubrication
- Worn pulleys & belts
- Misalignment of pulleys to shafts
- Misalignment of direct coupled machines
- Imbalance
- Structural looseness

Activity 1: HACCC Report

The JCI Predictive Offering

- Read the HACCC Report
- You will find the report in the Activities Folder

HACC Report

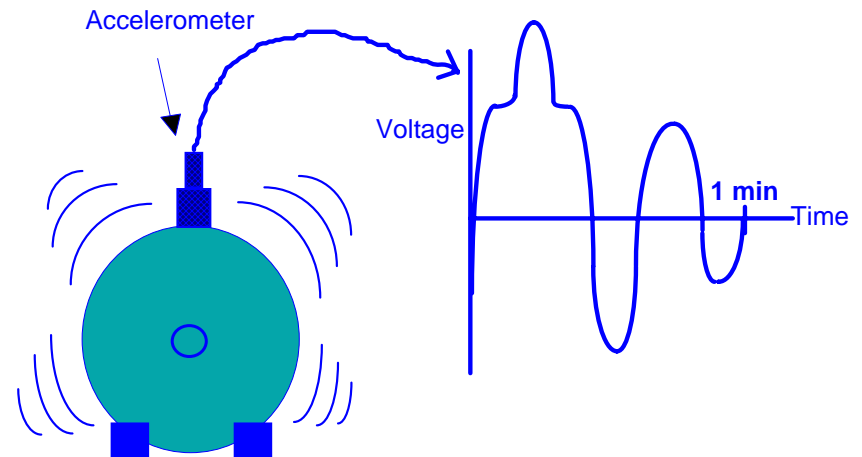
The JCI Predictive Offering

- After reading the report, can you name any service opportunities?
(list three)
- Which machines would you say are in good condition?
- In your opinion, which 5 machines are in the most need of repair?
(List them with from worst to better)
- List 5 machinery faults that can be determined using vibration predictive services.
- If you were to repair the two worst machines, approximate the service revenue you would generate.

Vibration Basics

What is Vibration?

- Any physical process characterized by cyclic variations in amplitude, intensity, or frequency
- Vibration is usually **not** the direct cause of a problem, rather it is the **symptom** of the problem.



Vibration Basics

Vibration Causes

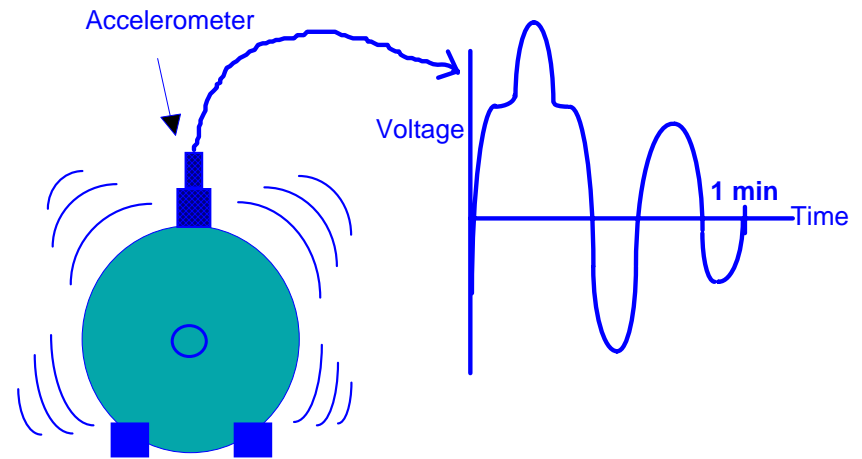
Common machinery problems that cause vibration

- Imbalance
- Worn pulleys and belts
- Misalignment of pulleys to shafts
- Misalignment of pulleys to one another
- Looseness
- Improper fit between races and shafts (internal looseness)
- Bearing Damage
- Improper lubrication
- Aerodynamic forces
- Hydraulic forces
- Improper loading of resilient mounts
- Inadequate motor mount support
- Resonance
- VFD's: operating at or near a natural frequency

Vibration Basics

The Vibration Signal

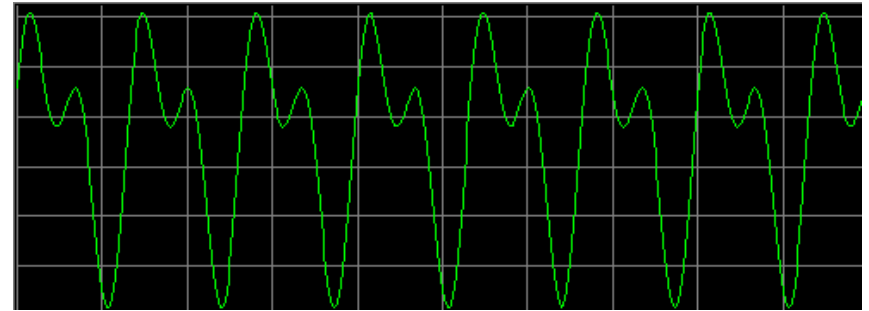
- A vibration sensor is mounted at or near a machine bearing support.
- Mounting methods include magnets, extension probes, and hard mounts.
- If the mount is good the sensor is “coupled” to the bearing support, and therefore vibrates just as the machine does.
- The sensor produces voltage that is proportional to the vibration.



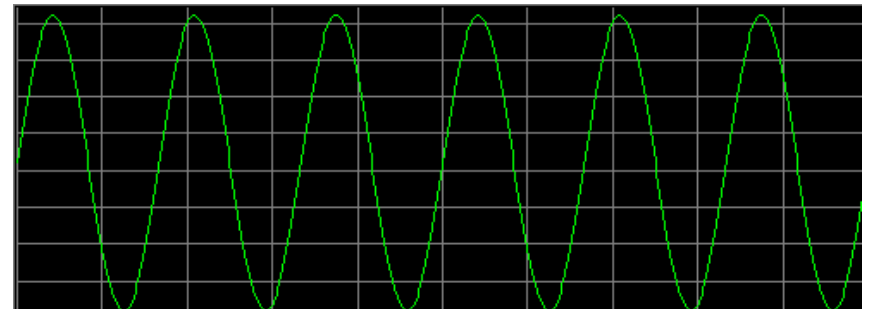
Vibration Basics

The Vibration Signal

Periodic Motion – Motion which repeats itself in a given time interval

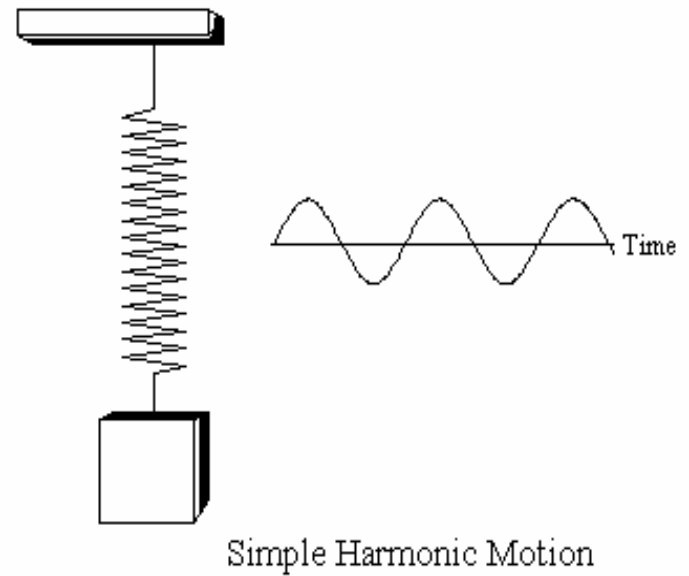
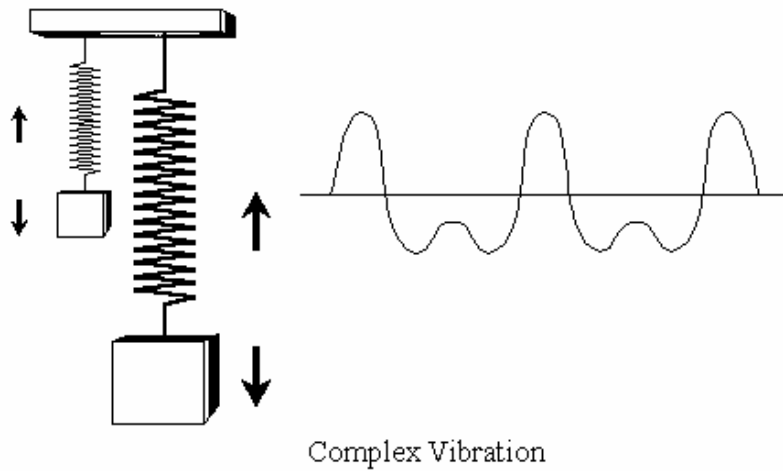


Harmonic Motion – A single frequency of vibratory motion which repeats itself in a given time interval.



Vibration Basics

The Vibration Signal

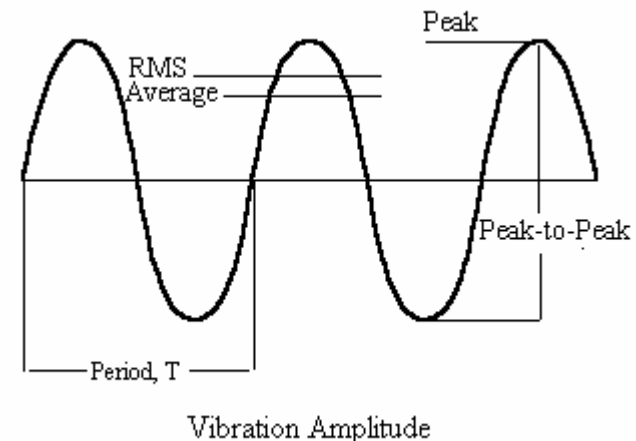


Vibration Basics

The Vibration Signal

- Vibration amplitude is the amount of vibration and indicates the severity of combined problems.

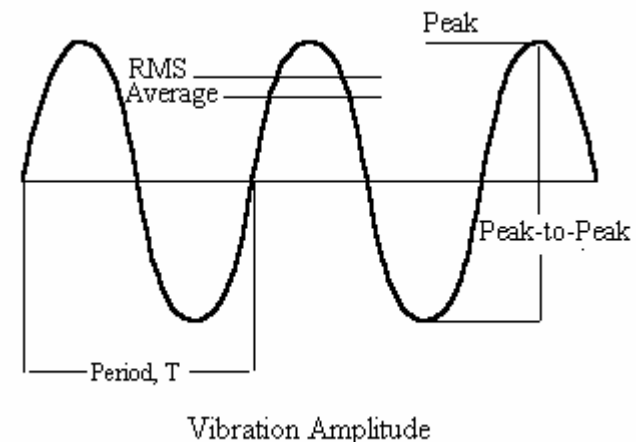
- 0-Pk maximum motion in either positive or negative direction. Expressed as an absolute value
- PK-PK maximum positive plus maximum negative motion
- RMS used to express power or energy in a waveform.



Vibration Basics

The Vibration Signal

- Vibration frequency indicates how often the vibration event occurs.
- Vibration frequency is used to determine specific problems.



Vibration Basics

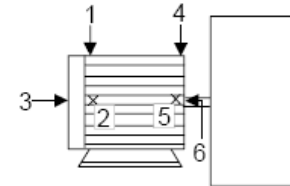
Collecting Vibration Data

- Data is collected by mounting at machinery bearing positions and then moving the sensor to subsequent positions.
- A vibration analyzer or data collector stores the data from the sensor.
- The collection process is broken into “routes” which can be collected in 1-2 hours.
- The data is permanently stored in a computer database.
- The software is also used in diagnosing specific machinery problems.

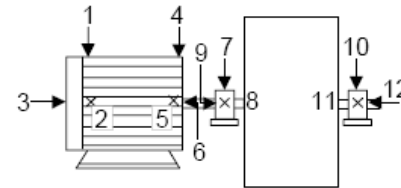
Vibration Basics

Collecting Vibration Data

- Vibration data is collected in three axis at each bearing position (if possible).
- The sensor is moved to each position as the route is collected.
- Some vibration equipment manufacturers use a 3-axis sensor, so three data points are collected simultaneously.
- The data for one machine can be collected in 5-15 minutes.



NOTE: Positions 7-12 do not apply to overhung conditions

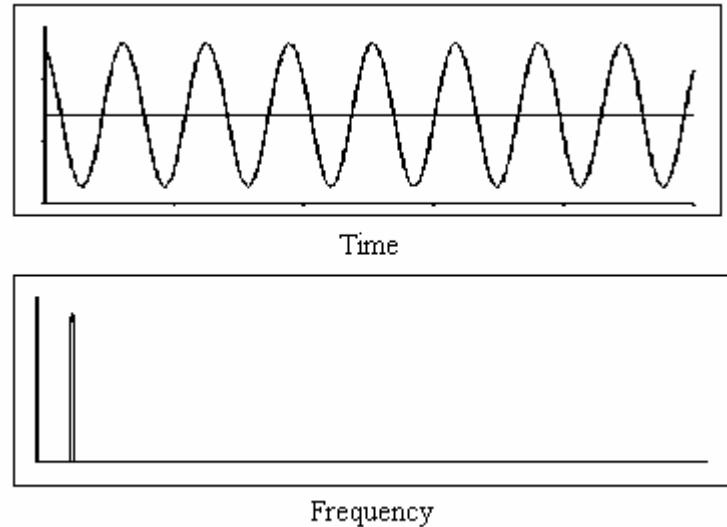


1. MOV Motor off end vertical
2. MOH Motor off end horizontal
3. MOA Motor off end axial
4. MDV Motor drive end vertical
5. MDH Motor drive end horizontal
6. MDA Motor drive end axial
7. FIV Fan inboard vertical
8. FIH Fan inboard horizontal
9. FIA Fan inboard axial
10. FOV Fan outboard vertical
11. FOH Fan outboard horizontal
12. FIA Fan outboard axial

Vibration Basics

The Vibration Spectrum

- The raw time waveform (Amplitude VS Time) is processed using FFT analysis.
- The waveform is converted and presented as a spectrum (Amplitude VS Frequency).

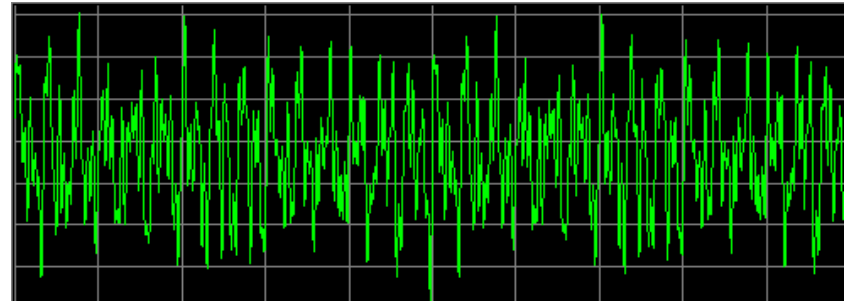


The Spectrum of a Sine Wave

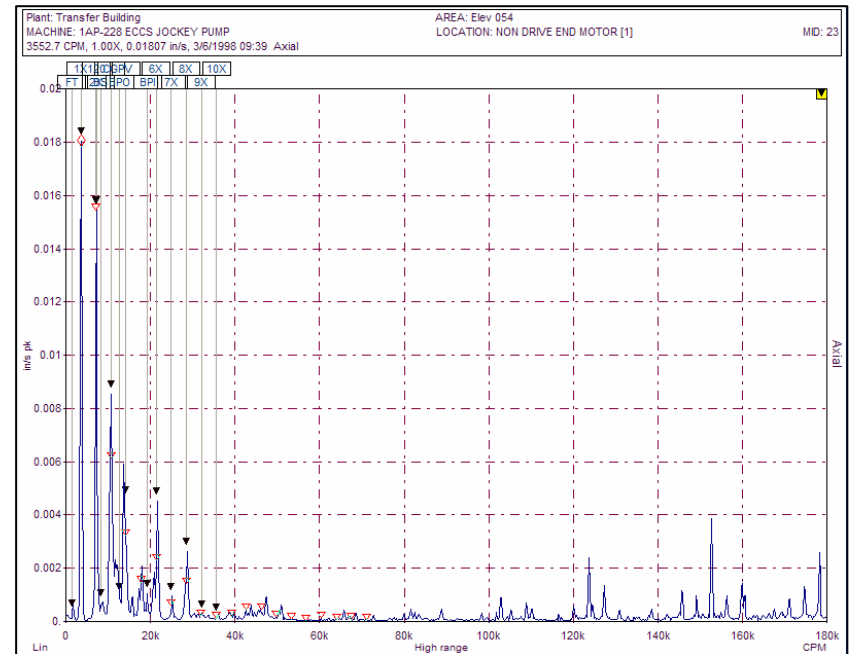
Vibration Basics

The Vibration Spectrum

- The waveform



- The Spectrum



Vibration Basics

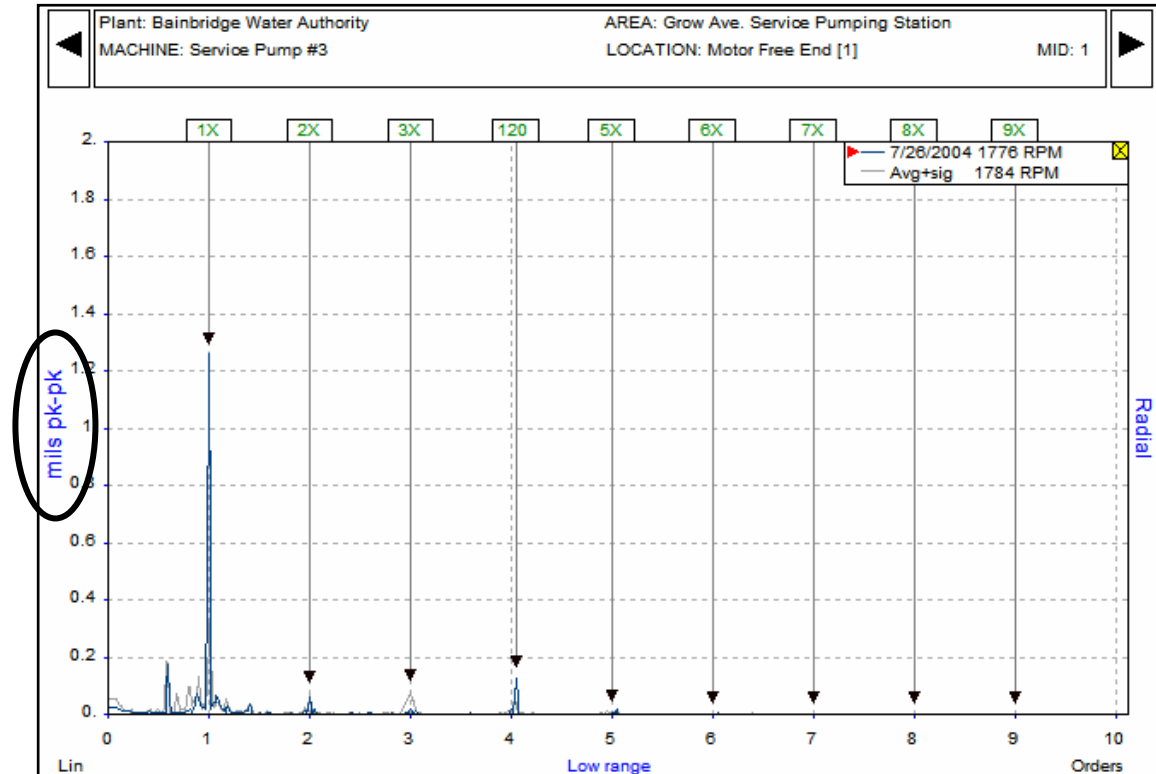
Units of Amplitude

Measure	Units	Description
Displacement	Mil (.001") Pk-Pk	Motion of equipment or rotor, relates to stress
Velocity	inches/second (IPS) 0-Pk	Time rate of motion, relates to component fatigue
Acceleration	G's (386.4 in/sec ²) 0-Pk	Relates to forces present in components

Vibration Basics

Units of Amplitude

- Displacement
Mils (PK to PK)

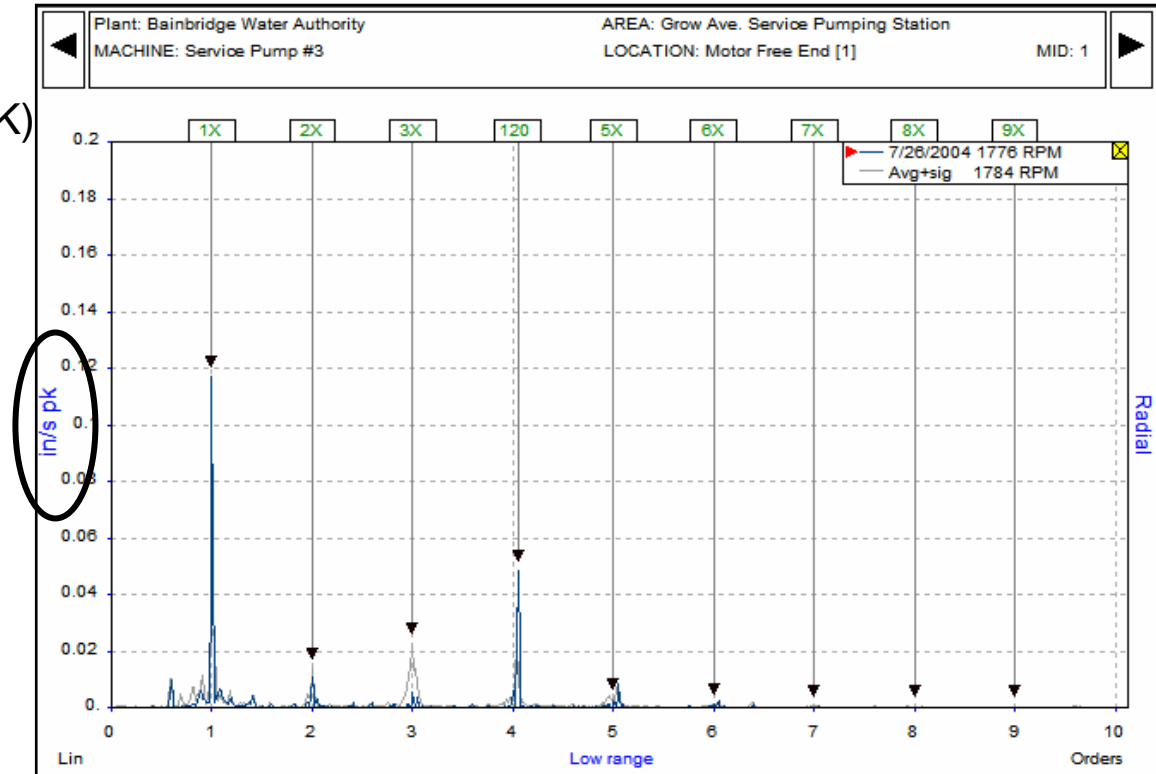


Vibration Basics

Units of Amplitude

- Velocity

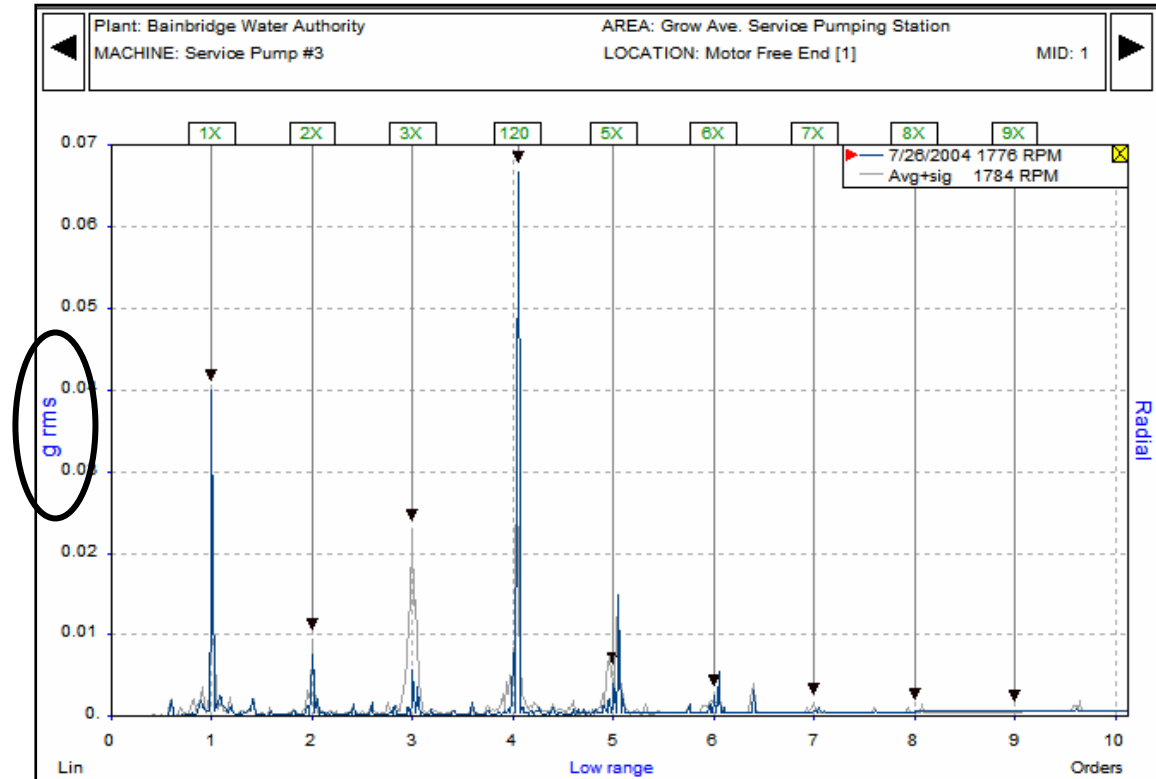
Inches/second (PK)



Vibration Basics

Units of Amplitude

- Acceleration
G's (RMS)

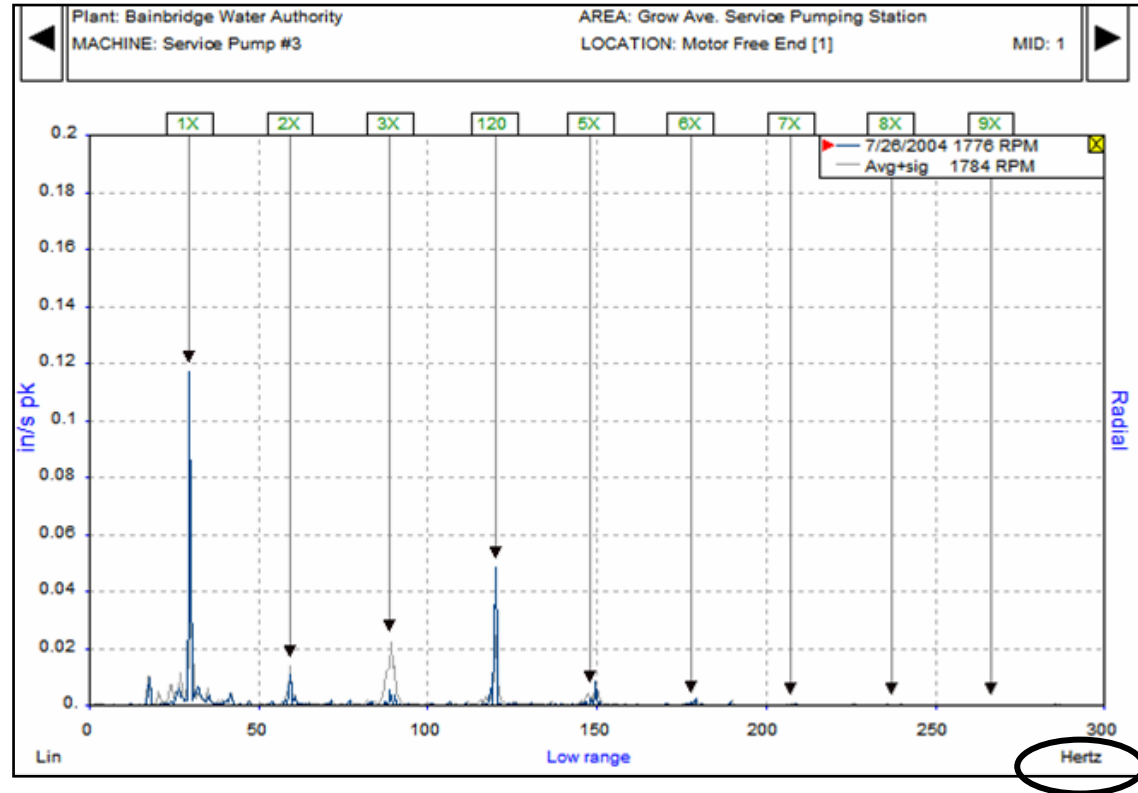


Vibration Basics

Units of Frequency

- Hertz

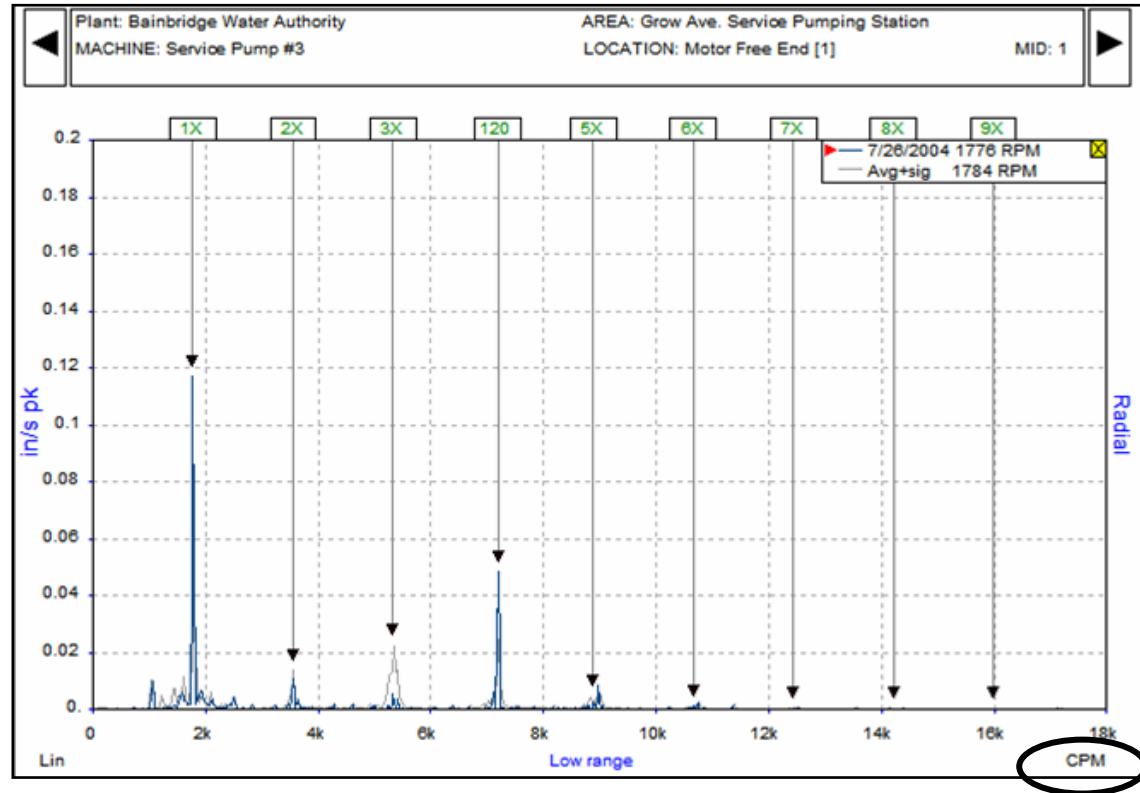
Cycles per Second



Vibration Basics

Units of Frequency

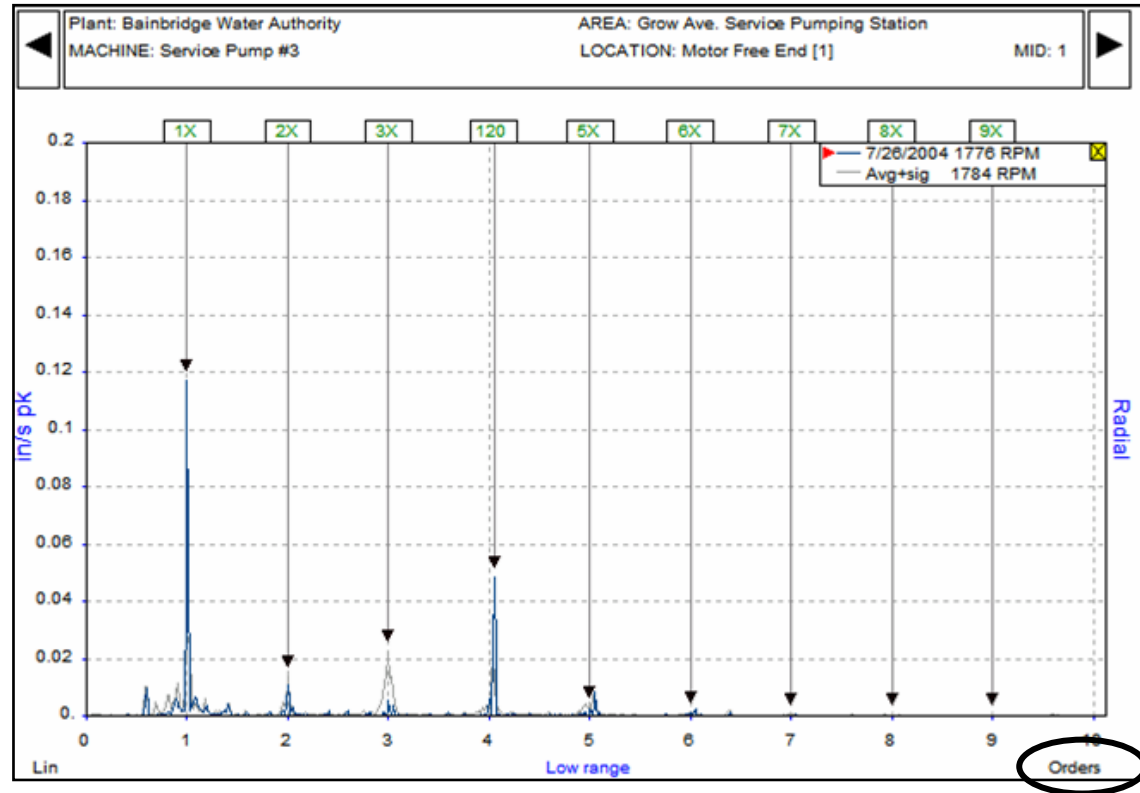
- CPM
Cycles per Minute



Vibration Basics

Units of Frequency

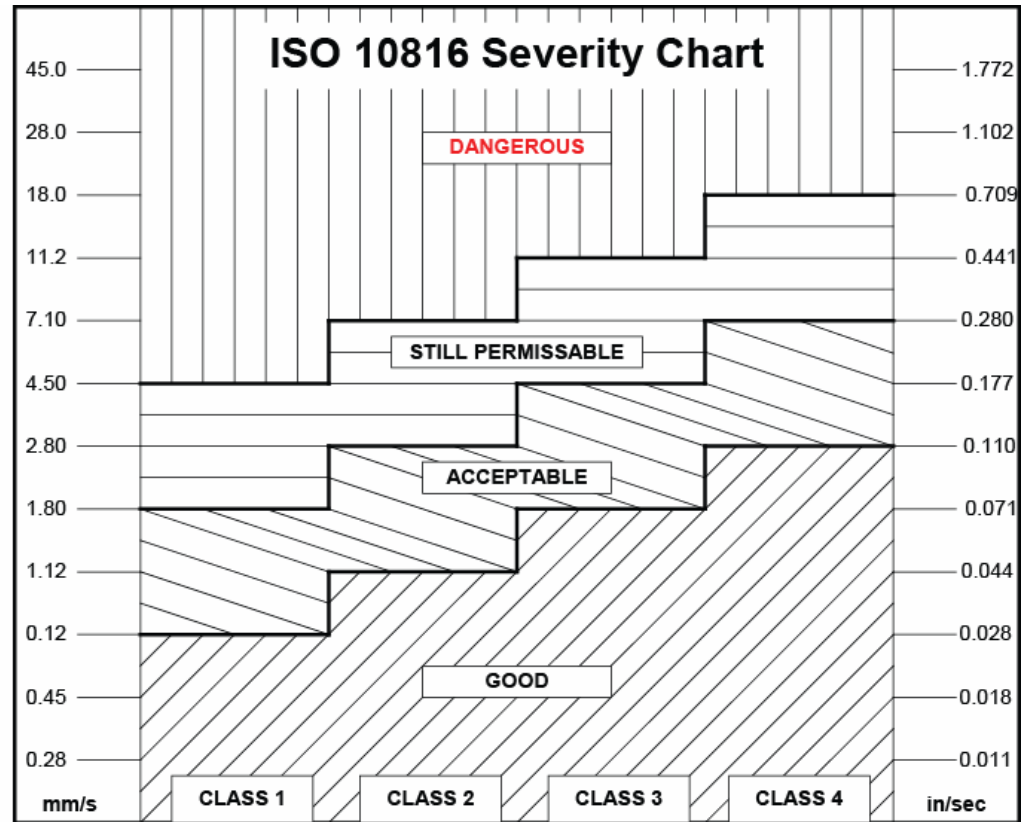
- Orders
CPM/RPM



Vibration Basics

Overall Amplitude Severity Guides

- Overall Amplitude to determine severity.



CLASS 1 - Small machines, especially production electrical motors up to 15kW (20 HP)

CLASS 2 - Medium sized machines, especially electrical motors >15Kw to 75KW (20-100 HP) without special foundations

CLASS 3 - Large machines on heavy foundations

CLASS 4 - Largest machines and turbo machines with special foundations

Vibration Basics

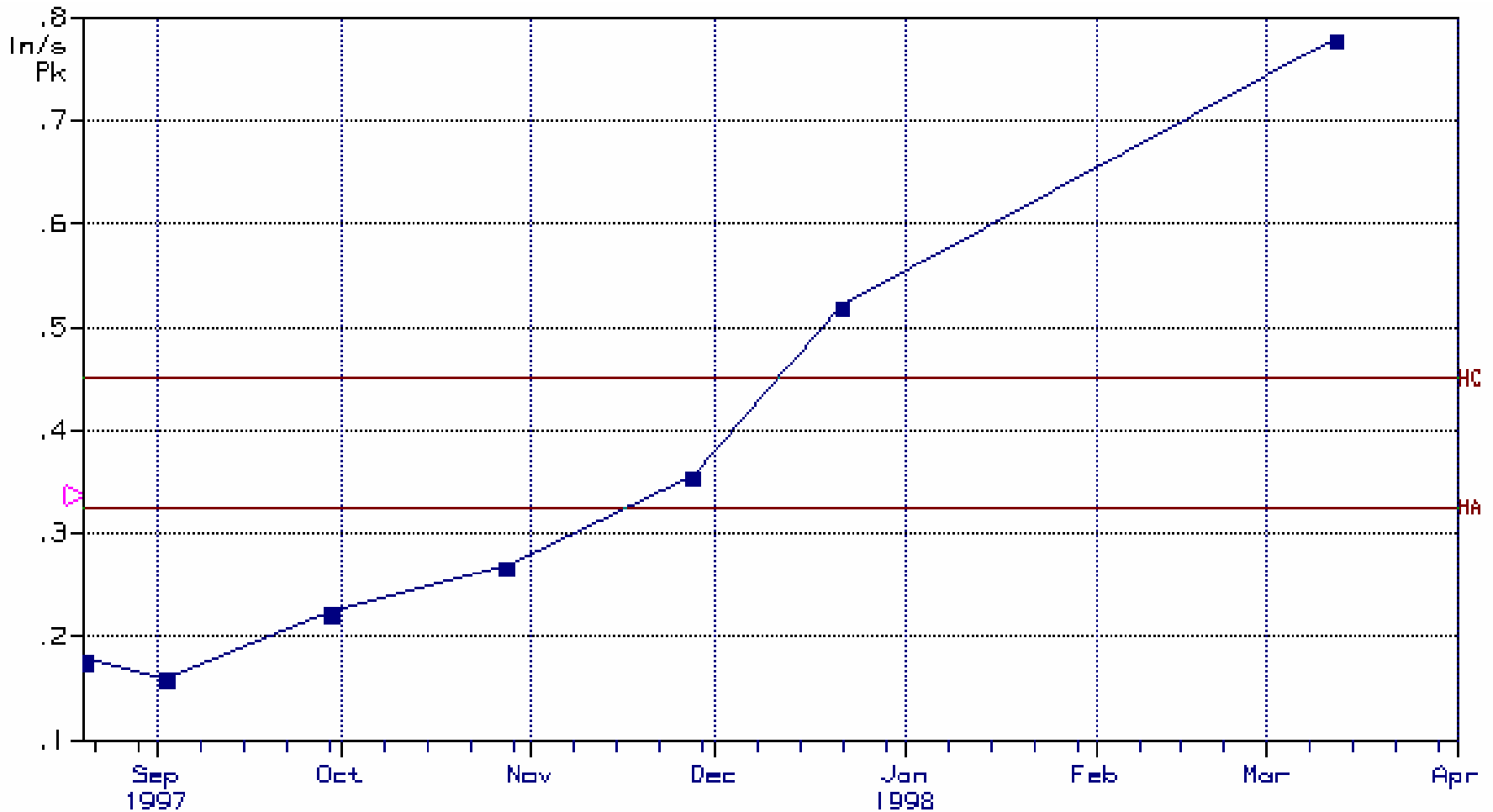
Overall Amplitude Severity Guides

- ISO 10816 Simplified
- Large machines
- Small machines on isolation

Acceptable Less than .20 IPS	No Alarms
Alert .20 IPS -.45	Alarm 1
Danger .45 IPS and greater	Alarm 2

Vibration Basics

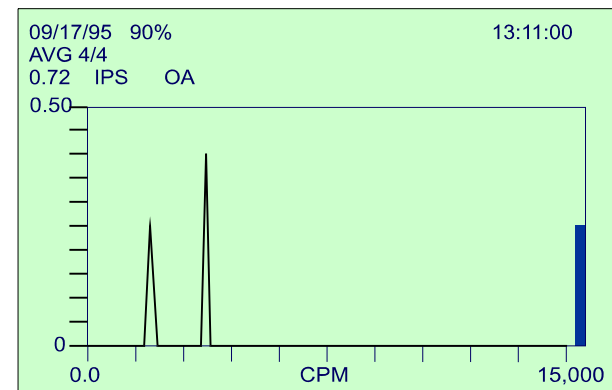
Trending Overall Amplitude



Activity 2

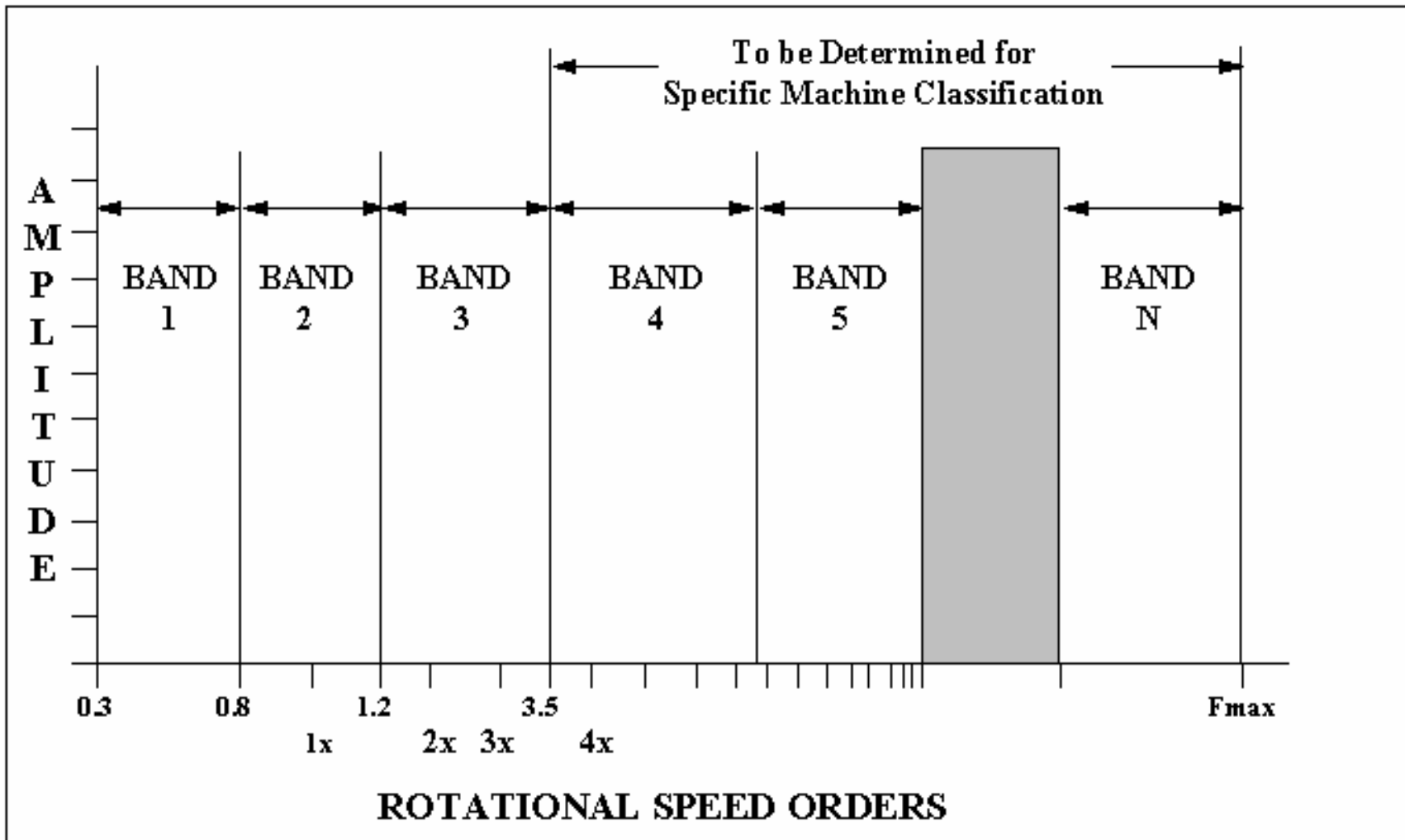
The vibration spectrum

- Go to Activity 2 in the Activities Folder.
- After reviewing page 1, go to the second slide:
 - What is the full scale amplitude?
 - Approximate the amplitude of the vibration spike.
 - What is the overall amplitude?
 - Name the units of amplitude.
 - Approximate the frequency of the vibration spike.



Vibration Analysis Techniques

Banded Vibration Levels



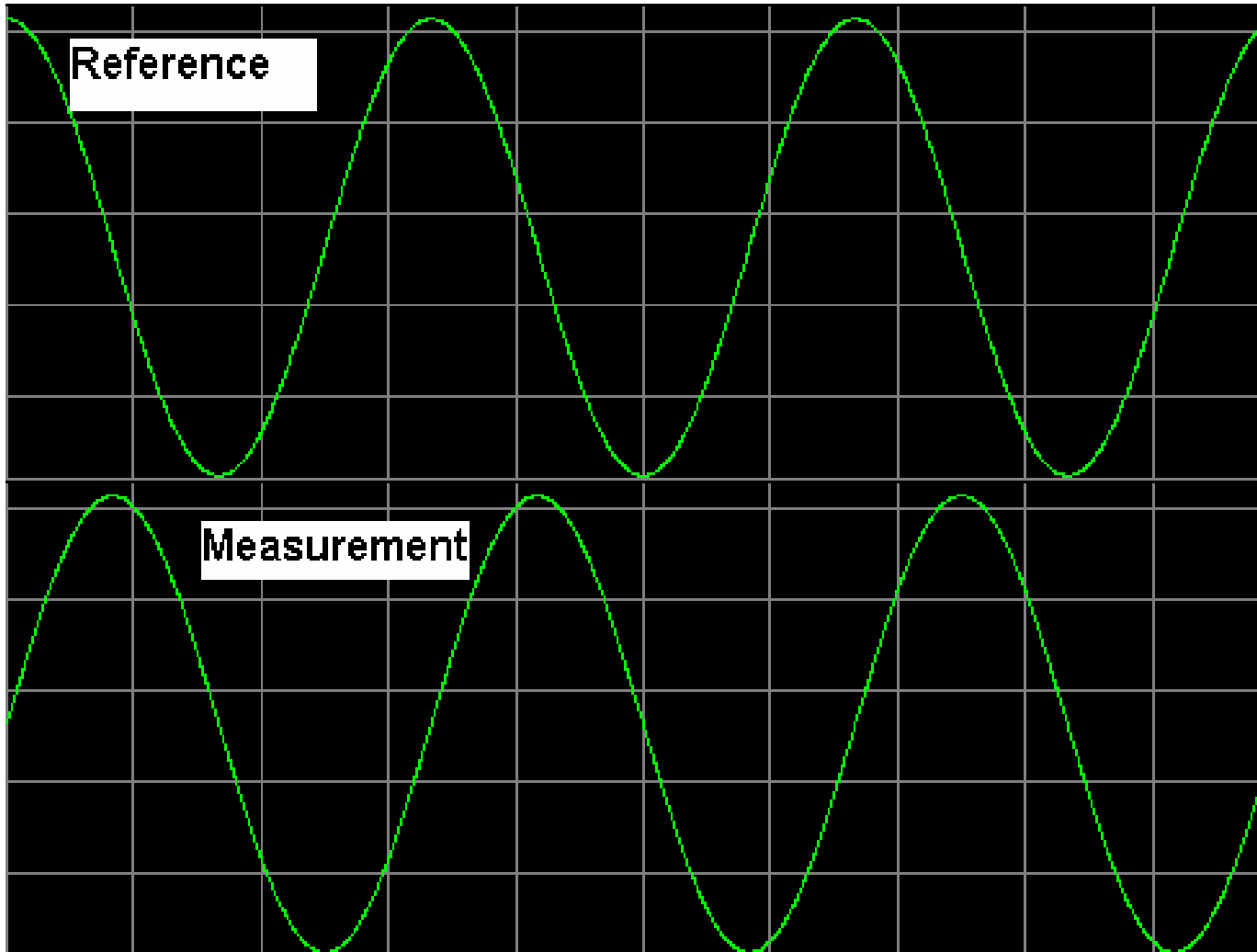
Vibration Analysis Techniques

Phase Analysis

- Time relationship between a fixed reference signal and a measurement signal.
- The reference signal can be a once-per-revolution tachometer pulse or it can be a fixed transducer location.

Vibration Analysis Techniques

Phase between 2 signals



Common Machinery Faults

Imbalance

Misalignment

Rolling Element Bearing

Common Machinery Faults

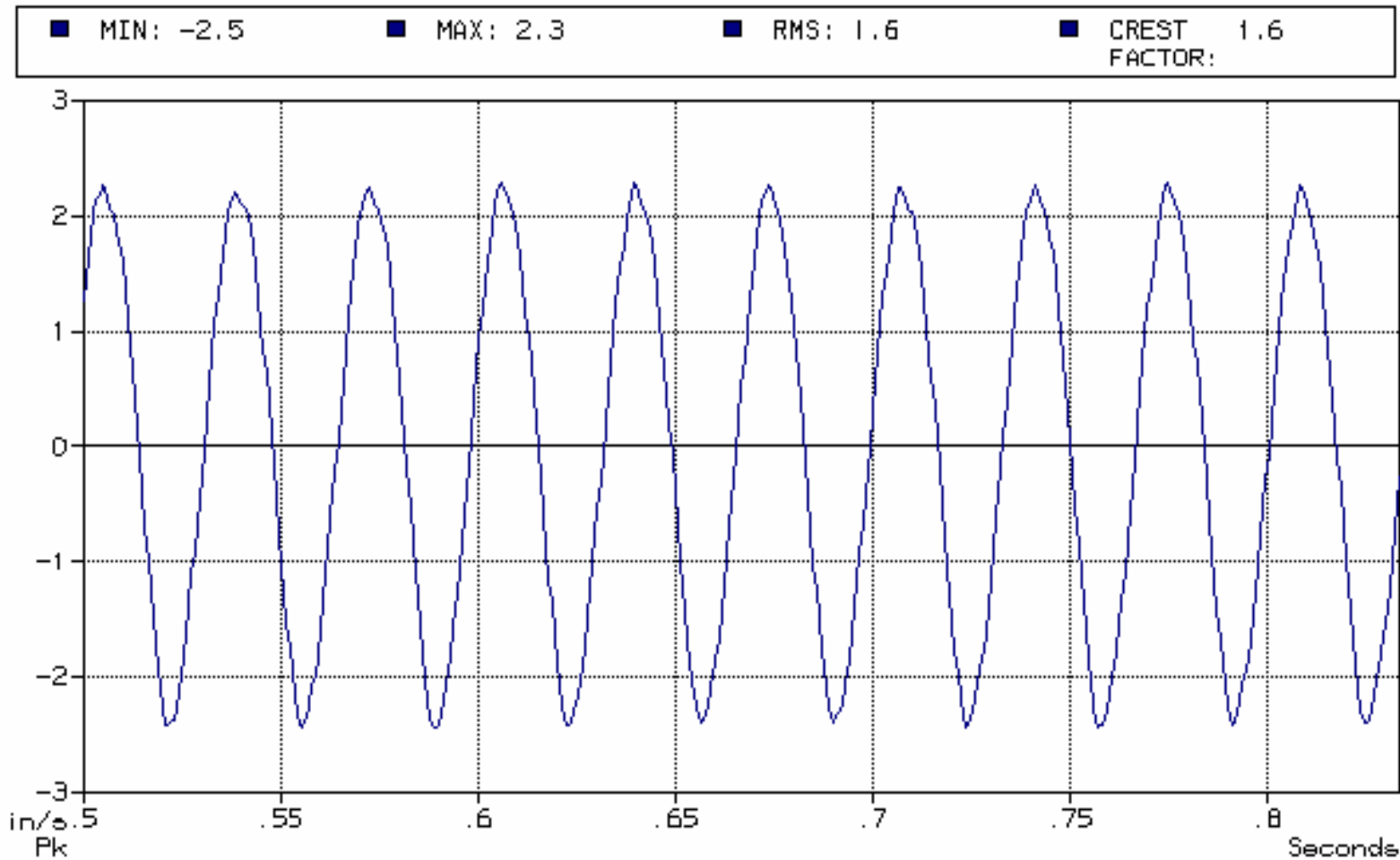
Imbalance

Unbalance occurs when the Mass Center and the Geometric Center of a rotor do not coincide.

Unbalance always occurs at running speed (1X) of the rotor.

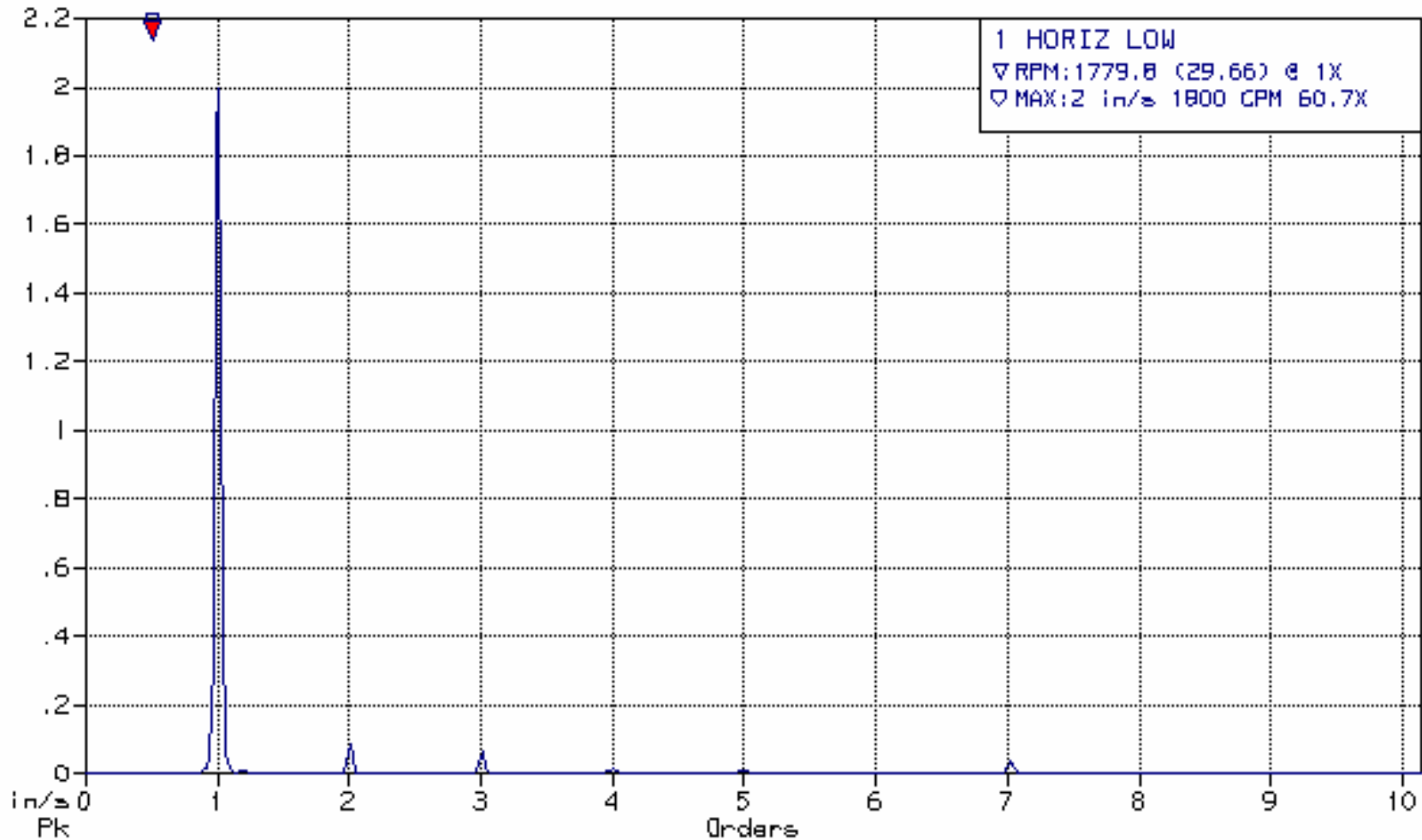
Common Machinery Faults

Imbalance Waveform



Common Machinery Faults

Imbalance Spectrum



Common Machinery Faults

Causes of Imbalance

Rotor improperly or not balance checked prior to assembly

Shaft Key not properly sized

Loose rotor to shaft fits

Uneven dirt accumulation on rotor

Lack of homogeneity on cast parts, such as bubbles, blow holes, porous sections

Causes of Imbalance

Rotor Eccentricity

Roller Deflection – Paper Machines

Machining Errors

Uneven mass distribution in electric motor rotor bars or winding.

Erosion or corrosion of rotor

Bowed or bent shaft

Common Machinery Faults

Imbalance Severity

1X Vibration Level	Diagnosis	Repair Priority
Less than 0.13 IPS	Slight Imbalance	No Action
0.13 IPS - 0.25 IPS	Moderate Imbalance	Desirable
0.25 IPS - 0.70 IPS	Severe Imbalance	Important
Greater than 0.70 IPS	Extreme Imbalance	Mandatory

Common Machinery Faults

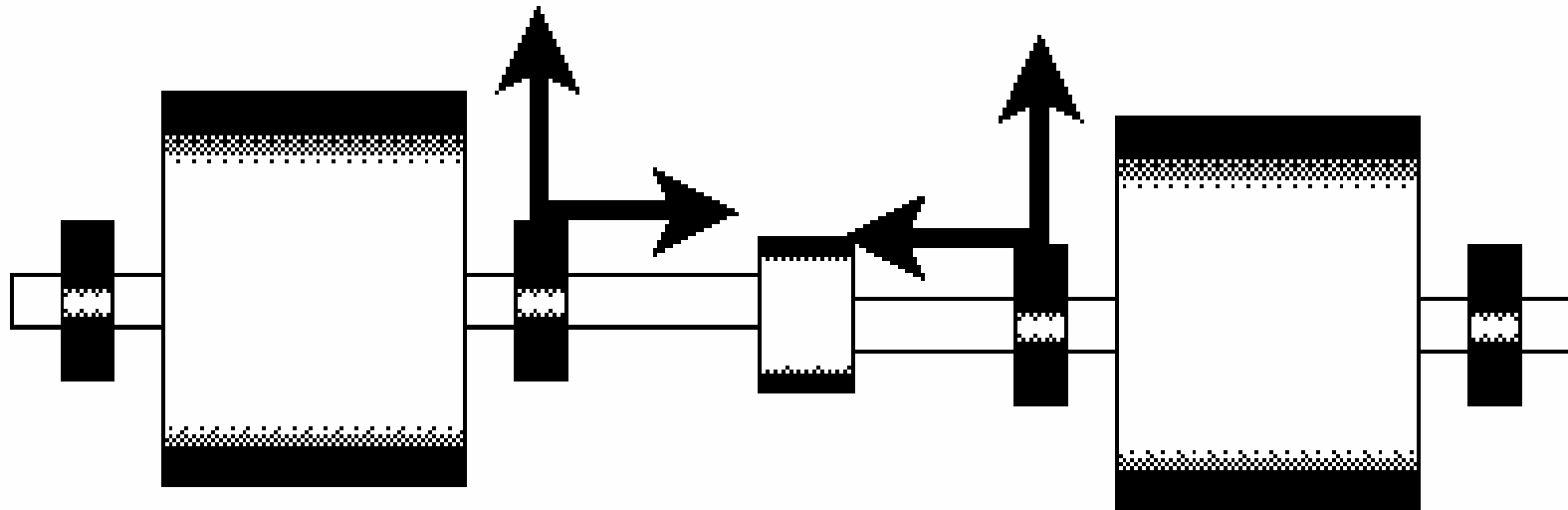
Misalignment

Can occur between any 2 bearings when the centerlines are not co-linear.

In belt drive machines when the sheaves are parallel offset or have vertical or horizontal angle.

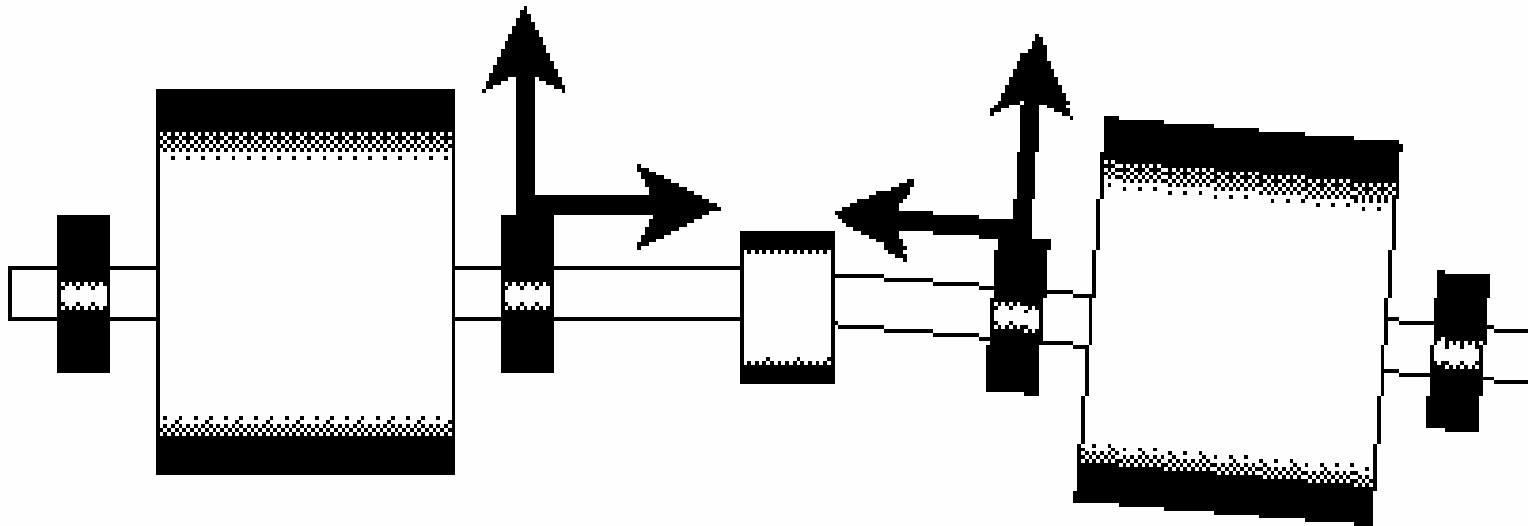
Common Machinery Faults

Parallel Misalignment



Common Machinery Faults

Angular Misalignment



Common Machinery Faults

Causes of misalignment

Inaccurate assembly of components

Cocked bearings

High radial or axial coupling runouts

Relative position of components shifting after assembly

Distortion due to forces exerted by piping

Distortion of flexible supports due to torque

Temperature induced growth of machine structure

Coupling face not perpendicular to the shaft axis

Soft foot, where the machine frame distorts when hold down bolts are tightened

Common Machinery Faults

Effects of Misalignment

High level of coupling wear, and heating of the coupling

Thrust transmission through the coupling when the coupling becomes locked

Cracked shafts due to fatigue caused by bending.

Excessive loading of the bearings.

Premature bearing failure

Misalignment Direct Drive

Misalignment shows up as 1X and 2X in spectrum

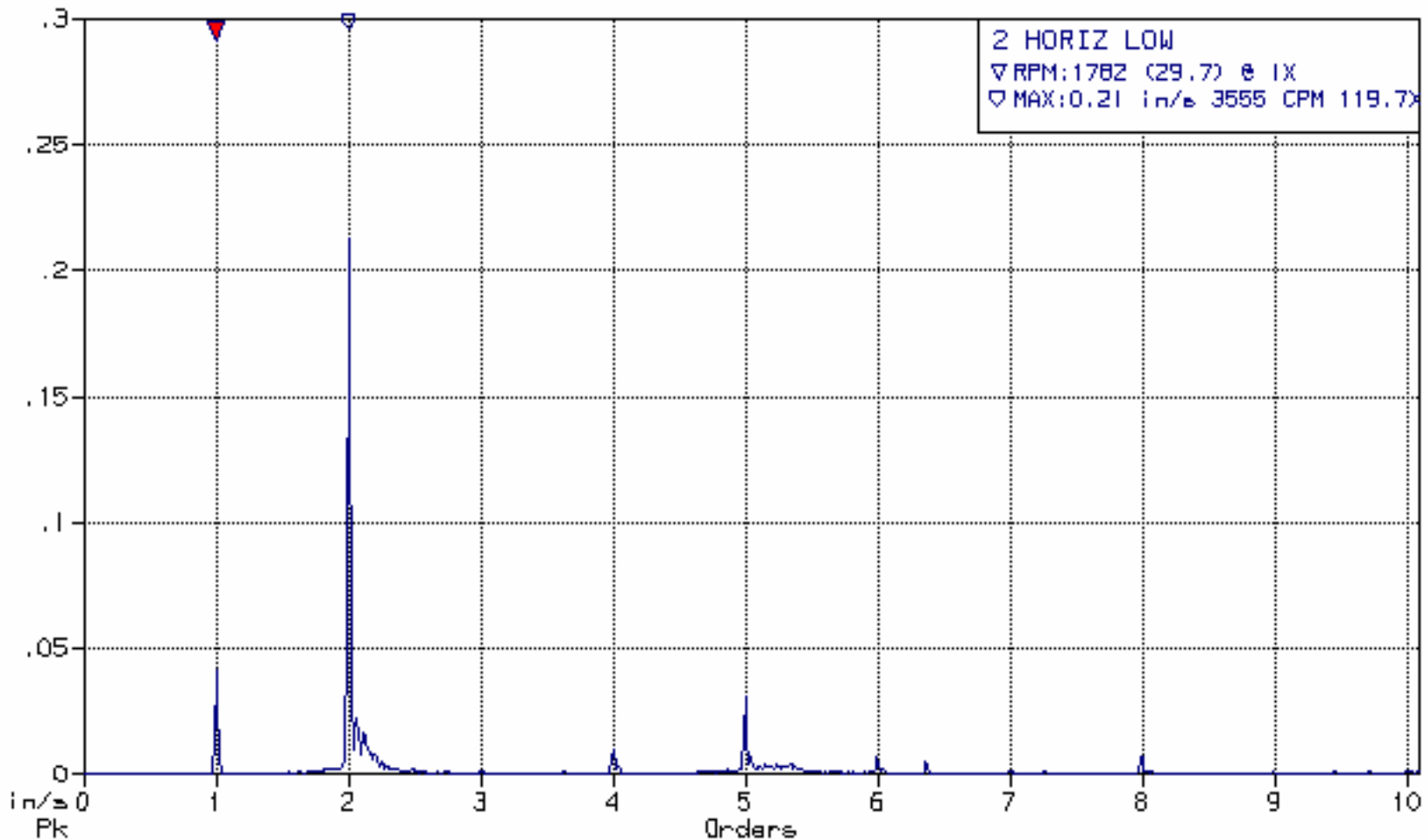
The dominant direction will be radial if the misalignment is parallel and axial if the misalignment is angular.

The 1X response is due to increased bending

The 2X response is due to crankshaft effect

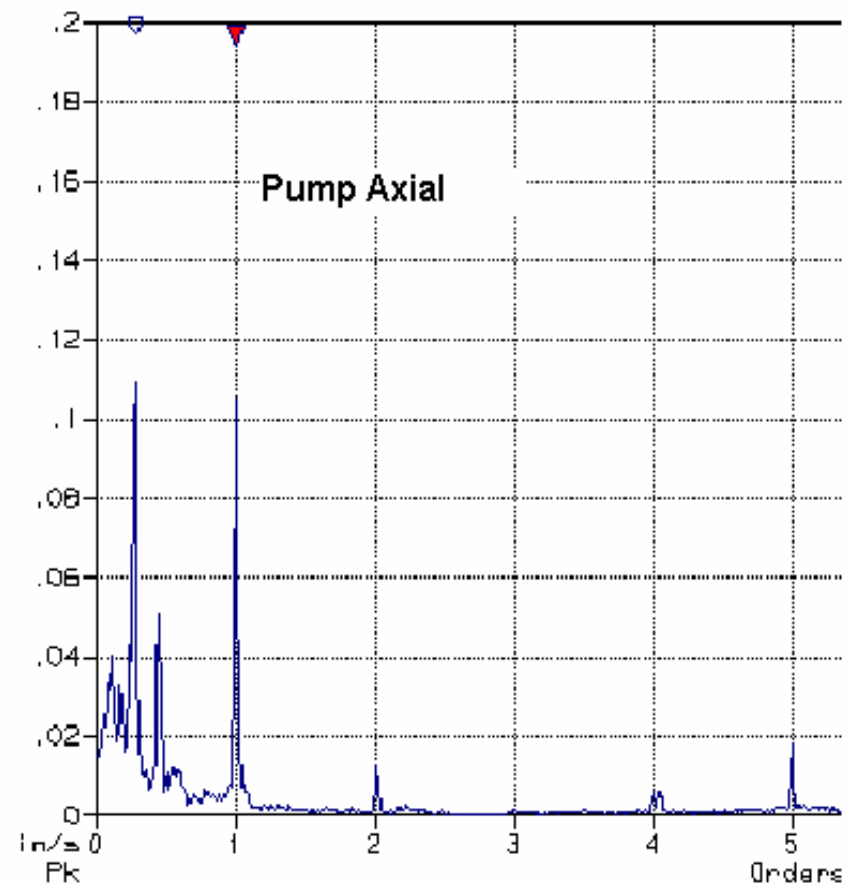
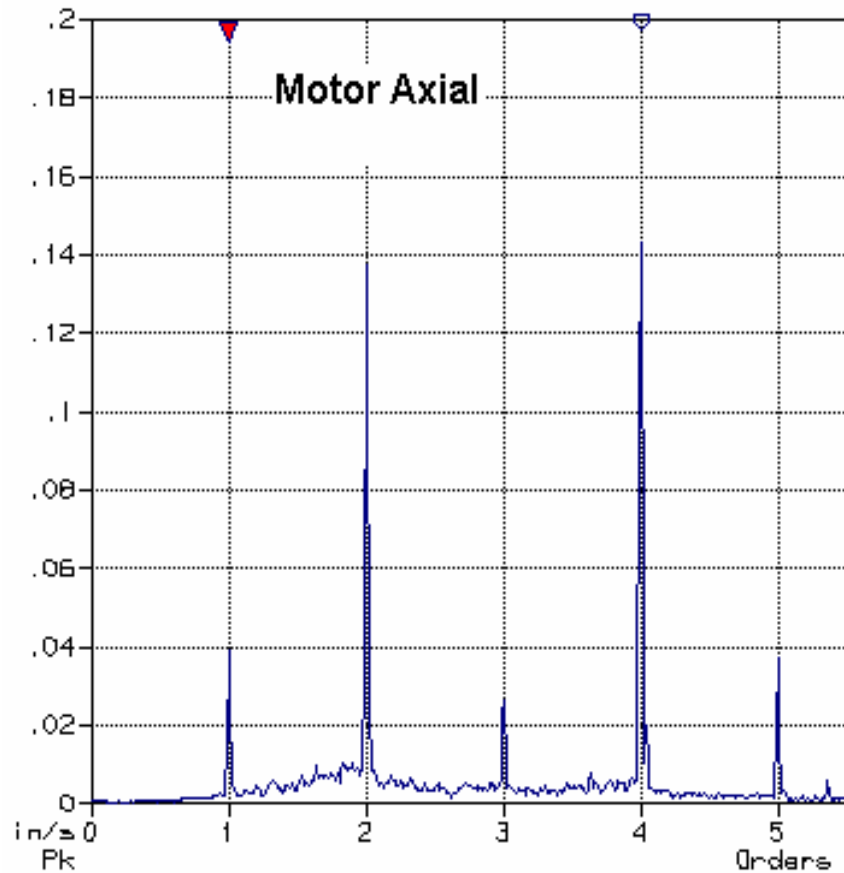
Common Machinery Faults

Example of Parallel Misalignment



Common Machinery Faults

Example of Complex Misalignment



Common Machinery Faults

Rolling Element Bearing Faults

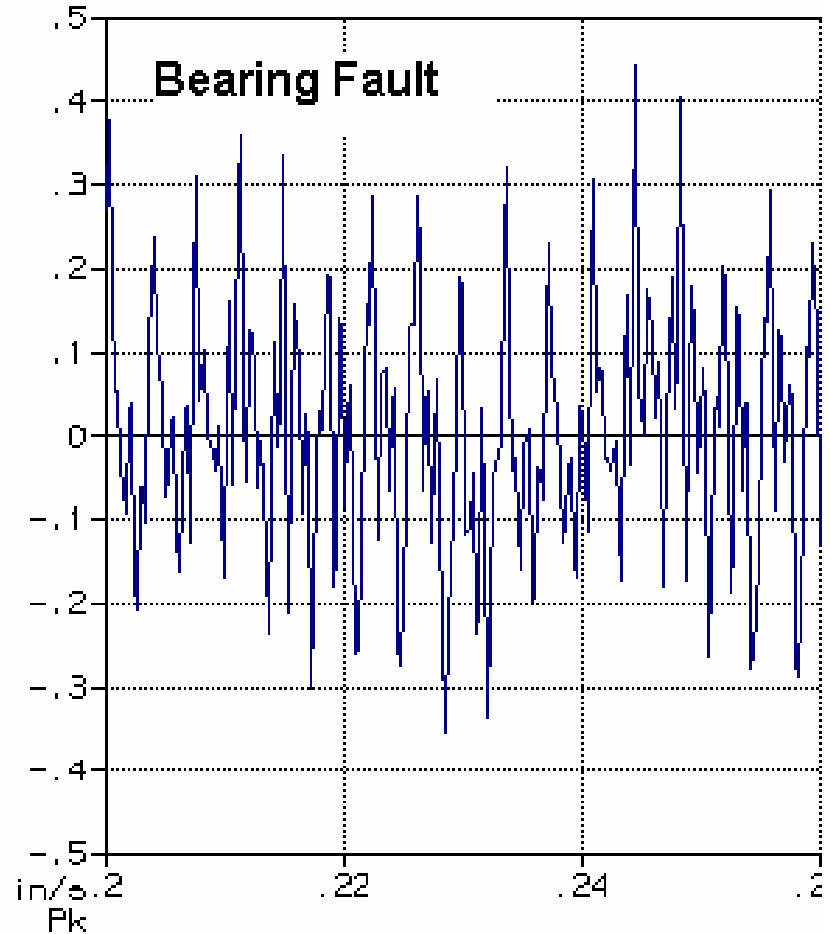
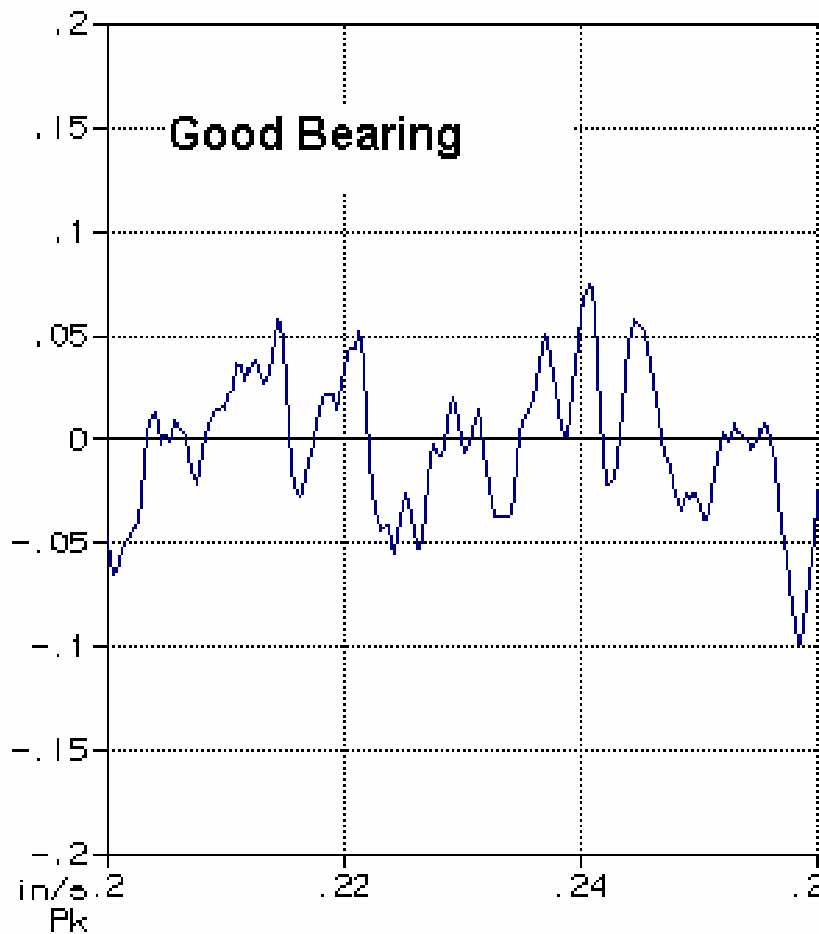
Always produce frequencies which are asynchronous to operating speed of rotor.

There are 4 fundamental frequencies which are produced – Ball Pass Outer Race, Ball Pass Inner Race, Ball Spin, and Fundamental Train Frequency.

These frequencies produced are a function of the pitch diameter, element diameter, number of elements, and contact angle.

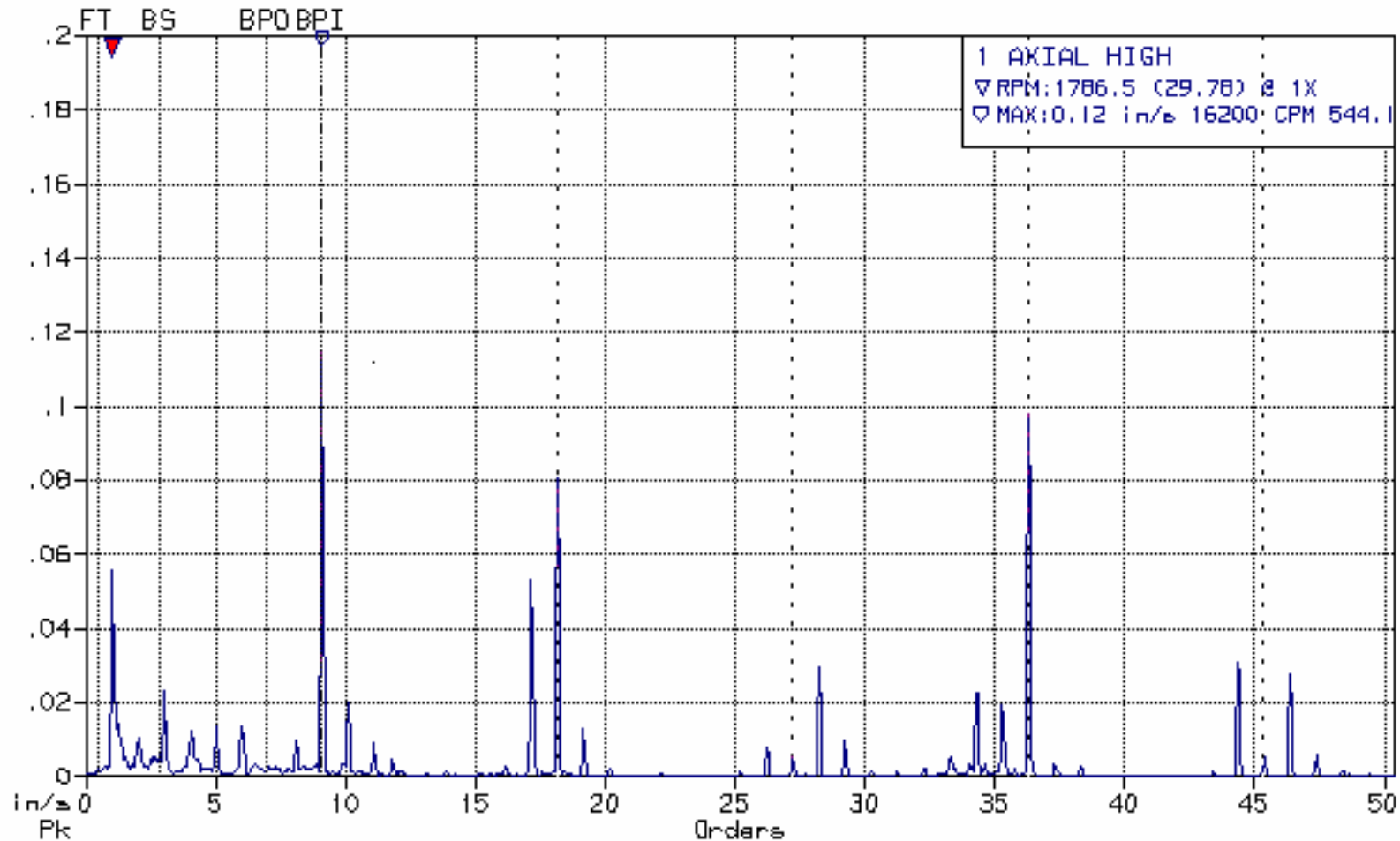
Common Machinery Faults

Bearing Defects-Waveform Analysis



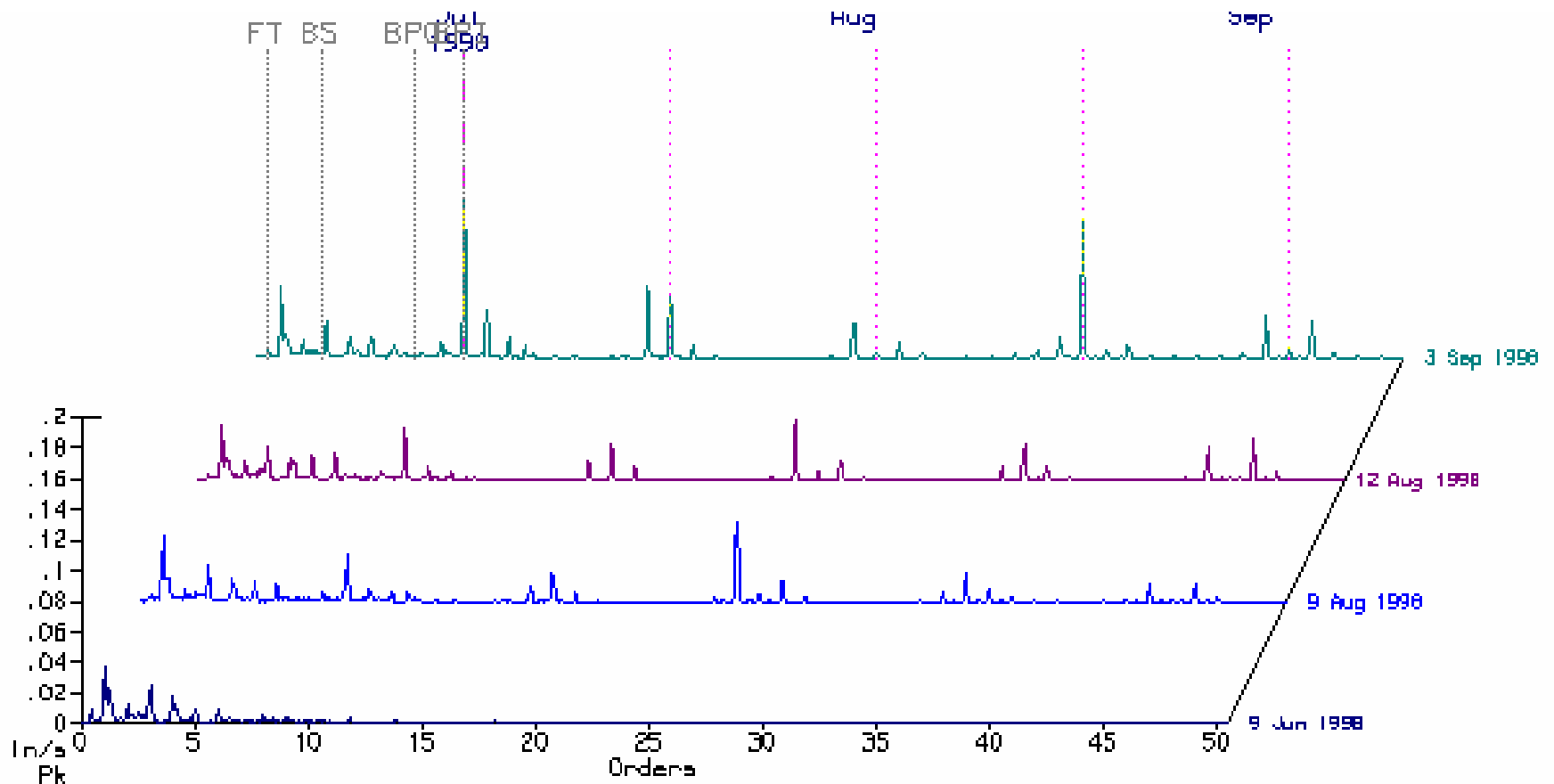
Common Machinery Faults

Bearing Defects - Spectrum Analysis

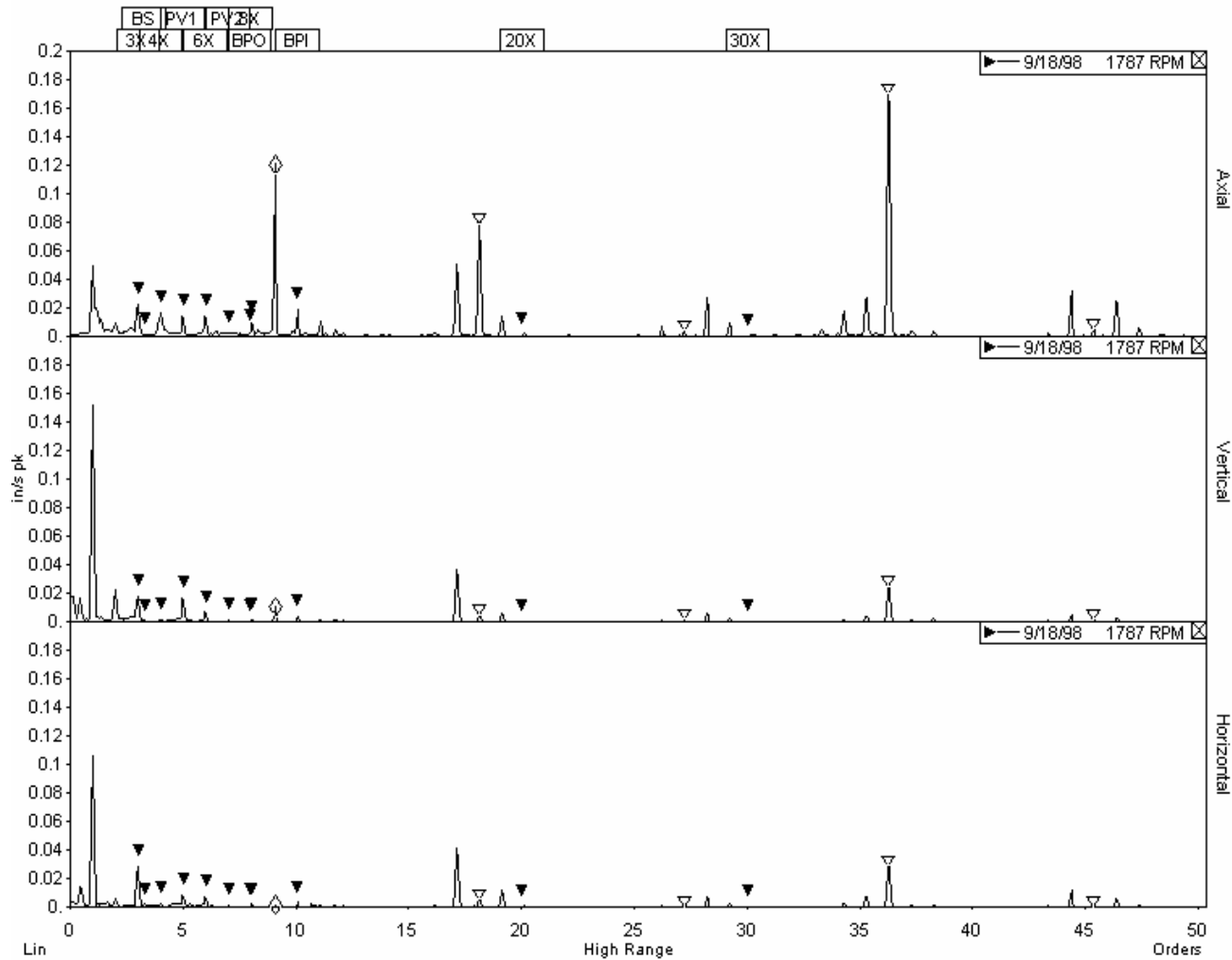


Common Machinery Faults

Bearing Defects – Spectral Trend



3 Axis View of Bearing Fault



Activity 3:

Remote Route

- Load remote route on your computer
- Instructions are found in the Activities Folder.

Preparing to Take Data

Nameplate Data

1. You collect Nameplate Data and Fax it to the Predictive Diagnostics Team.
2. The Predictive Diagnostic Team will create a database for your machines.
3. Allow 1 week for the databases to be completed.
4. Your routes will be downloaded into the Microlog.

JOHNSON CONTROLS **Pump Nameplate Information Form** *Exceeding Your Expectations!*

Branch _____ Branch # _____ Date needed _____

Branch Contact _____ FLSP _____

Customer Name _____ Customer Site _____

Cust Address _____ Cust City, State _____

Equipment ID: _____ CMMS Equipment ID: _____

Motor			Pump	
Make			Make	
Model			Model	
Serial number			Serial Number	
Speed	<input type="checkbox"/> VFD	Frame	Speed	Frame
HP	Volts	FLA	# of Vanes	
Off End Bearing			Inboard Bearing	
Drive End Bearing			Outboard Bearing	
Configuration	<input type="checkbox"/> Horizontal	<input type="checkbox"/> Vertical	___ # of Stages	
Impellers	<input type="checkbox"/> Overhung	<input type="checkbox"/> Centerhung		
# of pump bearings: _____				

Equipment ID _____ CMMS Equipment ID: _____

Motor			Pump	
Make			Make	
Model			Model	
Serial number			Serial Number	
Speed	<input type="checkbox"/> VFD	Frame	Speed	Frame
HP	Volts	FLA	# of Vanes	
Off End Bearing			Inboard Bearing	
Drive End Bearing			Outboard Bearing	
Configuration	<input type="checkbox"/> Horizontal	<input type="checkbox"/> Vertical	___ # of Stages	
Impellers	<input type="checkbox"/> Overhung	<input type="checkbox"/> Centerhung		
# of pump bearings: _____				

Preparing to Take Data

Nameplate Data - Machine Speed

Accurate machinery speed is very important to good data analysis.

1. You can use a tachometer.
 - Contact
 - Photo
 - Strobe
2. Or, you can calculate the fan speed.

Fan RPM

$$\frac{\text{Motor pulley diameter}}{\text{Fan pulley diameter}} \times \text{Motor RPM}$$

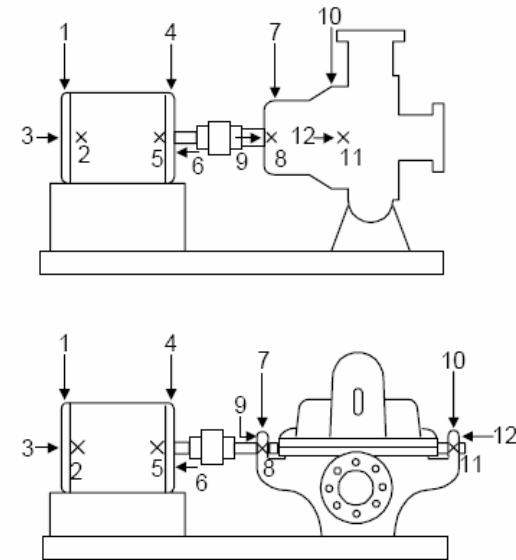
Activity 4:

Using a strobe to determine machinery RPM

- Your Instructor will demonstrate the use of the strobe as a tachometer.
- You will be asked to determine the RPM of a machine simulator.

Where You Take Measurements: Pumps

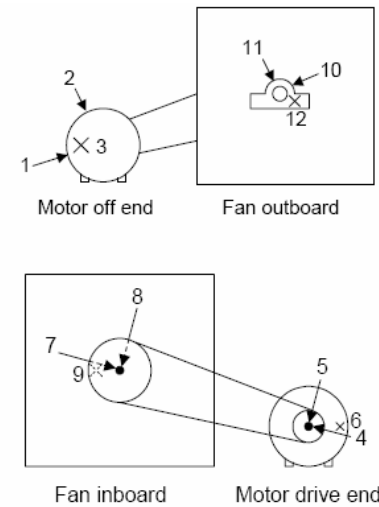
- At each bearing
 - MO
 - MD
 - PI
 - PO
- Three directions at each bearing
 - V- vertical
 - H- horizontal
 - A- Axial



1. MOV Motor off end vertical
2. MOH Motor off end horizontal
3. MOA Motor off end axial
4. MDV Motor drive end vertical
5. MDH Motor drive end horizontal
6. MDA Motor drive end axial
7. PIV Pump inboard vertical
8. PIH Pump inboard horizontal
9. PIA Pump inboard axial

Where You Take Measurements: Fans

- At each bearing
 - MO
 - MD
 - FI
 - FO
- Three directions at each bearing
 - IL- In line with belts
 - P- Perpendicular to belts
 - A- Axial



1. MOIL Motor off end in line
2. MOP Motor off end perpendicular
3. MOA Motor off end axial
4. MDIL Motor drive end in line
5. MDP Motor drive end perpendicular
6. MDA Motor drive end axial
7. FIIL Fan inboard in line
8. FIP Fan inboard perpendicular
9. FIA Fan inboard axial
10. FOIL Fan outboard in line
11. FOP Fan outboard perpendicular
12. FOA Fan outboard axial

Activity 6:

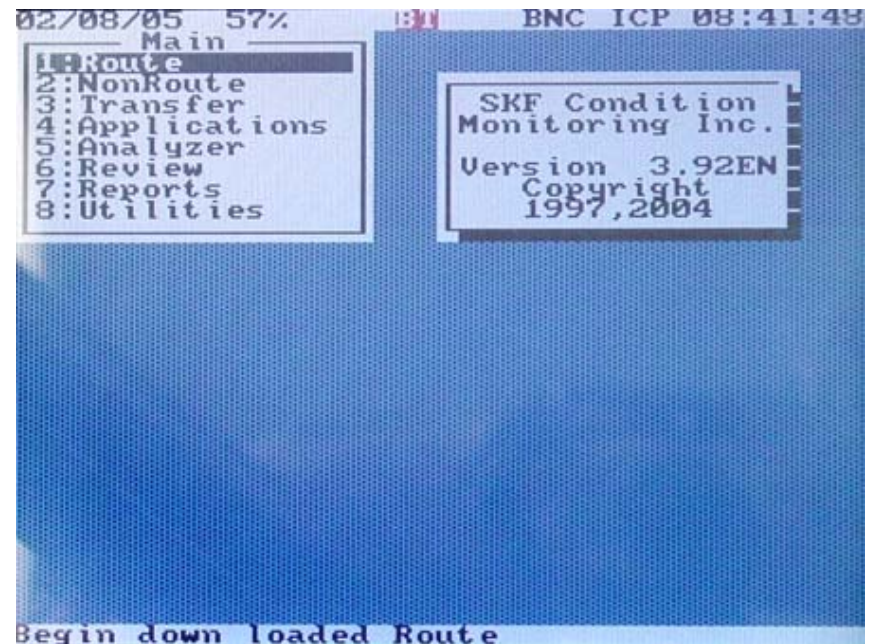
Nameplate Data

- You will be asked to collect nameplate data for assigned machine simulators.

How to Operate the Microlog

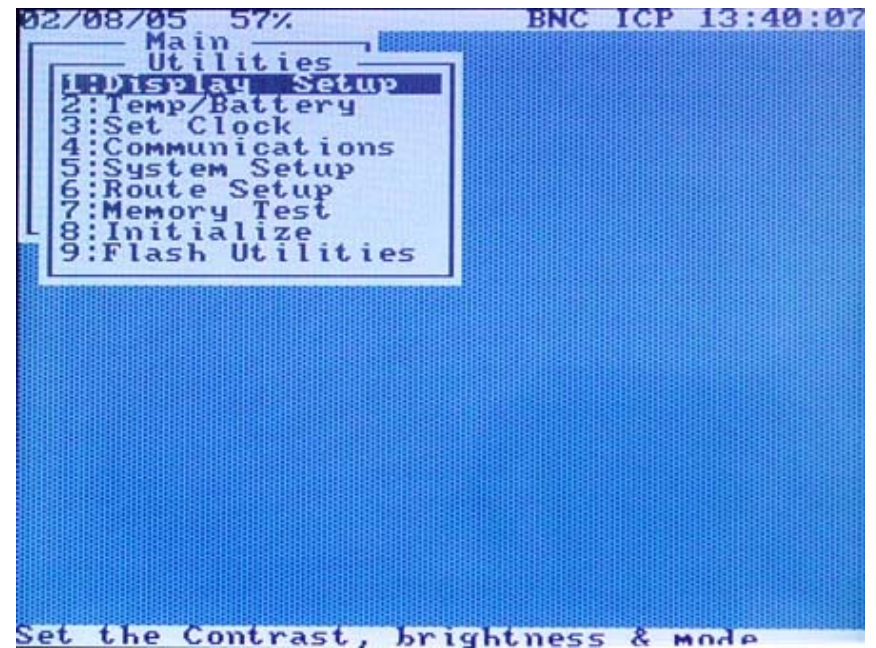
Navigating the Menus

- The Main menu is navigated with the Arrows.
- The Enter Key selects an item.
- The Menu Key offers “pull down” selections.



How to Operate the Microlog

Navigating the Menus



How to Operate the Microlog

Configuring the Microlog

System Setup

- Set to the Microlog to these settings.

```
02/08/05 57% BNC ICP 13:40:35
Main
Utilities
System Setup
FFT Hz/CPM:0.0
FFT Lin/Log:Linear
System:English
Auto Range:On
User Mode:Normal
Data Storage:Normal
Sensor Mode:Normal
Connector:BNC
Sensor Power:ICP
Settling Mode:Aggressive
Sensor/Cable Check:No
Calibration Reminder:Enabled

Use MENU KEY for selections
```

How to Operate the Microlog

Configuring the Microlog

Route Setup

```
02/08/05 57% BNC TCP 13:40:43
Main
Utilities
Route Setup
Route Mode: Normal
Route Spectrum: Show
Route Trigger Slope: +
Route Collection: Normal
Average Overlap: 75%
Operator ID Tagging: No
Route Display: Hierarchy
View MPA spectrum: No
HAL Enable: Disabled

Use MENU KEY for selections
```

How to Operate the Microlog

Configuring the Microlog

Communications Setup

```
02/08/05 57% BNC TCP 13:40:25
Main
Utilities
Communications
Baud: 9600
Modem Mode:None
Microlog Remote:NO
Phone #:
ATDT 555-1212
Modem Setup(Optional):

Use MENU KEY for selections
```

Activity 6:

Configure the Microlog

- System Setup
- Route Setup
- Communications Setup

Activity 7:

Microlog Operational Checks

Check the Cable

- Route Mode
- Training Route
- Condenser H2o Pump
- Lay the sensor on the table
- ***Be Very Still***
- Enter to take measurement
- Record the Overall Amplitude

Activity 7:

Microlog Operational Checks

Check the Accelerometer

- Reset measurement
- Hold the sensor
- ***Lightly tap the table***
- Enter to take measurement
- Record the Overall Amplitude

Activity 8:

Collecting Vibration Data

- Collect vibration data for assigned machine simulators.