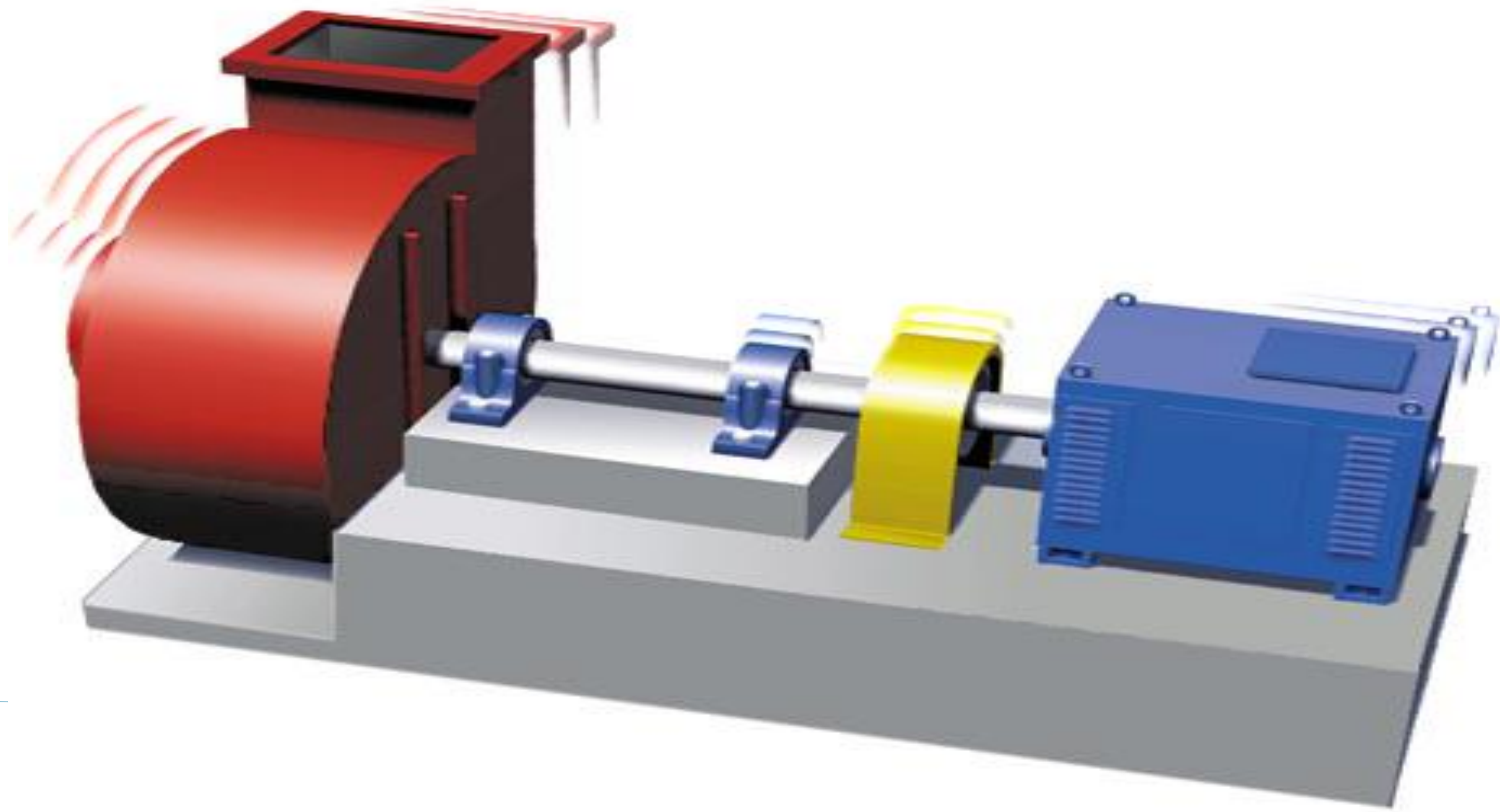
Basic Vibration Analysis Training



Mark S. Banal

Vibration Unit Trainer

1

Who Am I?

Mark Anthony S. Banal

Work Experience

- **DESCO Inc./GE Bently Nevada/Commtest** – Product Technical Manager – Online and Portable Vibration Monitoring and Protection System
- **SKF Philippines –** Product Technical Manager – Online System, Remote Diagnostics and Training
- **SKF Philippines** – Reliability Engineer – Condition Monitoring Technologies
- **3E/Emerson CSI** – Senior Technical Support Engineer– CSI 2130 Vibration Analyzer, CSI 5200 Oil Minilab, SpectraQuest Machinery Fault Simulator
- **SPM Instrument, AB** – Condition Monitoring Service Supervisor

Technical Skills

- **Started from scratch**
- More than thirteen (13) years experience in Condition Monitoring Technologies (vibration analysis, dynamic balancing and laser shaft alignment)
- ISO Category II Vibration Analyst – Vibration Institute
- ISO Category II Vibration Analyst - Technical Associate of Charlotte
- ASNT Level 2A Vibration Analyst – Technical Associate of Charlotte
- Experienced Vibration Analysis Trainer
- Technical support (hardware and software)
- On-site Dynamic Balancing and Laser Shaft Alignment
- Design and implementation of Online Vibration Monitoring and Protection System

Equipment Used: Portable System


SPM T30


CSI 2130


SKF Micrologs AX


SKF MCA


SKF Microlog CMVA60


Commtest vb7


SKF Microlog GX


SPM Vib-10


Bently Nevada Snapshot


Bently Nevada SCOUT100


SPM Leonova Infinity


SPM Bearing Checker

Equipment Used: Online System

Bently Nevada 3500

Shinkawa VM7

SKF IMx-T

CSI 4500

SKF IMx-S

ADRE 208P

ADRE 408

SKF MMS

SPM Intellinova

SKF DMx

Bently Nevada 1900/65

SPM Machine Guard

Software Familiarity

- System-1 (Configuration, Acquisition and Display)
- BN 3500 Rack Configuration Software
- ADRE Sxp
- ADRE for Windows
- Ascent Level 3 Software
- AMS: Machinery Health Manager Software
- Aptitude Analyst
- Condmaster Nova
- 1900/65A Configuration

Industries Served

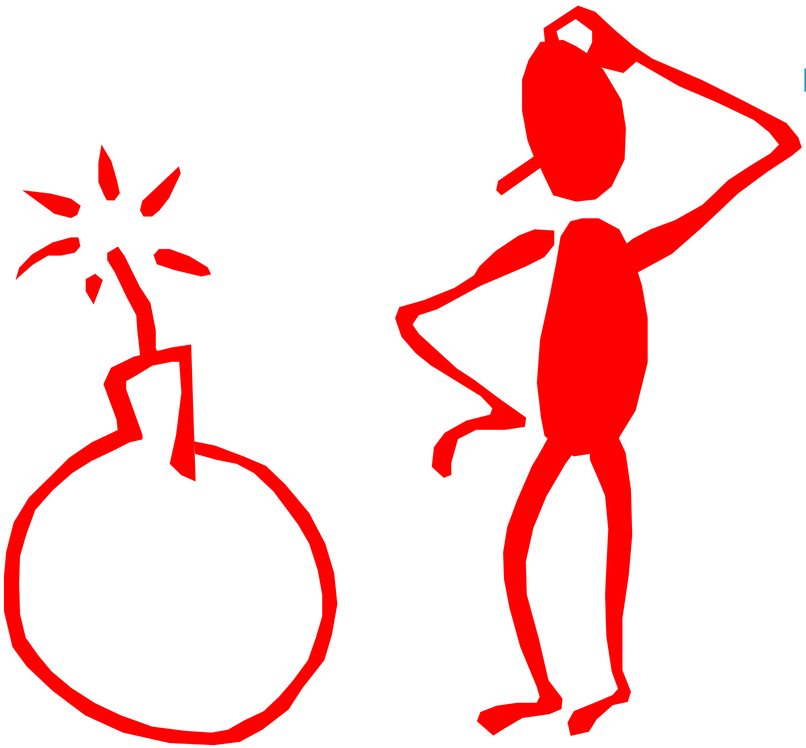
- Mining and Minerals
- Petrochemical
- Oil Refinery
- Power Generation
- Liquid Nitrogen Facilities
- Iron Ore Processing
- Pharmaceutical
- Building Facilities
- Industrial Plants
- Sugar Central

The Rules of the Game

- If you have a question

PLEASE ASK IT!

The Rules of the Game



- If you have feedback

We Need It!

Objective

The course objective is to:
Teach the fundamentals of vibration technology.

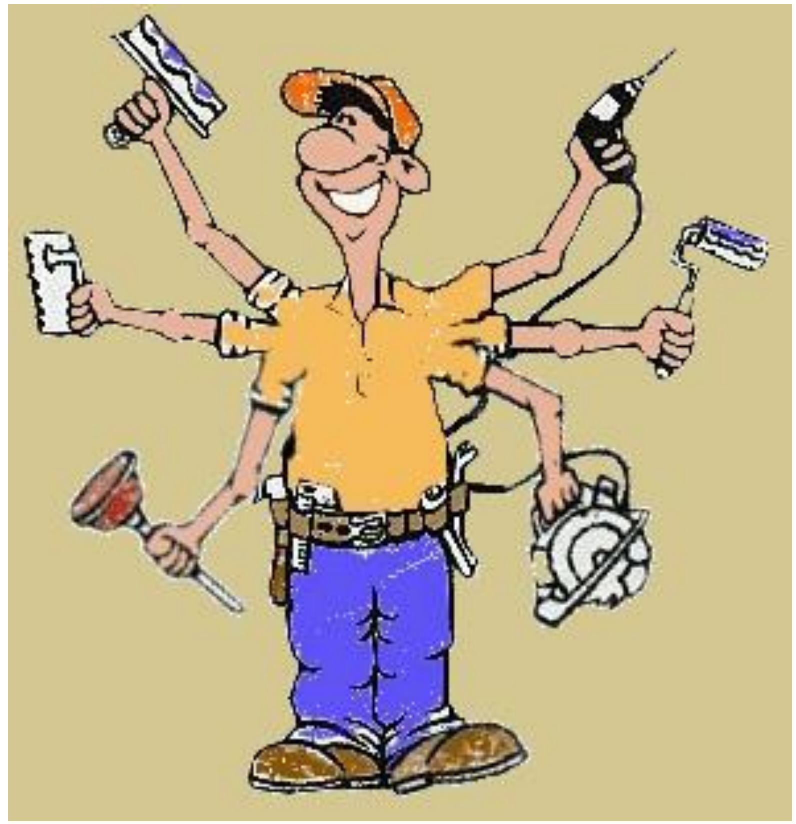
It aims to provide a practical approach to detecting and analyzing common machine problems using vibration monitoring and analysis.

Expectations

After this training, you should be able to discuss the following topics:

- Maintenance Strategies
- Basics of machinery vibration
- Understand measuring point convention
- Selection of vibration instrument
- Selection of vibration transducers
- Practical approach in vibration analysis

2 Maintenance Strategies



Machine Condition Evaluation

Sound A

Sound B

Typical industry problems

Problems	Implications
Harsh operating conditions - dirty, wet, abrasive - temperature extremes - heavy and vibrating loads	• Premature machinery failures and high repair costs • High lubricant consumption • Poor reliability
Hard to maintain equipment (Large / heavy equipment) - outdoor conditions - hard to assemble / align	• High maintenance and repair costs • High machinery downtime • Reduced equipment efficiency (increased energy consumption) • Risk of worker injuries
Little warning of impending problems (input to automation)	• Greater equipment damage and downtime • Reduced worker productivity

Maintenance Philosophies

✓Cost effective for small equipment

✗ Downtime and secondary damage

1960's
Reactive
> Fix when broken

✓ Time based and 1st line of defense

✗ Wasteful and requires large inventory

1970's
Preventive
>Scheduled Overhauls

✓Decreased unnecessary repairs and reduced downtime

✗ Investment in technology and people

1980's
Predictive
>Condition Based

1990's
Proactive Reliability Maintenance (PRM®)
>Fix root cause
>Apply optimal level

✓ Asset Efficiency Optimization

Future

Cost of Maintenance

Direct maintenance costs

- staff, overtime, contractors
- spares, tools

Indirect maintenance costs

- high production costs
- lost production
- reduced quality
- poor customer service

Run To Failure, Breakdown

- Can be least expensive form of maintenance!
- Instrument cost for monitoring is not required.
- Disadvantages:
  - Inventory
  - Secondary damage
  - Labor
  - Planning and scheduling

Preventive Maintenance (PM) – *Time-based*

Advantages:

- Provides a first line of defense
- Basic proactive strategy

Disadvantages:

- Often wasteful
- Does not prevent some failures
- Can introduce problems
- Requires a large parts inventory

Predictive Maintenance (PdM) – *Condition-based*

Advantages:

- Reduce downtime
- Reduces secondary damage
- Decreases unnecessary parts replacement

Disadvantages:

- Initial investment cost is high (Hardware, Software, Training)

Condition-Based Maintenance

- A type of planned maintenance system that predicts today the occurrence of a likely machine failure in the future.
- Very much dependent in Machine Condition Monitoring Program
- Employs computer-aided tools and techniques for more accurate machine health prediction

"CBM does not replace run-to-failure or preventive programs; it augments them."

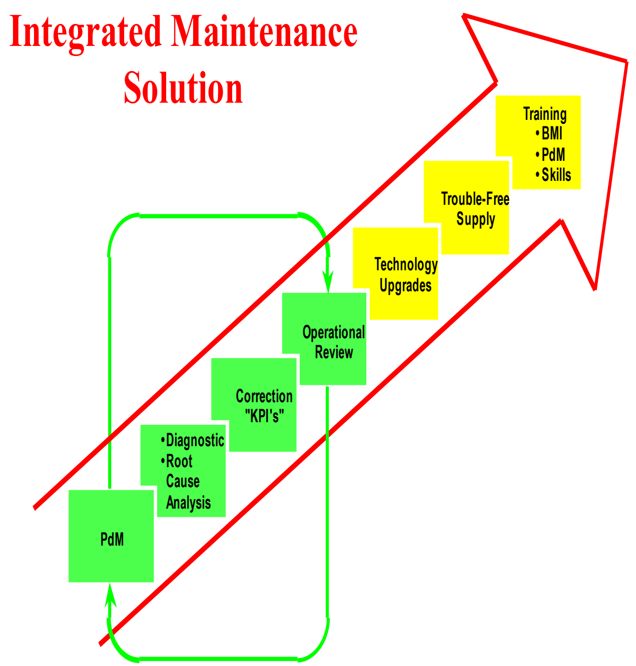
Proactive Reliability Maintenance (PRM)
Predictive & Corrective

Advantages:

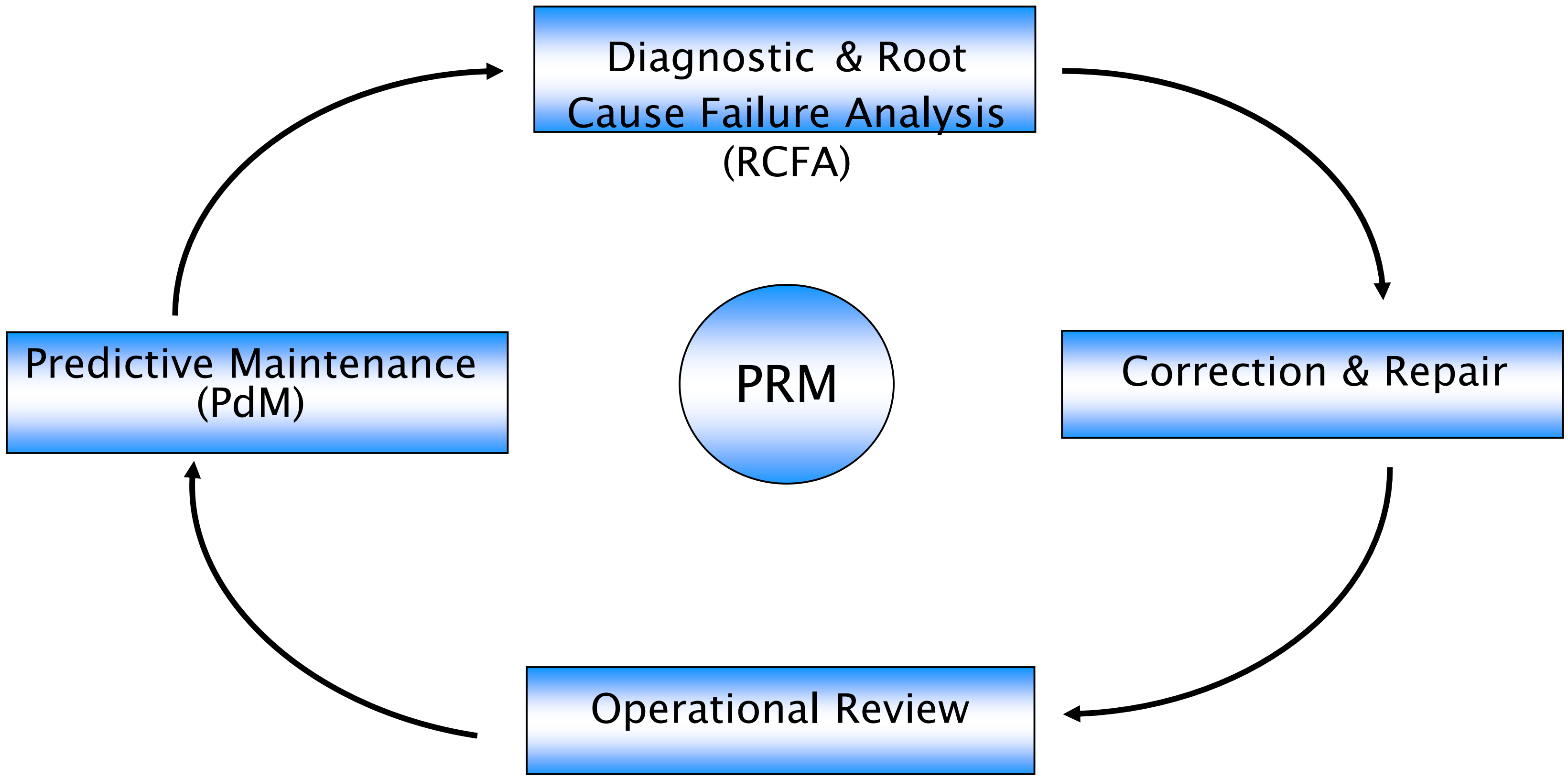
- Reduces maintenance costs
- Address root-causes of failures
- Reduces downtime, secondary damage, unnecessary parts replacement / inventory
- Extends equipment life

Disadvantages:

- none, if life cycle costs are appropriately considered

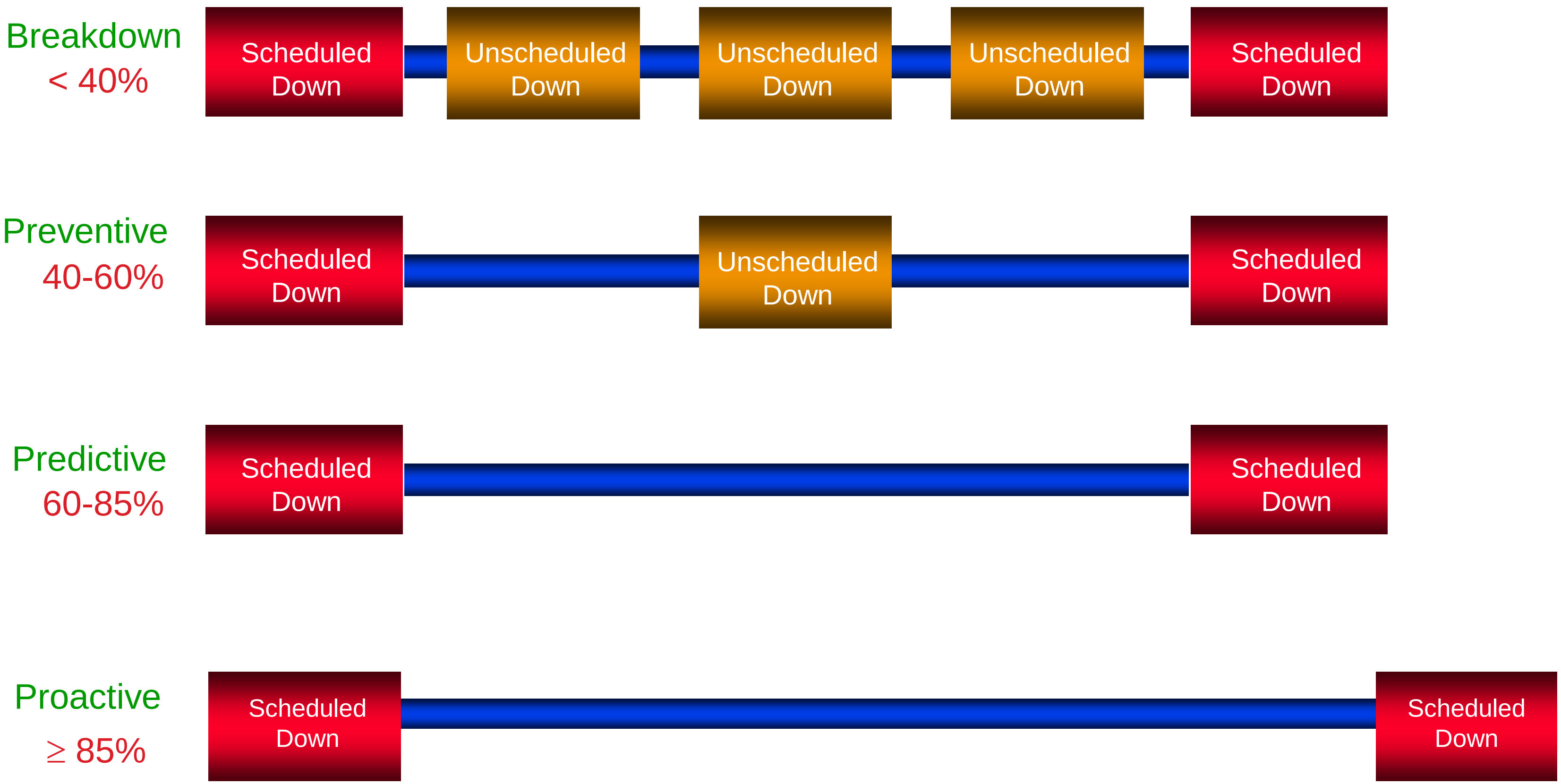


Proactive Reliability Maintenance (PRM) Concept

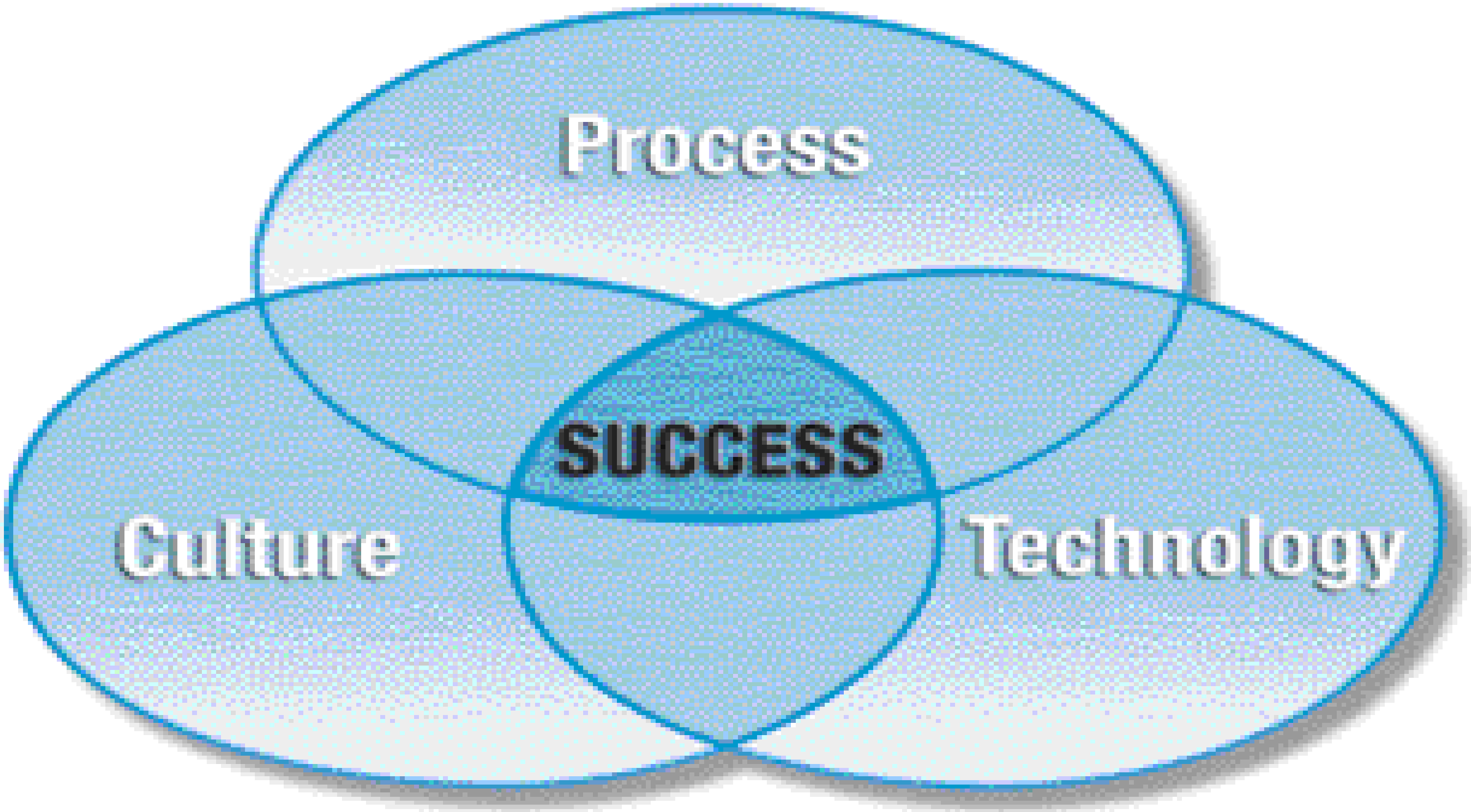


Maintenance Strategy – Downtime Analysis

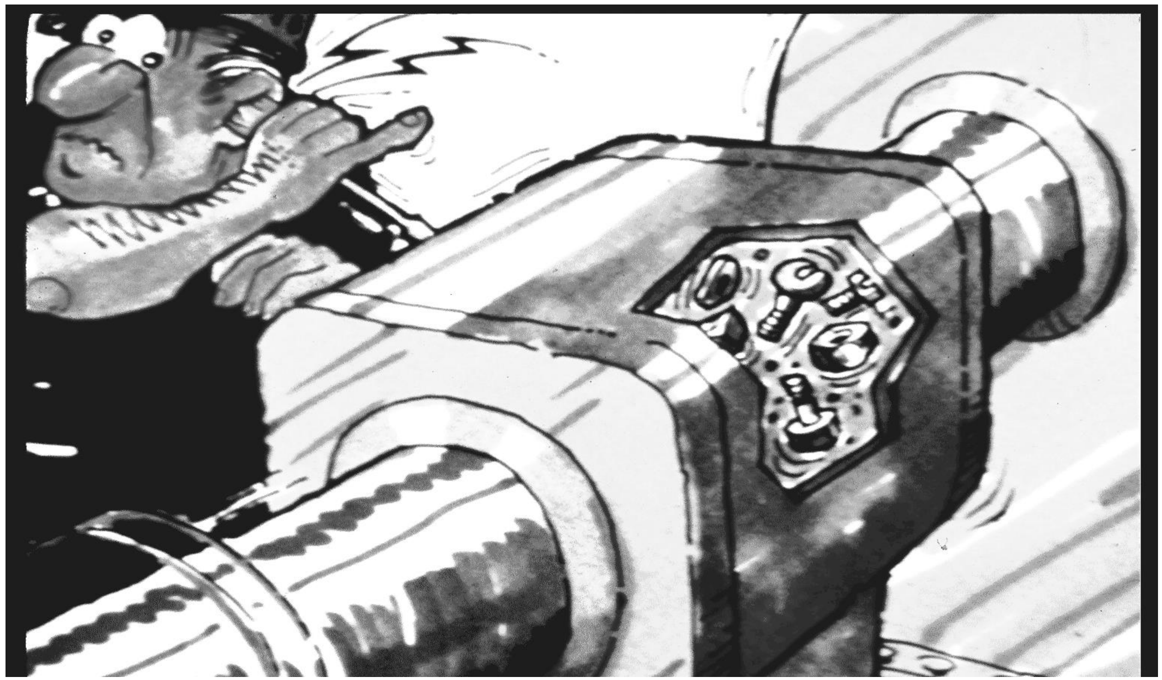
Maintenance Type / Machine Efficiency



Key Success Factors

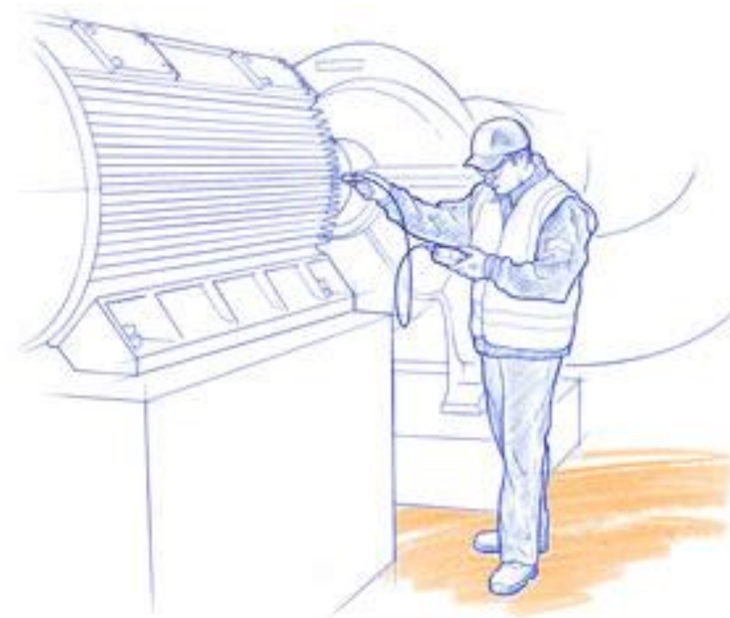


3 Concept of Condition-Based Maintenance Program



Condition Monitoring

the assessment on a continuous or periodic basis of the mechanical condition of the machineries, equipment and systems from the observations and/or recordings of **selected measurement parameters**



Principles of condition based maintenance

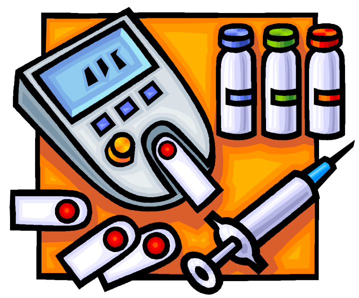
- Monitor a variety of machine conditions to identify a change in health using either periodic, continuous, or semi-continuous data collection/ acquisition from samples, sensors, etc.
- Application of the appropriate tests or related diagnostic techniques
- Validation and analysis of the data
- Interpreting the results into meaningful recommendations for appropriate maintenance action, leading to a reduction in cost and an increase in machine reliability

The IDEAL Condition-Based Maintenance Program

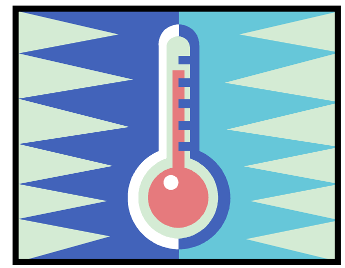
- Identify a potential problem
- Verify the problem – diagnosis and analysis
- Identify root cause if appropriate
- Issue corrective work order to fix problem and address the root cause
- Verify the correction and adjust acceptance limits up or down

Diagnosing a machine is just like a person:

Vibration:
The ‘pulse’ of the machine

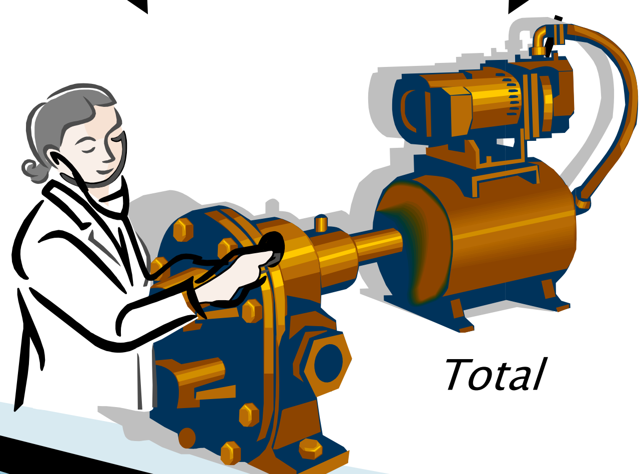


Oil:
The ‘life blood’ of the machine

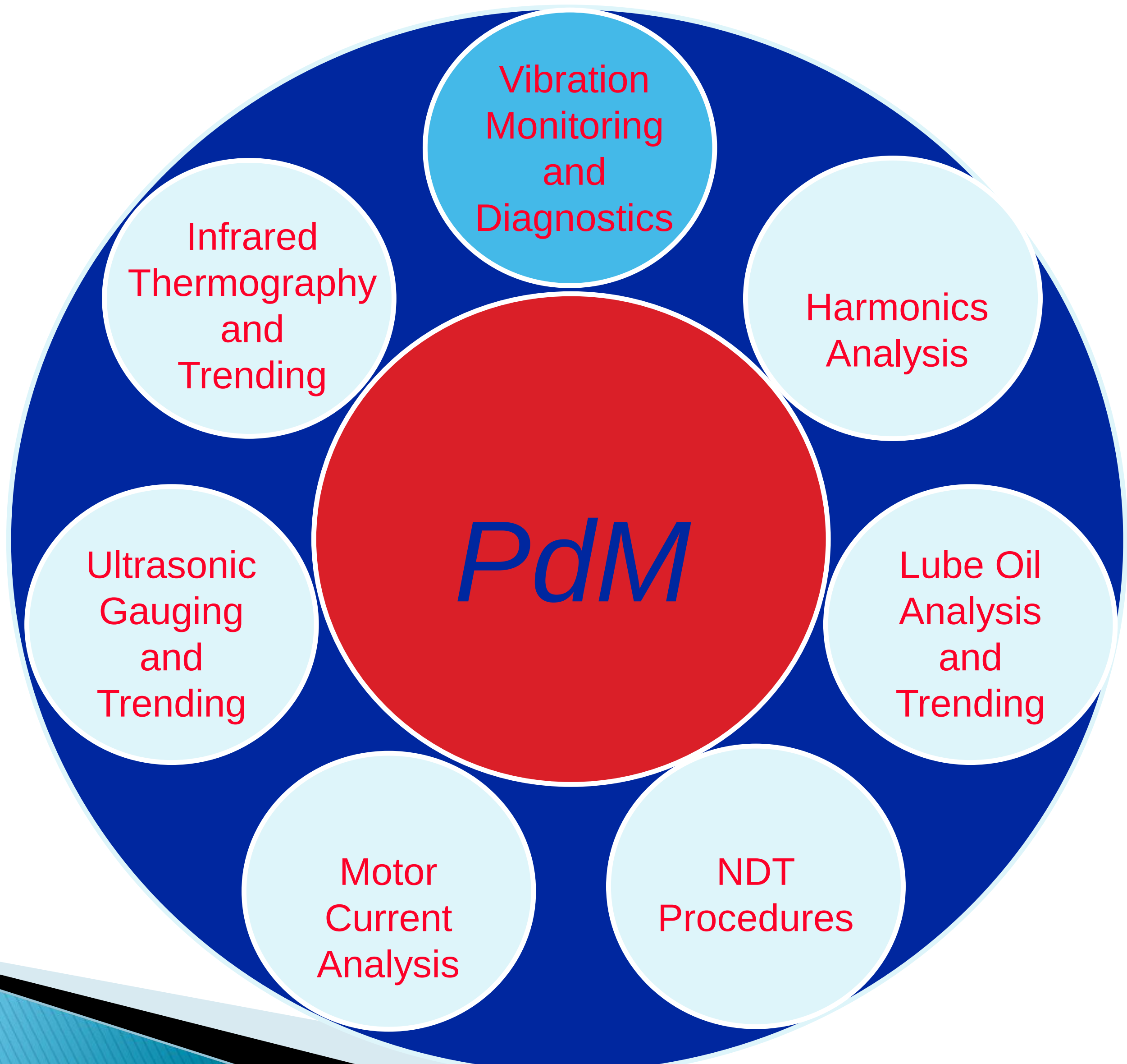


Thermography:
‘Taking its temperature’

Motor Current:
The ‘brain waves’ of the machine



Condition-Based Maintenance



Choosing A CBM System

- What machinery do I monitor?
- What measurements do I perform on the selected machinery?
- How often do I perform the selected measurements?
- What type of Predictive Maintenance equipment do I monitor with?

The Four Stages of Effective Predictive Maintenance Program

Detection

- Trending a machines vibration level to detect and quantify any changes from the norm.

Analysis

- When a significant change is detected the vibration is analysed to determine the nature of the problem

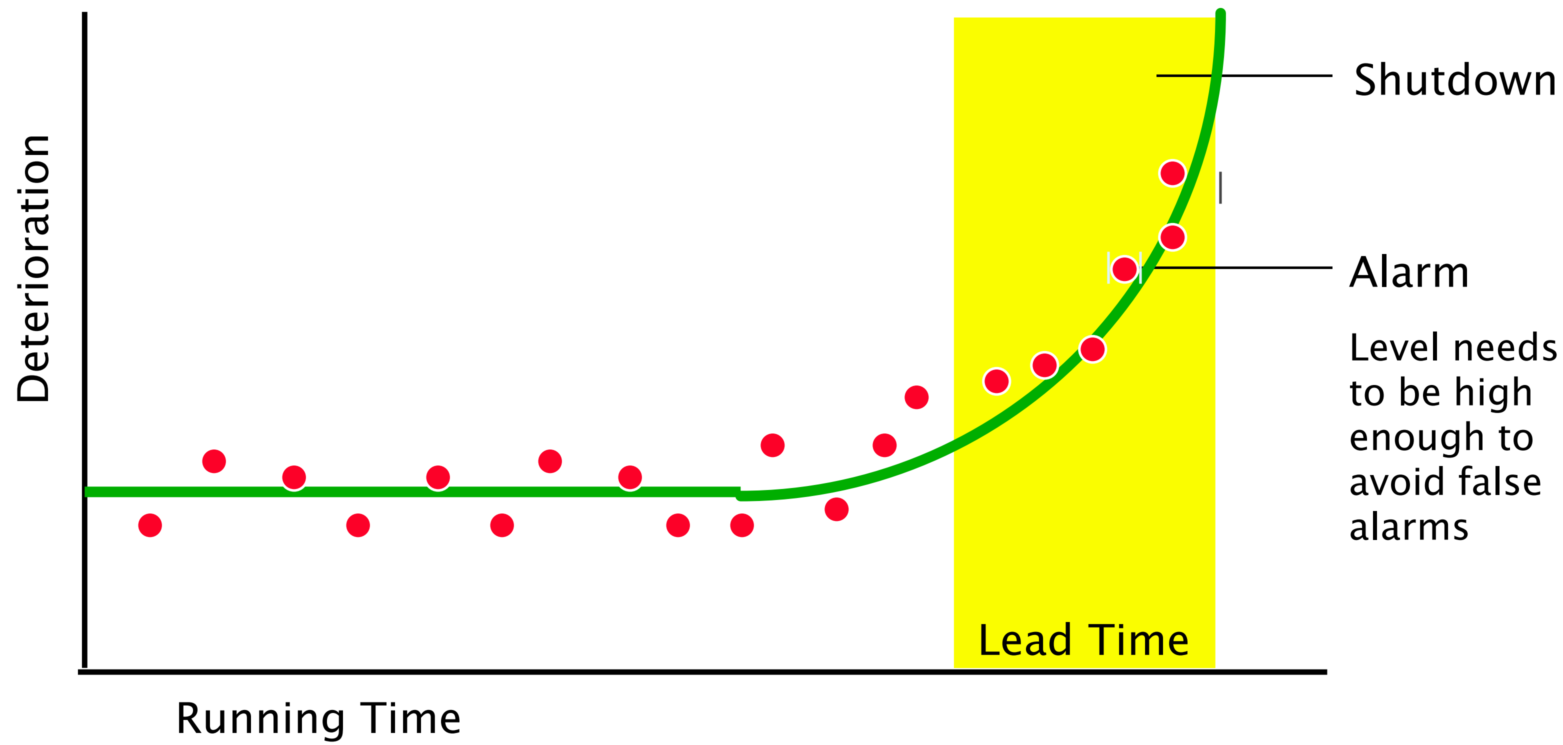
Correction .

- The advanced warning provided by the detection and analysis enables corrective action to be prepared and scheduled.

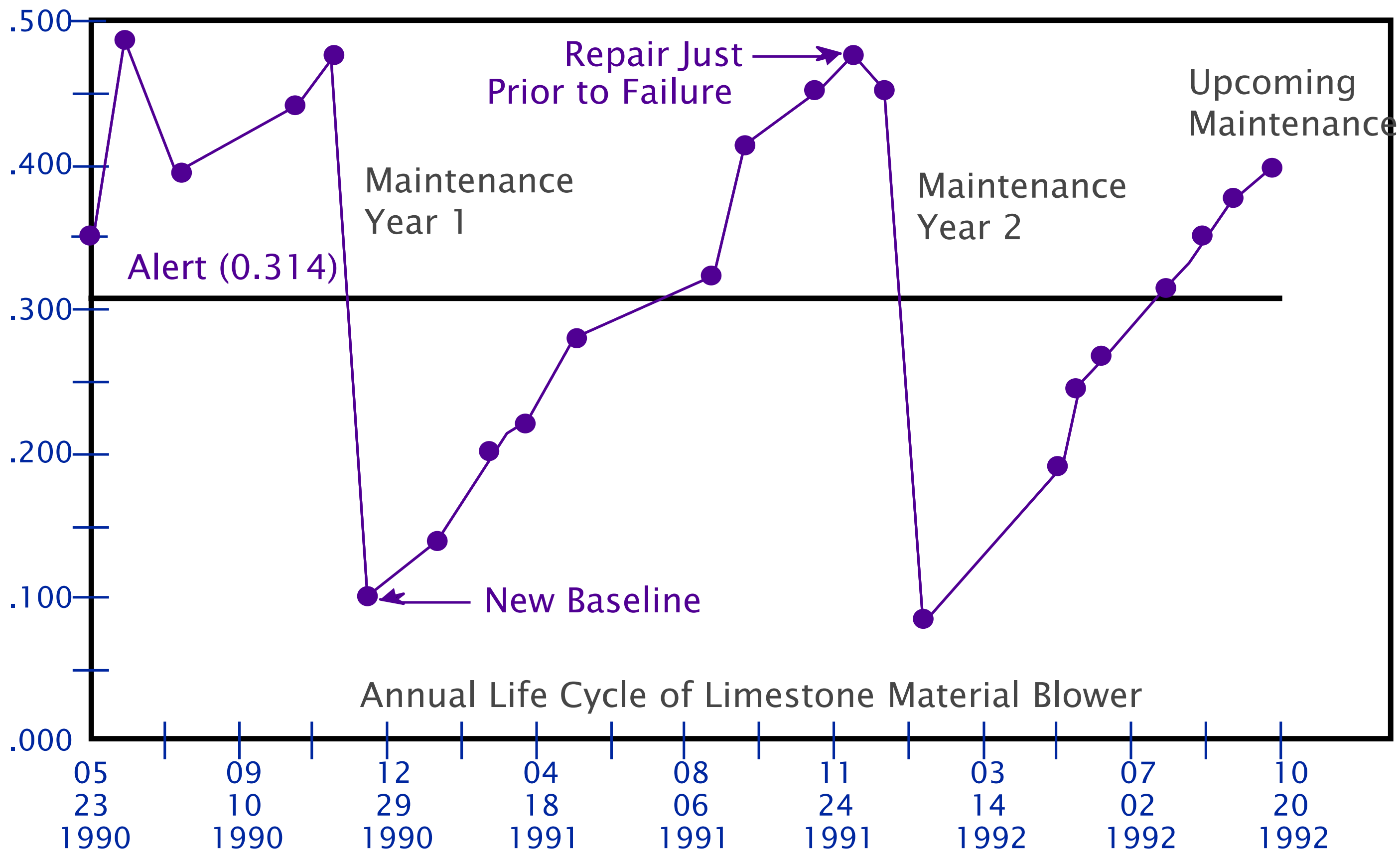
Verification.

- After correction new readings are obtained to ensure that all defects have been eliminated and to establish new baseline characteristics.

How deterioration advances toward failure

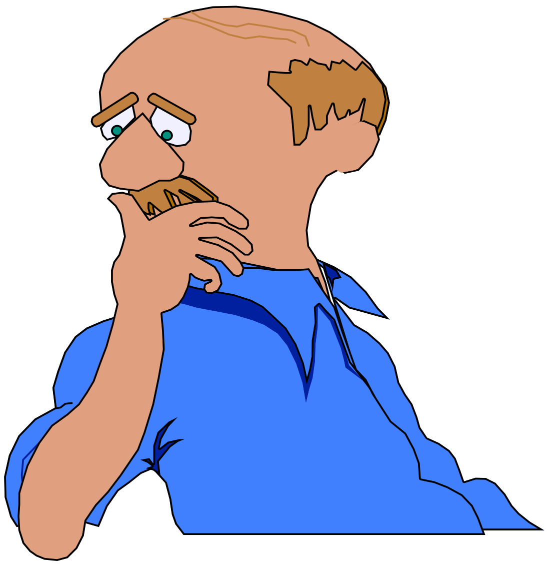


Trend graph


.500
.400
.300
.200
.100
.000
Repair Just
Prior to Failure
Upcoming
Maintenance
Maintenance
Year 1
Maintenance
Year 2
Alert (0.314)
New Baseline
Annual Life Cycle of Limestone Material Blower
05 23 1990
09 10 1990
12 29 1990
04 18 1991
08 06 1991
11 24 1991
03 14 1992
07 02 1992
10 20 1992

Selecting Machinery to Monitor

- Personnel Safety
- Problem Machinery
- Affect on Production
- Probability of Failure
- Manning Level



Machinery classifications

- Critical Equipment
- Semi-Critical Equipment
- Balance of Plant Equipment

Critical Equipment

- Essential, un-spared machines
- High maintenance cost
- High impact on production output
- Progress very rapidly toward catastrophic failure
- Critical failure causes high safety risk
- Continuous online vibration protection system is an integral part of operating critical equipment
- Run up/Run down information critical for analysis

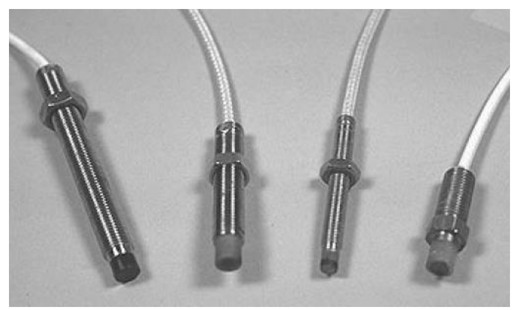
Typical Instrumentation

CSI 2130

Bently Nevada 3500

ADRE 408

Velomitor



Displacement Probe

Accelerometer

Semi-Critical Equipment

- Hazardous/Unsafe environments
- Lack of manpower
- More frequent monitoring (continuous data collection)
- Network capabilities
- Consistent data collection
- Permanently mounted sensors
- No automatic shut-down features

Typical Instrumentation

CSI 2130

Bently Nevada 1900/65

Velomitor

Accelerometer

Balance of Plant Equipment

- Require less frequent monitoring
- Non-critical machinery
- Low safety/environmental risk
- Failure has little effect on production

Typical Instrumentation

CSI 2130


SKF MCA

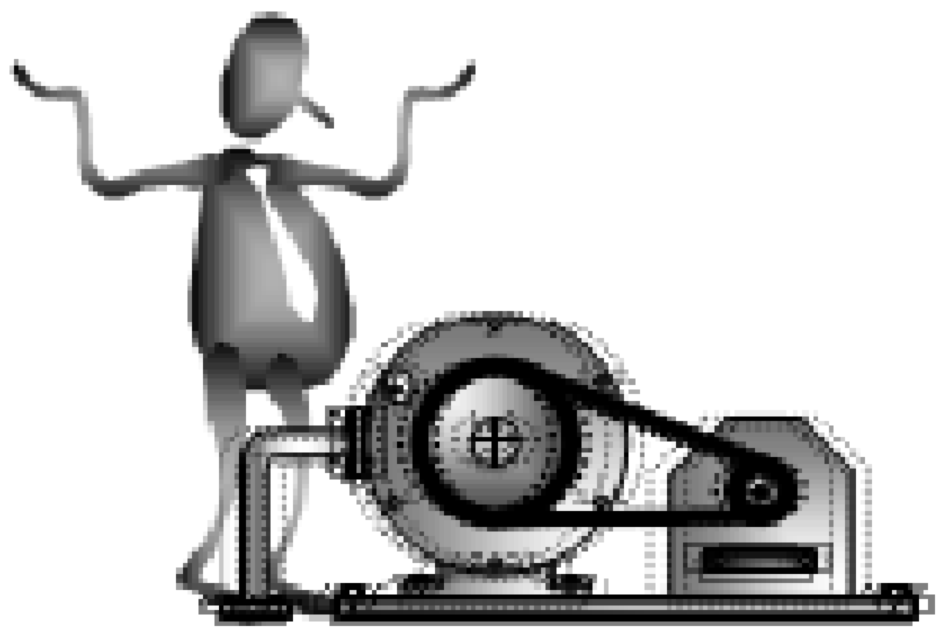
SPM Bearing Checker


Velomitor


Accelerometer


SPM Vib-10

4 Why is Monitoring Vibration Important?

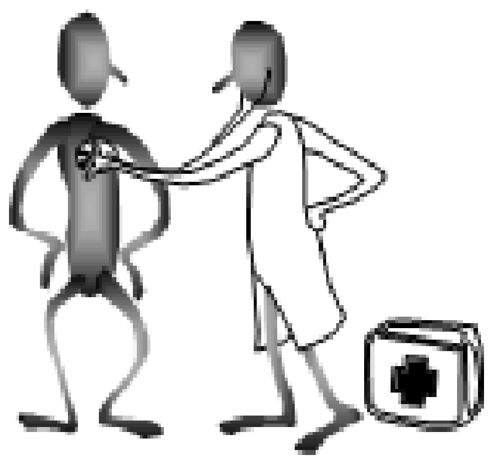


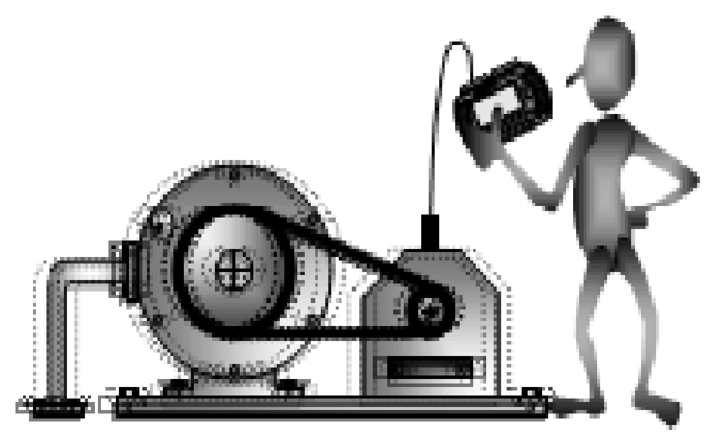
Why monitor machine vibration?

- Operating a machine until it breaks down might be acceptable if the machine were a "**disposable**" one. Most machines, however, are not "**disposable**" due to their cost and effect on the operation and safety.

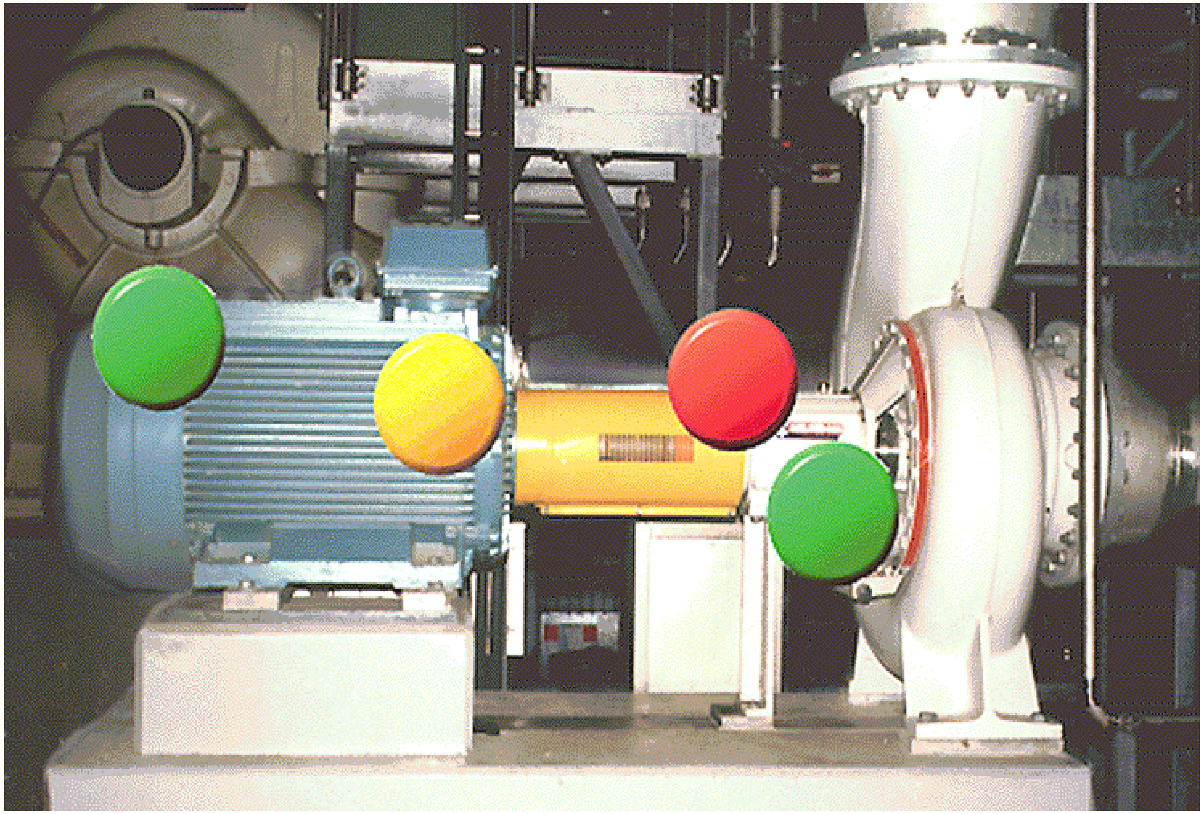
- Monitoring the vibration characteristics of a machine gives us an understanding of the "**health**" condition of the machine

- Machine vibration monitoring finds potentially damaging vibration, we can prevent problems arising and this saves a lot of **time, money and frustration.**

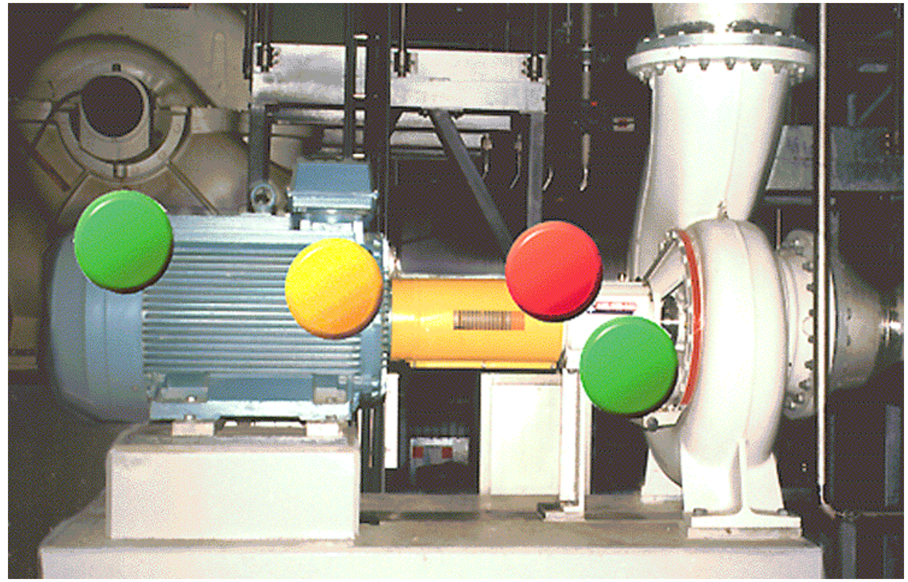


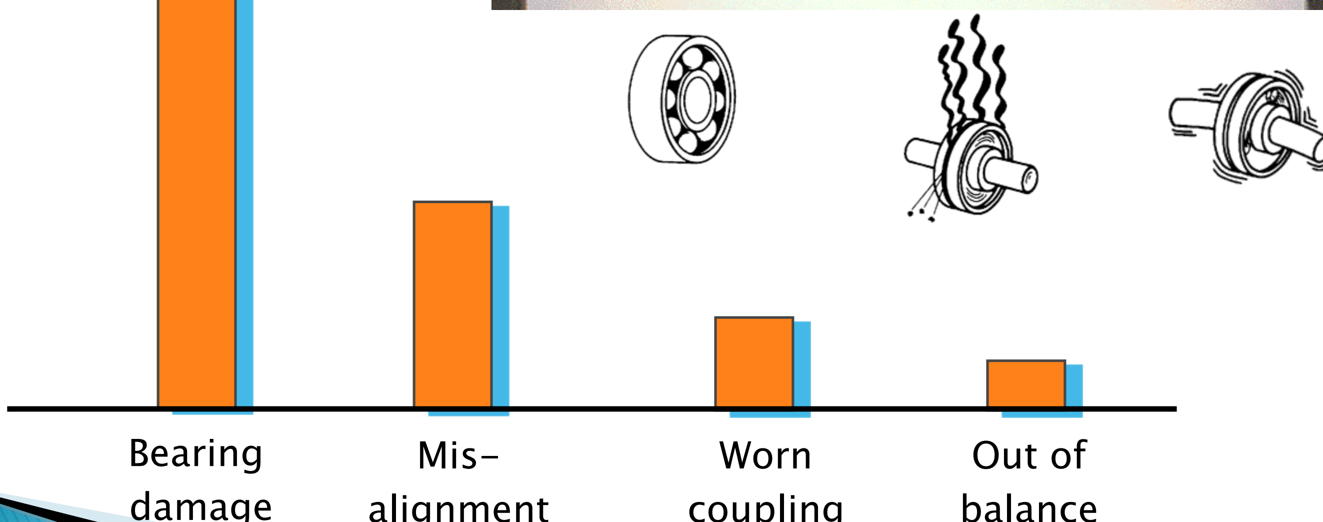


What do we need to know – Maintenance Level

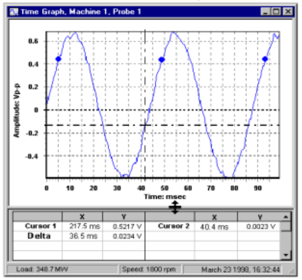


Typical Machinery Problems

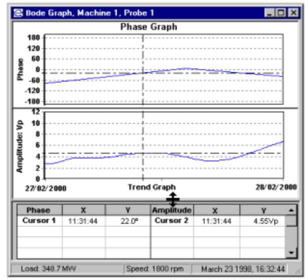




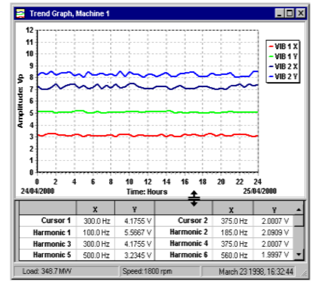
Vibration Diagnostic Plots



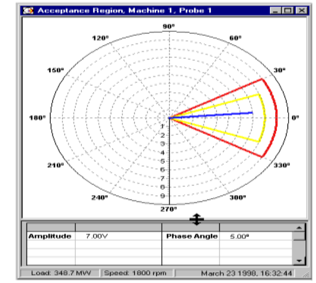
Time Waveform



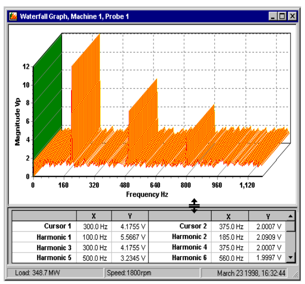
Bode Plot



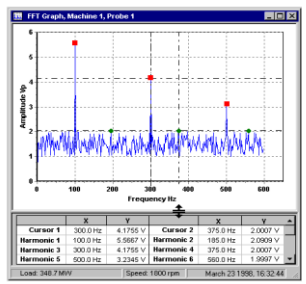
Trend (Multiple OI)



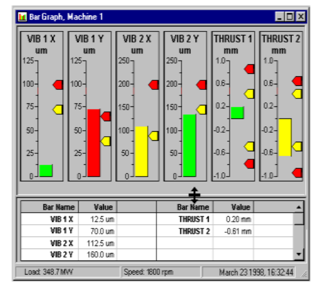
Acceptance Region



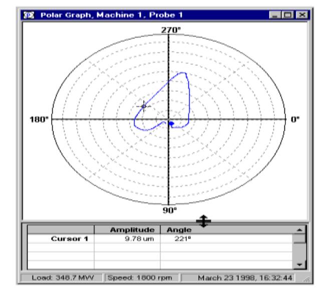
Waterfall/Cascade



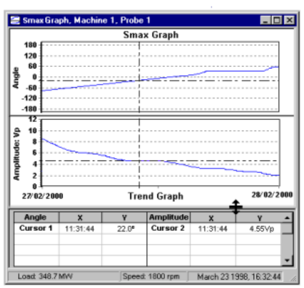
Single Spectrum



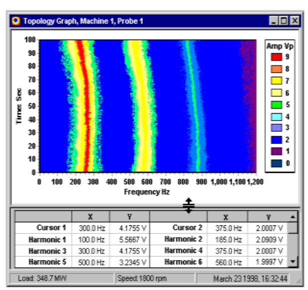
Live Bargraph



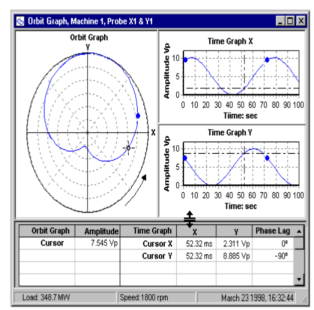
Polar Plot



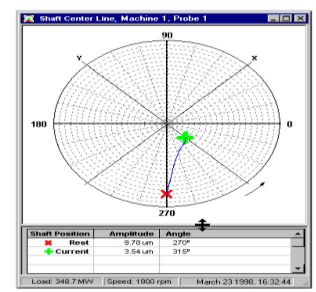
Smax Plot



Topology Plot

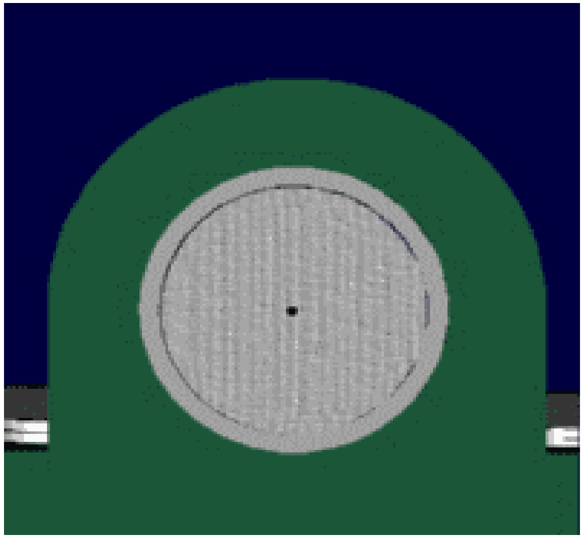


Orbit Plot



Shaft Centreline

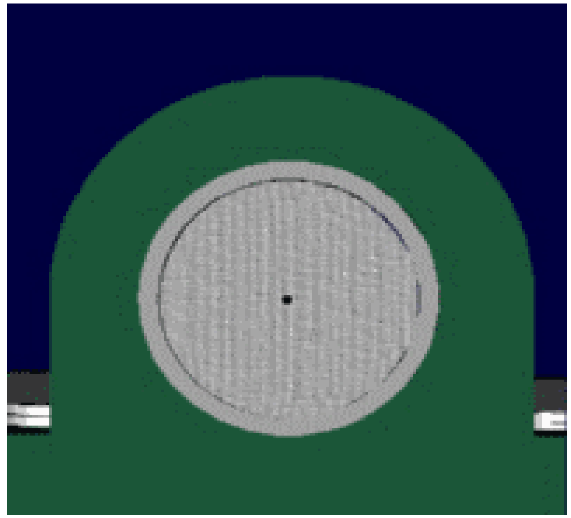
What is Vibration?



Wikipedia:

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road.

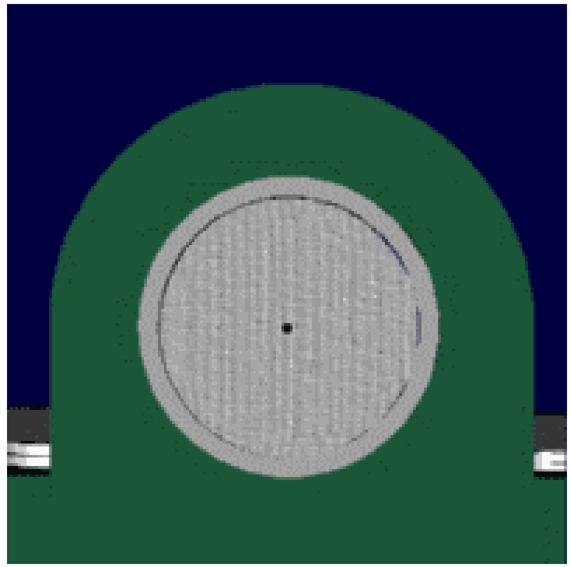
What is Vibration?



Webster Dictionary :
vi·bra·tion *noun* \vī-ˈbrā-shən\

:a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed (as when a stretched cord produces musical tones or molecules in the air transmit sounds to the ear)

What is Vibration?

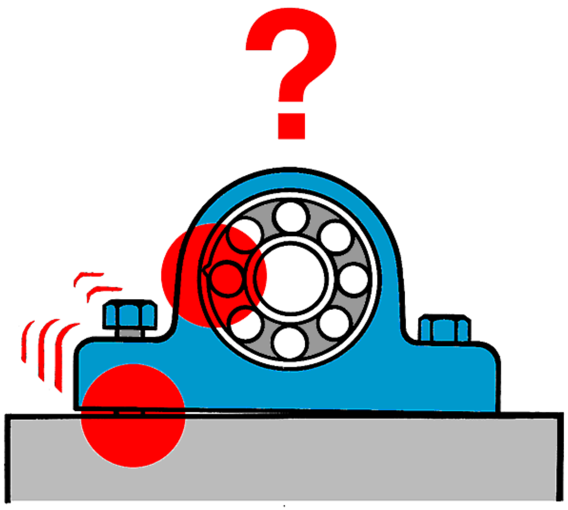


Simply put,

Back and forth movement of a structure or mechanical system

Why use vibration?

- All machines vibrate
- Developing problems are accompanied by an increase in vibration
- The vibration's unique characteristics will be determined by the nature of developing fault



Vibration Analysis

"Of all the parameters that can be measured non-intrusively in industry today, the one containing the most information is the vibration signature."

Art Crawford

What is vibration caused by?

Machine imperfections:

- Design
- Manufacture
- Installation
- Operation
- Maintenance

What is vibration caused by?

Common machine problems that generate mechanical vibration:

- Unbalance
- Misalignment
- Bent Shaft
- Bearing Defect
- Belt and Pulley Problem
- Gear Problem
- Electrical Problem
- Aerodynamic Forces
- Reciprocating Forces
- Cavitation Problem

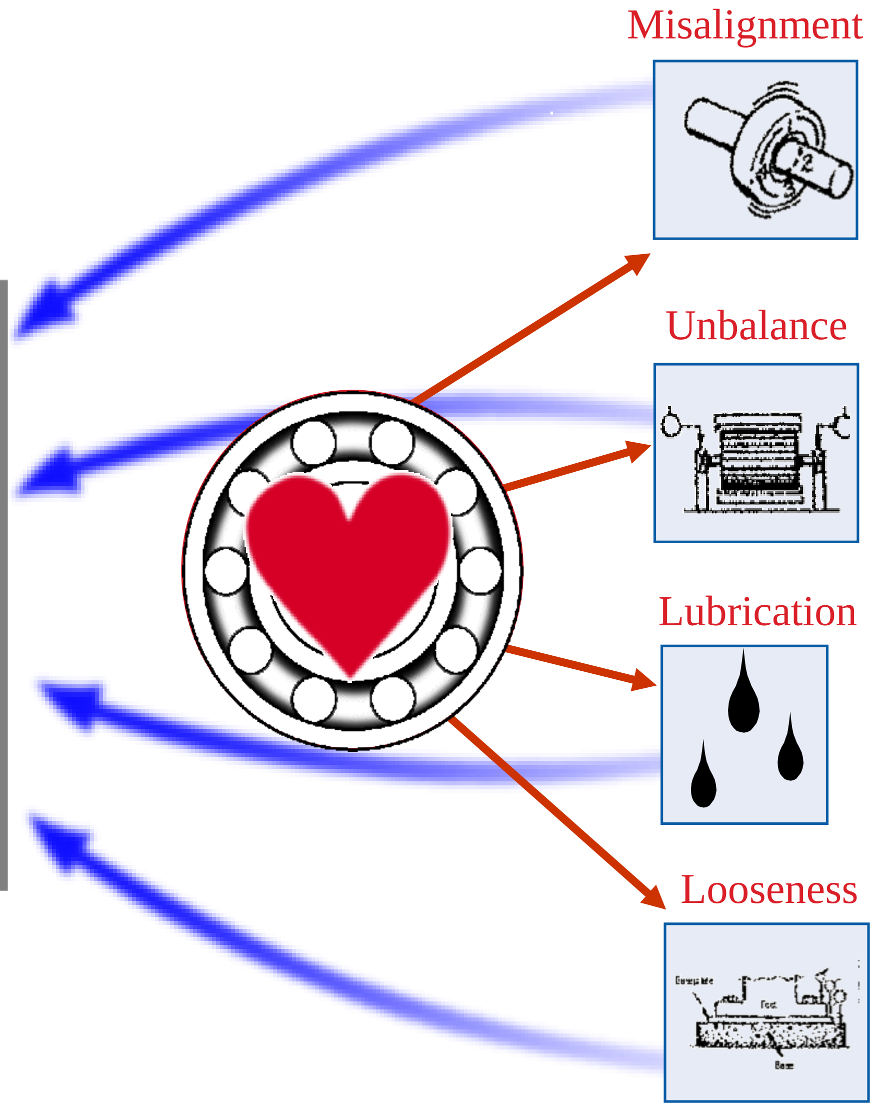
What amplifies equipment vibration?

Common machine problems that amplify vibration (but don’t generally caused it)

- Looseness
- Resonance

Condition-Based Maintenance

The Bearing Knows!



Sir Isaac Newton

For every action there is an equal and opposite reaction

In vibration – for every force there is a reaction or movement

Even better – no force, no motion

Example: A precision machine producing low forces produces low vibration

Force Origins of Vibration

Internal – Produced within the machine

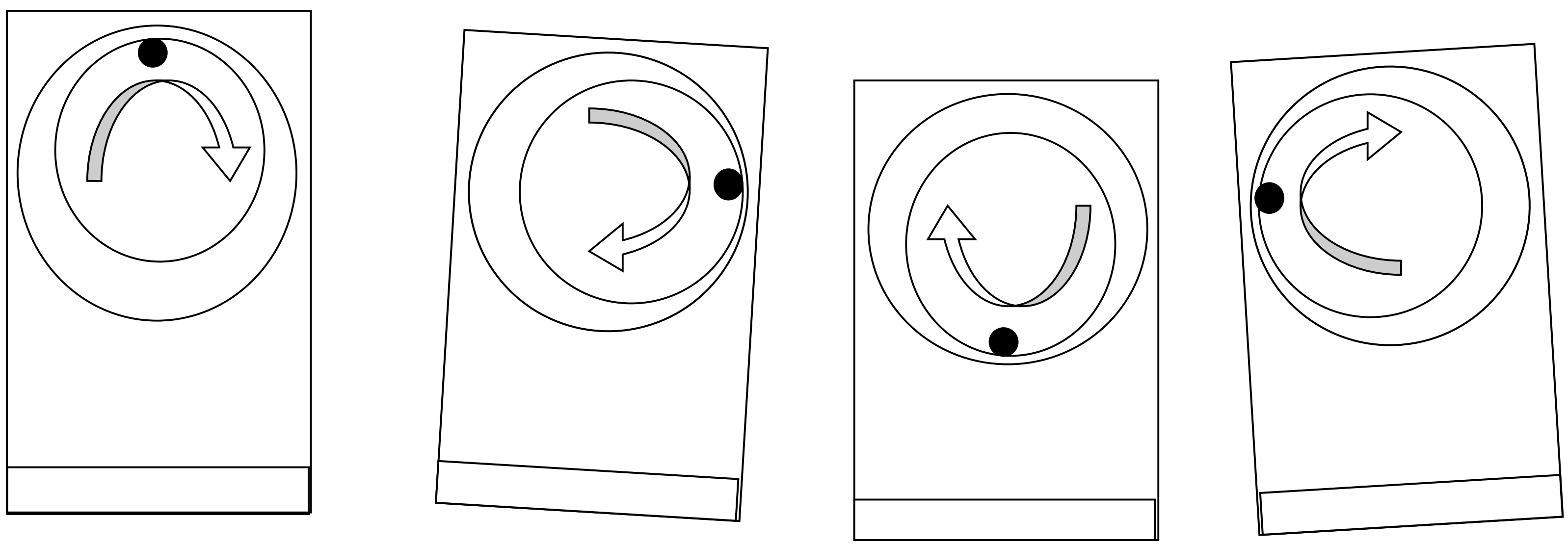
- Unbalance, misalignment, pumping forces, bearing problems

External – Forces transmitted through the foundation, floor, piping, air, water from other machinery or the process into the machine

Types of Vibration Forces

Periodic Forces/Rotational Forces

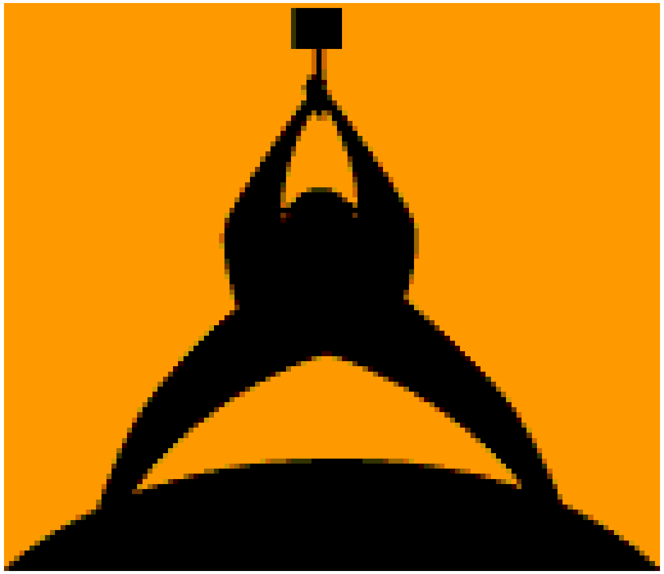
- Repetitive and “smooth”
- Unbalance, misalignment, pump vane pass



Types of Vibration Forces

Impact, Impulse

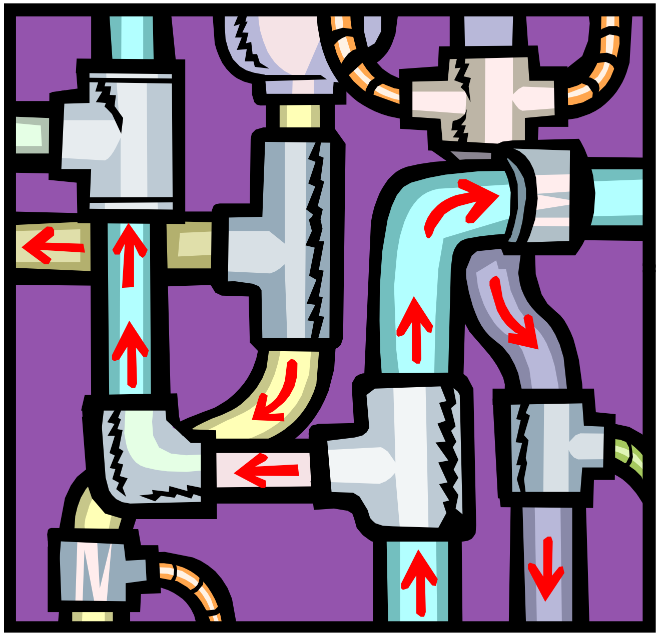
- Bearing faults, loose parts



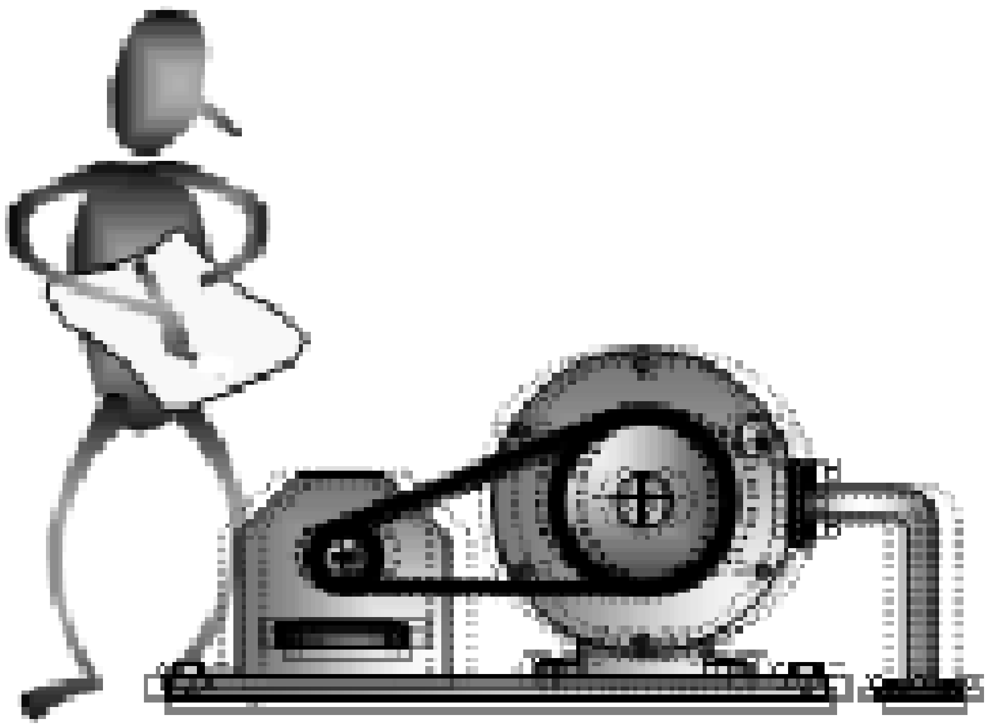
Types of Vibration Forces

Random Excitation

- Cavitation, flow, severe bearing damage



4 How is Machine Vibration Described?



Objectives:

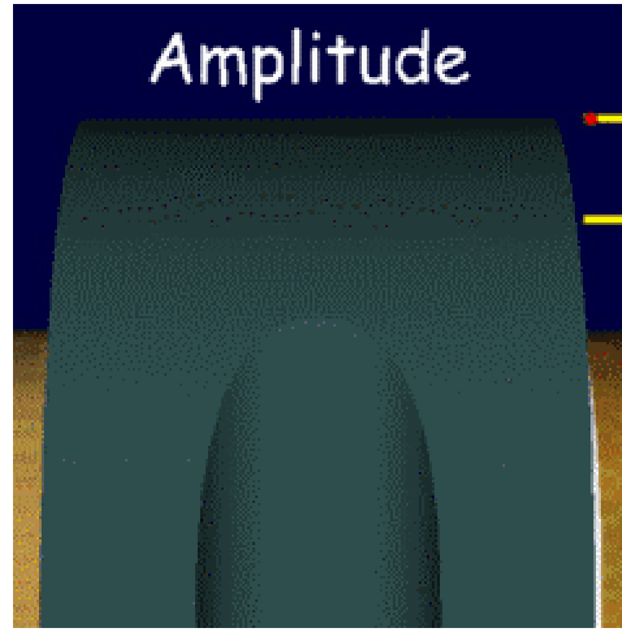
- Know the five most important methods of describing machine vibration
- Understand the term “amplitude”
- Understand the term “frequency” (spectrum and waveform)
- Understand the term “phase”
- Understand the term “shape”
- Understand the term “shaft position”

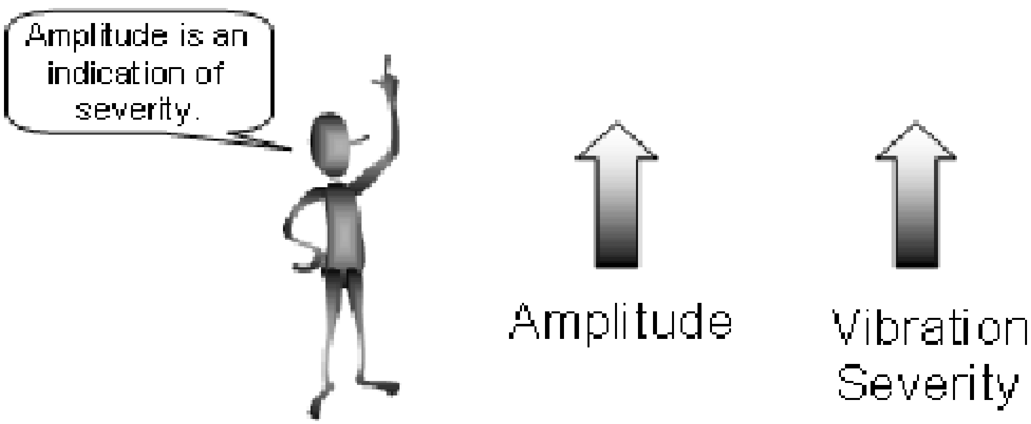
Measurable Vibration Characteristics

- Amplitude : How much it is vibrating?
- Frequency : What is vibrating?
- Phase : How it is vibrating?

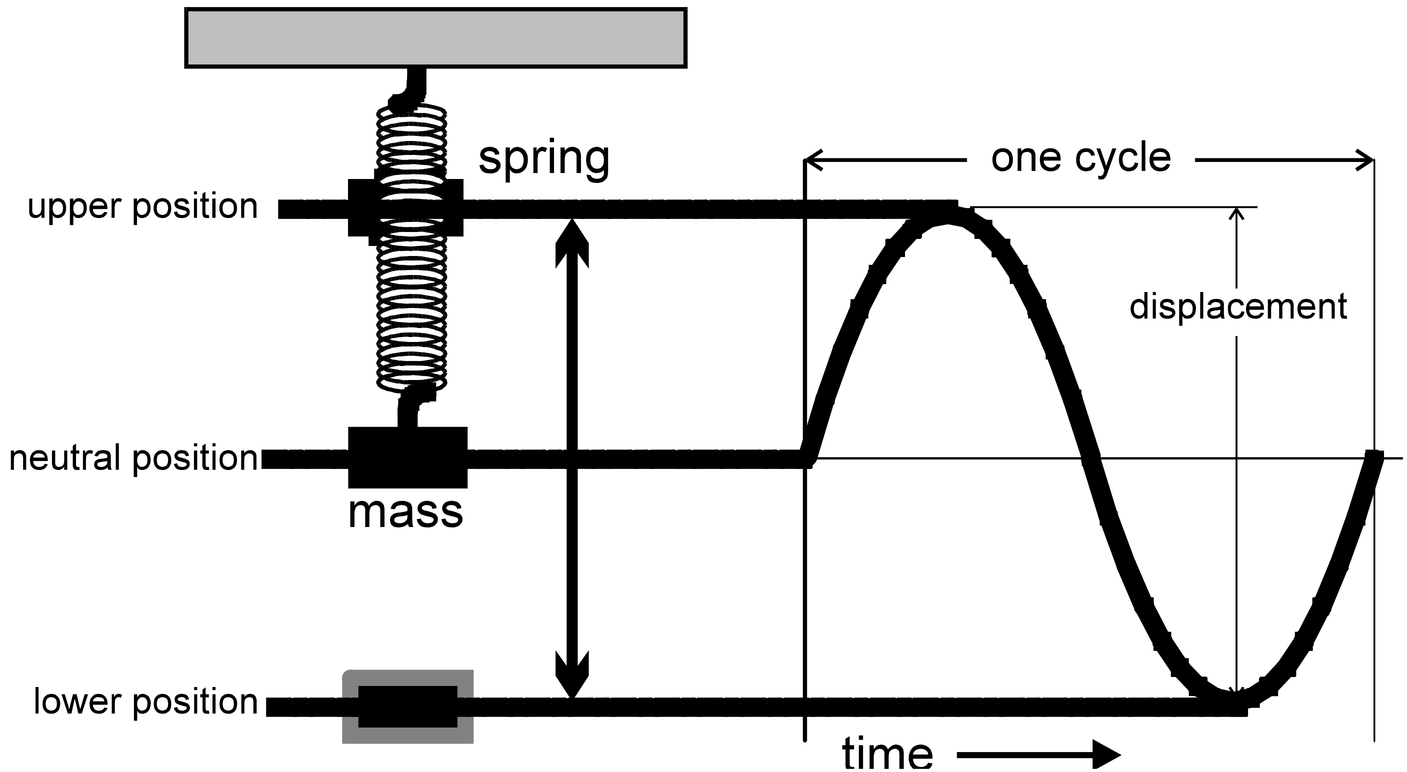
Amplitude

- it is the magnitude of vibration
- a machine with large vibration amplitude is one that experiences large, fast, or forceful vibratory movements.
- the larger the amplitude, the more movement or stress is experienced by the machine, and the more prone the machine is to damage.
- thus, amplitude is an indication of the **severity** of vibration

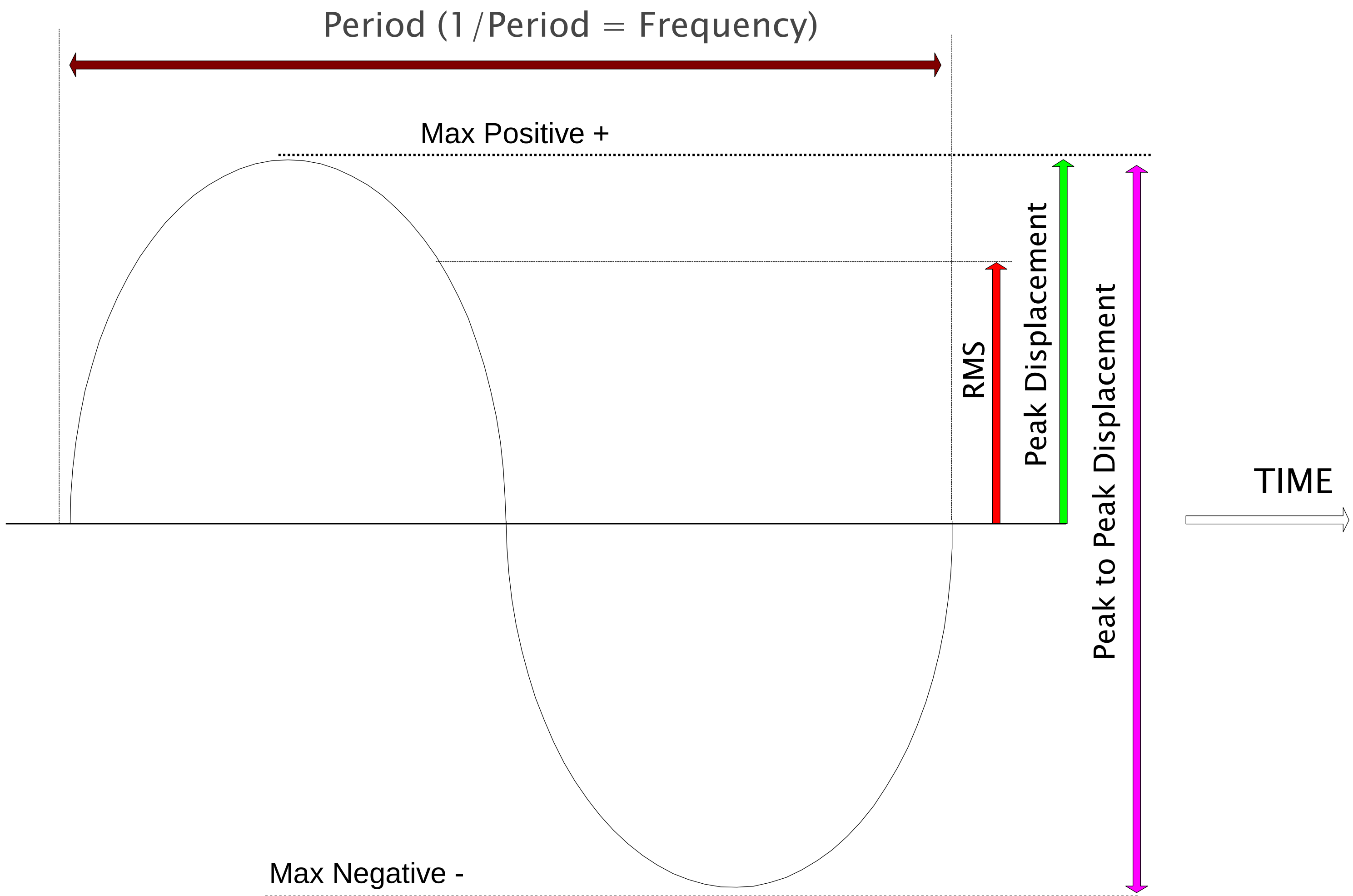




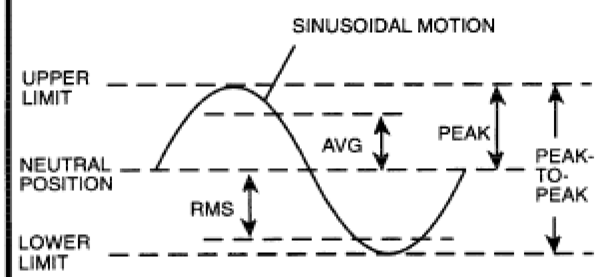
Vibration Amplitude



Detection Type



Comparison of peak, Peak to peak or RMS



MULTIPLY NUMBER OF → BY / TO OBTAIN ↓	PEAK-TO-PEAK	PEAK	RMS	AVERAGE
PEAK-TO-PEAK	1.000	2.000	2.828	3.142
PEAK	.500	1.000	1.414	1.571
RMS	.354	.707	1.000	1.5
AVERAGE	.318	.636	.900	1.000

FIGURE 16
COMPARISON OF PEAK, PEAK-TO-PEAK, RMS, AND AVERAGE FOR A PURE SINUSOIDAL TIME WAVEFORM

Amplitude Units

- Displacement (Distance/Stress – mils, µm)
- Velocity(Speed/Fatigue – mm/s, in/s)
- Acceleration(Force – g, m/s^2)

Comparison of the basic international units used to quantify vibratory motion

	ISO	SI	Imperial
Acceleration	g (1g=9.807m/s^2)	m/s^2	g
Velocity	mm/s	mm/s	in/sec
Displacement	µm	µm	thou (mils)

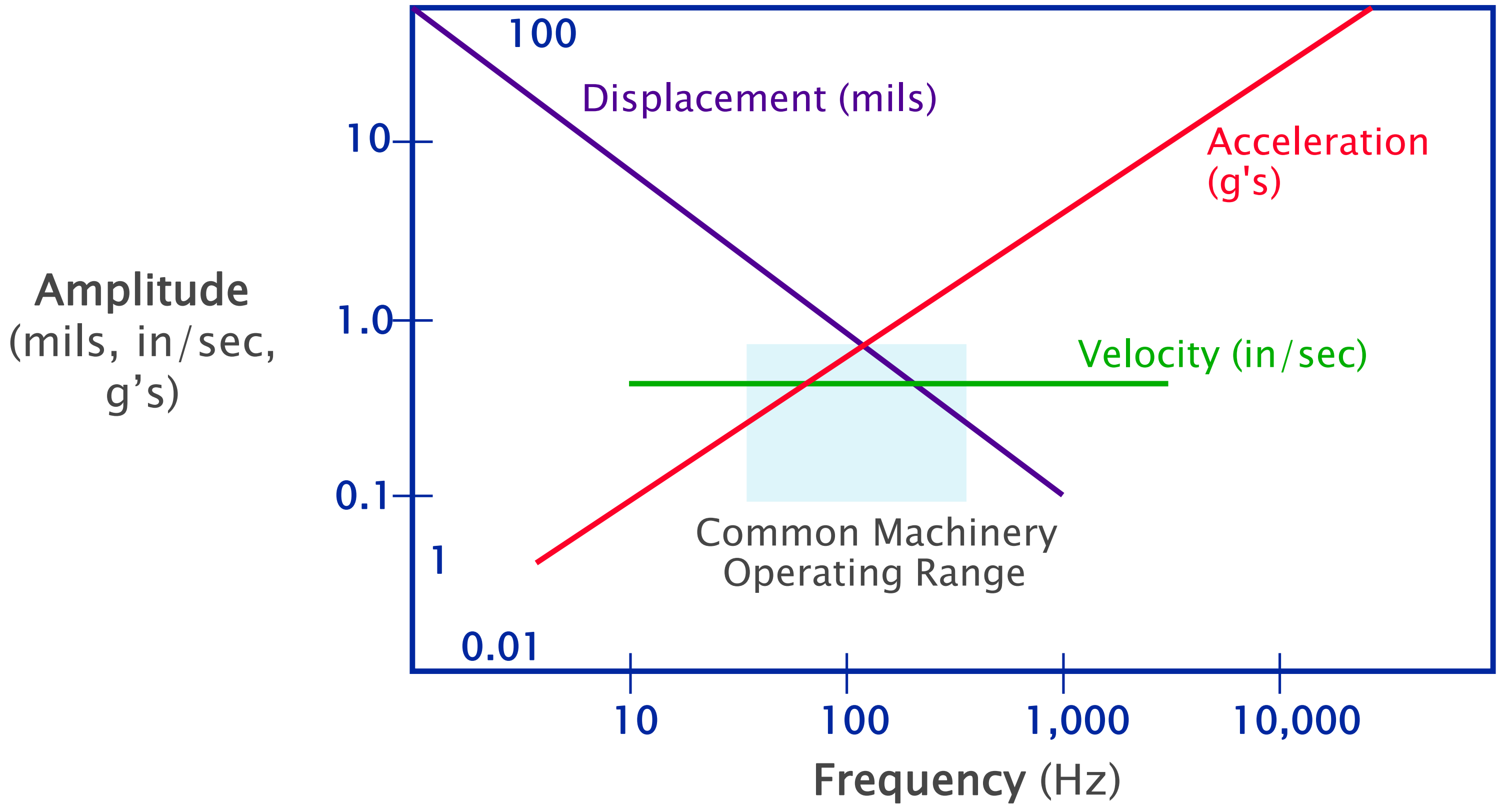
Conversion Formulas

TABLE I
CONVERSION FORMULAS FOR VARIOUS AMPLITUDE UNITS (Ref. 5)

ENGLISH	METRIC
$D = 19{,}100\ (V)/F$	$D_M = 19{,}100\ (V_M)/F$
$D = 70{,}471{,}000\ (A)/F^2$	$D_M = 1.79 \times 10^9\ (A)/F^2$
$V = DF/19{,}100$	$V_M = D_M F/19{,}100$
$V = 3690\ (A)/F$	$V_M = 93{,}580\ (A)/F$
$A = DF^2/70{,}471{,}000$	$A = D_M F^2/1.79 \times 10^9$
$A = VF/3690$	$A = V_M F/93{,}580$

English units	Metric units
A= Acceleration (g PK)	A= Acceleration (g PK)
V= Velocity (in/sec PK)	V= Velocity (mm/sec PK)
D= Displacement (mils PK-PK)	D= Displacement (microns PK-PK)
F= Frequency (CPM)	F= Frequency (CPM)

Measurement Selection



Vibration Alarm Limits

- Manufacturer recommendation
- Plant/Company Standard
- ISO 10816-1
- Technical Associates of Charlotte (Ascent Software is using this guidelines)

ISO Guidelines

ISO 10816-1 overall velocity vibration guidelines

<table>
<tr><th colspan="2">Velocity Severity</th><th colspan="4">Velocity Range Limits and Machine Classes
ISO Standard 10816-1</th></tr>
<tr><th rowspan="2">mm/s RMS</th><th rowspan="2">in/s PEAK</th><th rowspan="2">Small Machines Class I</th><th rowspan="2">Medium Machines Class II</th><th colspan="2">Large Machines</th></tr>
<tr><th>Rigid Supports Class III</th><th>Less Rigid Supports Class IV</th></tr>
<tr><td>0.28</td><td>0.02</td><td rowspan="3">Good</td><td rowspan="4">Good</td><td rowspan="5">Good</td><td rowspan="6">Good</td></tr>
<tr><td>0.45</td><td>0.03</td></tr>
<tr><td>0.71</td><td>0.04</td></tr>
<tr><td>1.12</td><td>0.06</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>1.80</td><td>0.10</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>2.80</td><td>0.16</td><td rowspan="2">Unsatisfactory (Alert)</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>4.50</td><td>0.25</td><td rowspan="2">Unsatisfactory (Alert)</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>7.10</td><td>0.40</td><td rowspan="5">Unacceptable (Danger)</td><td rowspan="2">Unsatisfactory (Alert)</td></tr>
<tr><td>11.20</td><td>0.62</td><td rowspan="4">Unacceptable (Danger)</td><td rowspan="2">Unsatisfactory (Alert)</td></tr>
<tr><td>18.00</td><td>1.00</td><td rowspan="3">Unacceptable (Danger)</td></tr>
<tr><td>28.00</td><td>1.56</td><td rowspan="2">Unacceptable (Danger)</td></tr>
<tr><td>45.00</td><td>2.51</td></tr>
</table>

ISO Vibration Standard 10816-1

Broad Band Vibration Criteria for Specific Machine Groups
Based on ISO 10816-1

ISO 10816-1 replaces ISO 2372 as a general guide outlining measurement and evaluation of mechanical vibration in typical industrial machinery. Note that although these guidelines are defined in accordance to machine classification as noted below, these guides provide a standardized starting point for evaluation. Once the general classification of the machine has been identified, the application, mounting technique, and operational conditions must also be factored into the level of acceptance in applying the evaluation criteria. In application-specific installations, this guideline may be modified in accordance to application requirements.

Per ISO 10816-1:
Velocity measurements can be categorized as follows:

Class I machines may be separated driver and driven, or coupled units comprising operating machinery up to approximately 15kW (approx 20hp).
Class II machinery (electrical motors 15kW(20hp) to 75kW(100hp), *without special foundations*, **or** *Rigidly mounted* engines or machines up to 300kW (400hp) *mounted on special foundations*
Class III machines are large prime movers and other large machinery with large rotating assemblies *mounted on rigid and heavy foundations* which are reasonably stiff in the direction of vibration.
Class IV includes large prime movers and other large machiery with large rotating assemblies *mounted on foundations which are relatively soft in the direction of the measured vibration* (i.e., turbine generators and gas turbines greater than 10MW (approx. 13500hp) output.

Criteria for Overall Condition Rating – Technical Associates of Charlotte

Metric Version Of Table II

TABLE II

TECHNICAL ASSOCIATES OF CHARLOTTE, P.C.

CRITERIA FOR OVERALL CONDITION RATING (RMS OVERALL VELOCITY, mm/sec.)*

1. Assuming Machine Speed = 600 to 60,000 RPM.
2. Assuming Measurements by Accelerometer or Velocity Pickup securely mounted as Close as Possible to Bearing Housing.
3. Assuming Machine Is Not Mounted on Vibration Isolators (for Isolated Machinery, Set Alarm 30% - 50% Higher).
4. Set Motor Alarms the Same as that for the Particular Machine Type unless Otherwise Noted.
5. Set Alarms on Individual External Gearbox Positions about 25% Higher than that for a particular Machine Type.

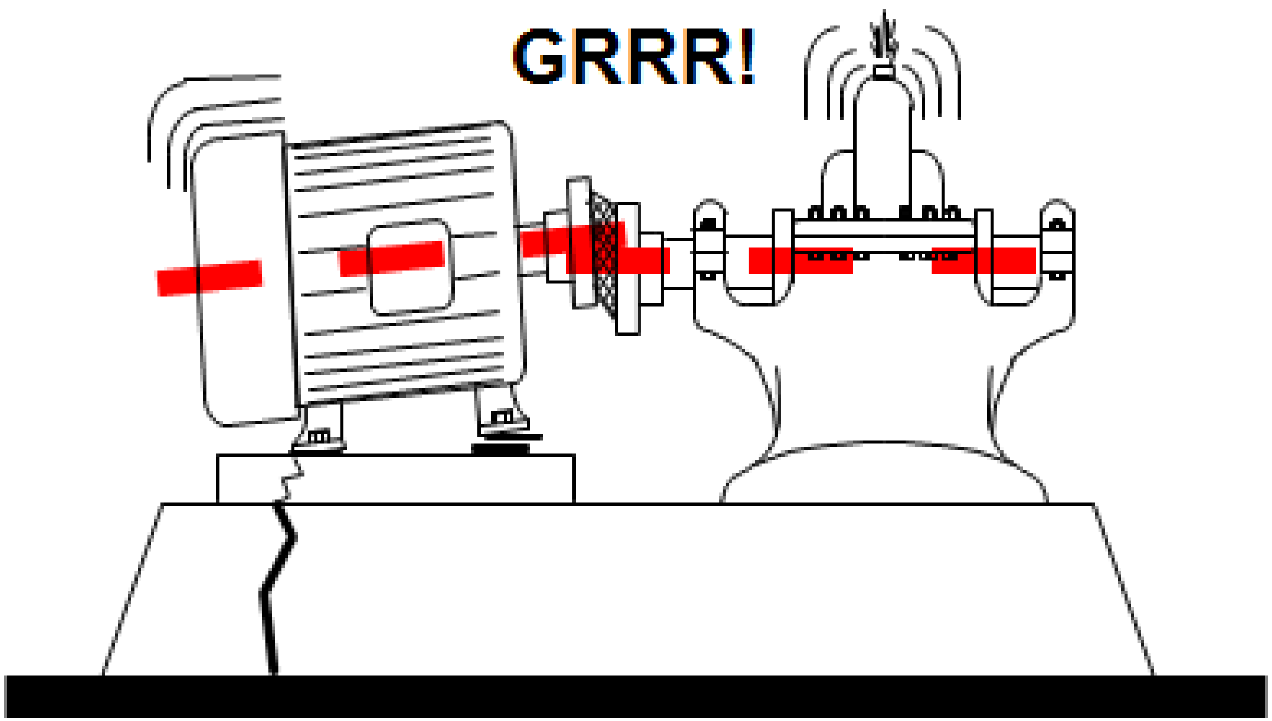
MACHINE TYPE	GOOD	FAIR	(WARNING) ALARM 1	(FAULT) ALARM 2
COOLING TOWER DRIVES				
Long, Hollow Drive Shaft	0 - 7.0	7.0 - 11.0	11.0	16.0
Close Coupled Belt Drive	0 - 5.0	5.0 - 7.5	7.5	12.0
Close Coupled Direct Drive	0 - 3.5	3.5 - 5.5	5.5	8.0
COMPRESSORS				
Reciprocating	0 - 6.0	6.0 - 9.0	9.0	13.5
Rotary Screw	0 - 5.5	5.5 - 8.0	8.0	12.0
Centrifugal With or W/O External Gearbox	0 - 3.5	3.5 - 5.5	5.5	8.0
Centrifugal - Integral Gear (Axial Meas.)	0 - 3.5	3.5 - 5.5	5.5	8.0
Centrifugal - Integral Gear (Radial Meas.)	0 - 2.5	2.5 - 4.5	4.5	6.5
BLOWERS (FANS)				
Lobe-Type Rotary	0 - 5.5	5.5 - 8.0	8.0	12.0
Belt-Driven Blowers	0 - 5.0	5.0 - 7.5	7.5	11.5
General Direct Drive Fans (with Coupling)	0 - 4.5	4.5 - 6.5	6.5	10.0
Primary Air Fans	0 - 4.5	4.5 - 6.5	6.5	10.0
Large Forced Draft Fans	0 - 3.5	3.5 - 5.5	5.5	8.0
Large Induced Draft Fans	0 - 3.0	3.0 - 5.0	5.0	7.0
Shaft-Mounted Integral Fan (Extended Motor Shaft)	0 - 3.0	3.0 - 5.0	5.0	7.0
Vane-Axial Fans	0 - 2.5	2.5 - 4.5	4.5	6.5
MOTOR/GENERATOR SETS				
Belt-Driven	0 - 5.0	5.0 - 7.5	7.5	12.0
Direct Coupled	0 - 3.5	3.5 - 5.5	5.5	8.0
CHILLERS				
Reciprocating	0 - 4.5	4.5 - 7.0	7.0	10.5
Centrifugal (Open-Air) - Motor & Comp. Separate	0 - 3.5	3.5 - 5.5	5.5	8.0
Centrifugal (Hermetic) - Motor & Impellers Inside	0 - 2.5	2.5 - 4.0	4.0	6.0
LARGE TURBINE/GENERATORS				
3600 RPM Turbine/Generators	0 - 3.0	3.0 - 5.0	5.0	7.0
1800 RPM Turbine/Generators	0 - 2.5	2.5 - 4.0	4.0	6.0
CENTRIFUGAL PUMPS				
Vertical Pumps (4m - 6m Height) — Height from Grade to Top Motor Bearing.	0 - 6.0	6.0 - 9.0	9.0	13.5
Vertical Pumps (3m - 4m Height) — May be Necessary to Spec. Lower Alarm	0 - 5.0	5.0 - 7.5	7.5	11.5
Vertical Pumps (2m - 3m Height) — for Lower Motor Bearing & for Upper	0 - 4.0	4.0 - 6.0	6.0	9.5
Vertical Pumps (0m -2m Height) — Pump Bearing (depending on height).	0 - 3.5	3.5 - 5.5	5.5	8.0
General Purpose Horizontal Pump - Direct Coupled	0 - 3.5	3.5 - 5.5	5.5	8.0
Boiler Feed Pumps - Horizontal Orientation	0 - 3.5	3.5 - 5.5	5.5	8.0
Hydraulic Pumps - Horizontal Orientation	0 - 2.0	2.0 - 3.5	3.5	5.5
MACHINE TOOLS				
Motor	0 - 1.2	1.2 - 1.8	1.8	2.7
Gearbox Input	0 - 1.8	1.8 - 2.7	2.7	4.0
Gearbox Output	0 - 1.2	1.2 - 1.8	1.8	2.7
Spindles:				
a. Roughing Operations	0 - .70	.70 - 1.2	1.2	1.8
b. Machine Finishing	0 - .45	.45 - .72	.72	1.1
c. Critical Finishing	0 - .27	.27 - .45	.45	.72

*NOTE: The "ALARM 1" and "ALARM 2" overall levels given above apply only to in-service machinery which has been operating for some time after initial installation and/or overhaul. They do not apply (and are not meant to serve as) Acceptance Criteria for either new or rebuilt machinery.

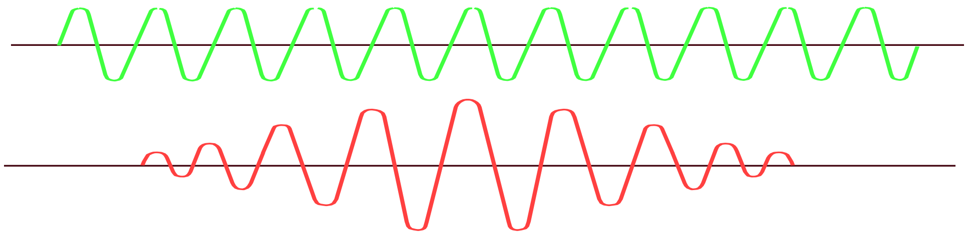
 R=1097-3RMSMM

Vibration Frequency

Once high vibration on the equipment is detected, the next question, is **WHY?**



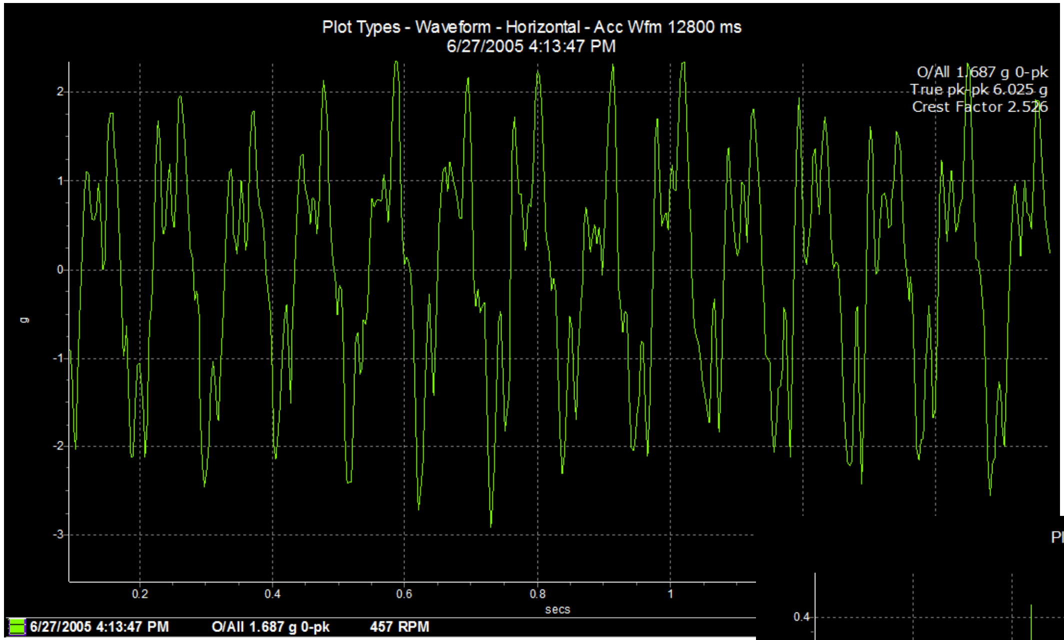
Amplitude vs. Frequency

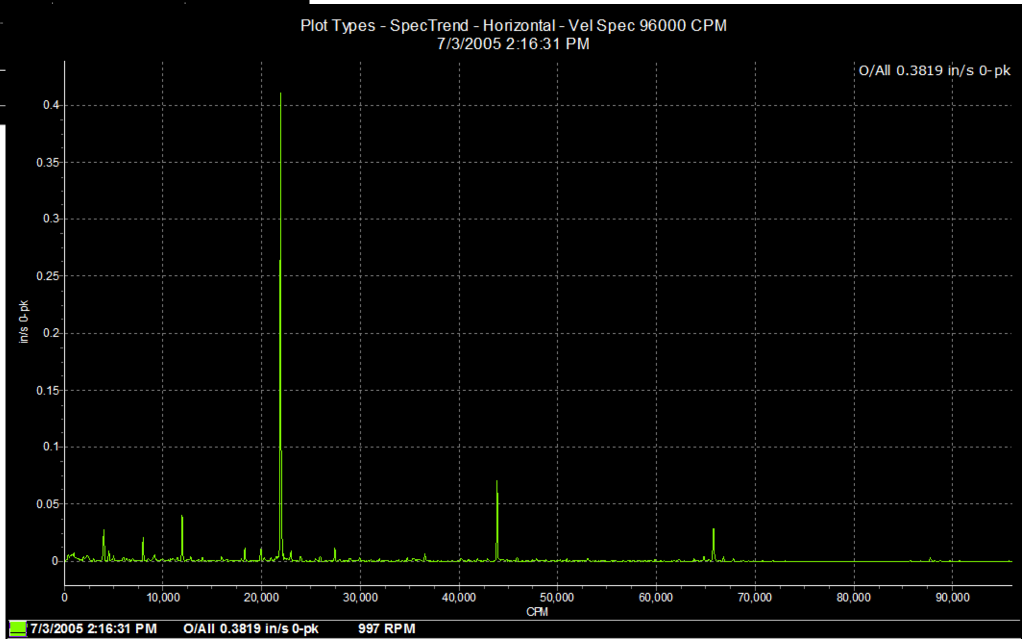


When analyzing vibration we look at two components of the vibration signal, its amplitude and its frequency.

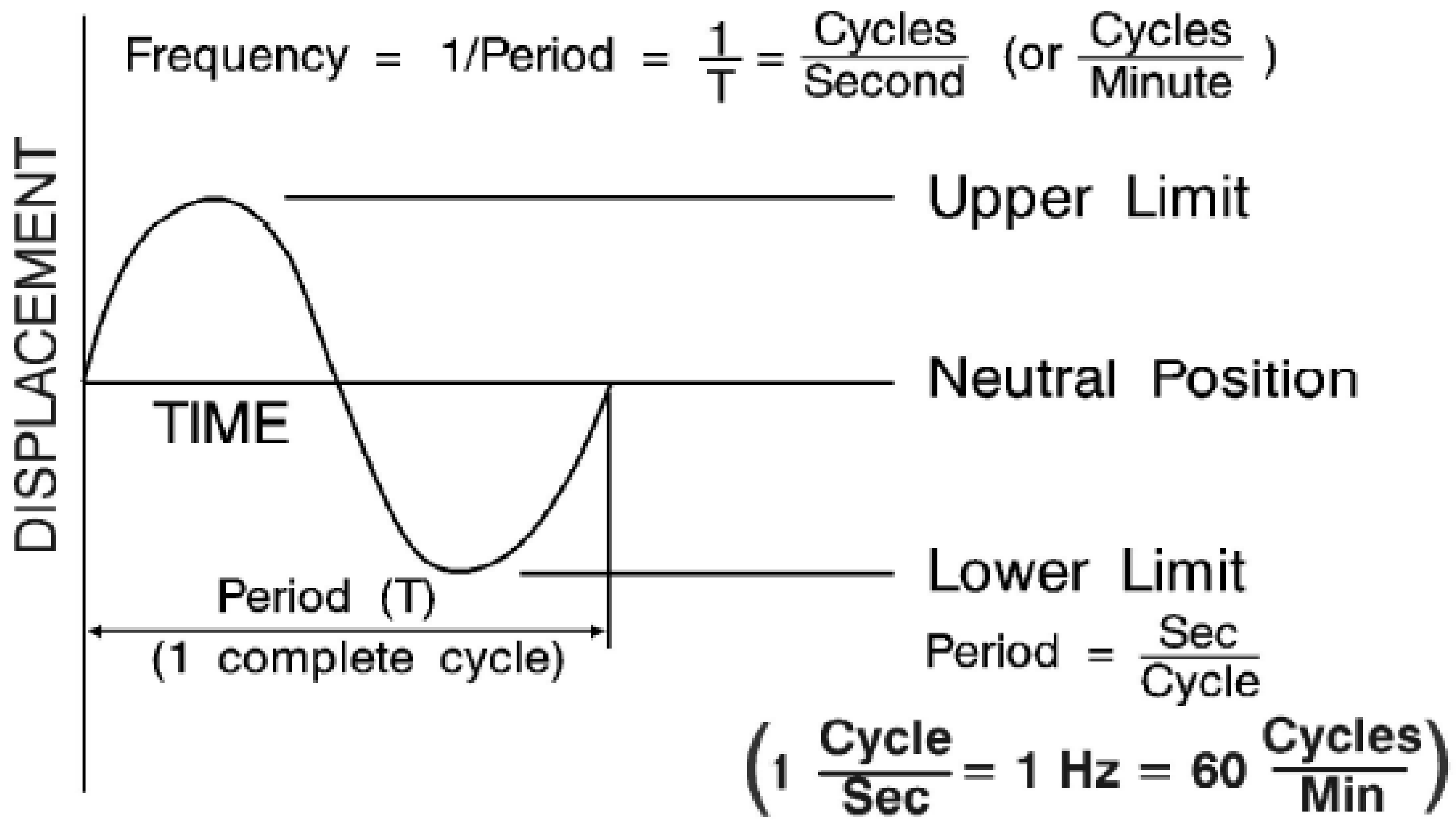
- Vibration amplitude indicates the severity of the problem.
- Vibration frequency indicates the source of the problem.

Vibration Frequency





Vibration Frequency & Time Waveform Analysis



Relationship of time and frequency

Frequency/Time Triangle

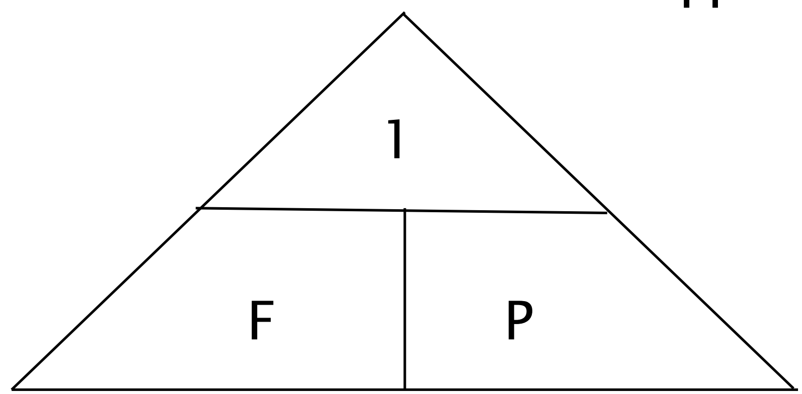
P = Period (Time – Fraction of a Second)
F = Frequency (cycles/Sec)

1 = One Second

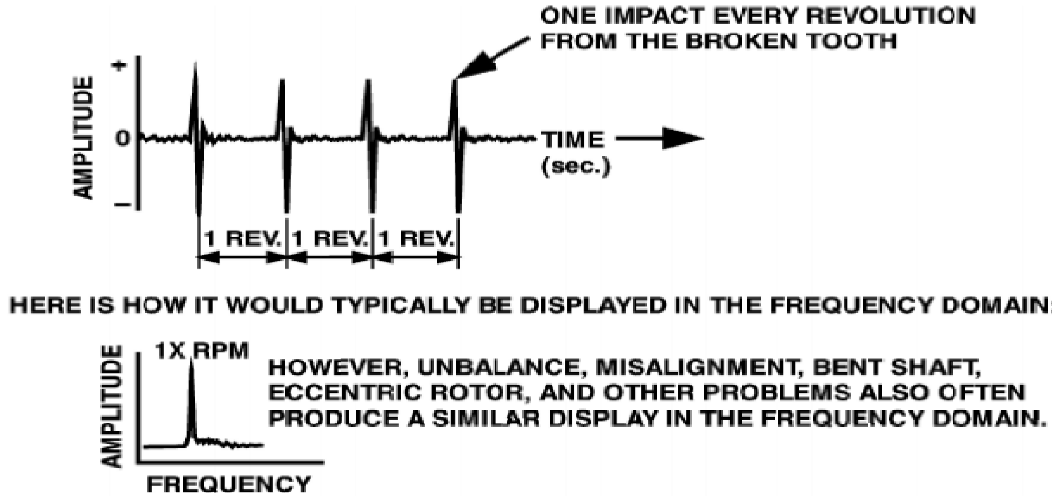
$F = 1/P$

$P = 1/F$

$FP = 1$



TWF Analysis & Frequency Calculation



If the time between each impact was given as 5 milliseconds (.005 sec), what is the frequency?

$$F = \frac{1}{T}$$

$$= \frac{1}{.005 \text{ SECOND/CYCLE}}$$

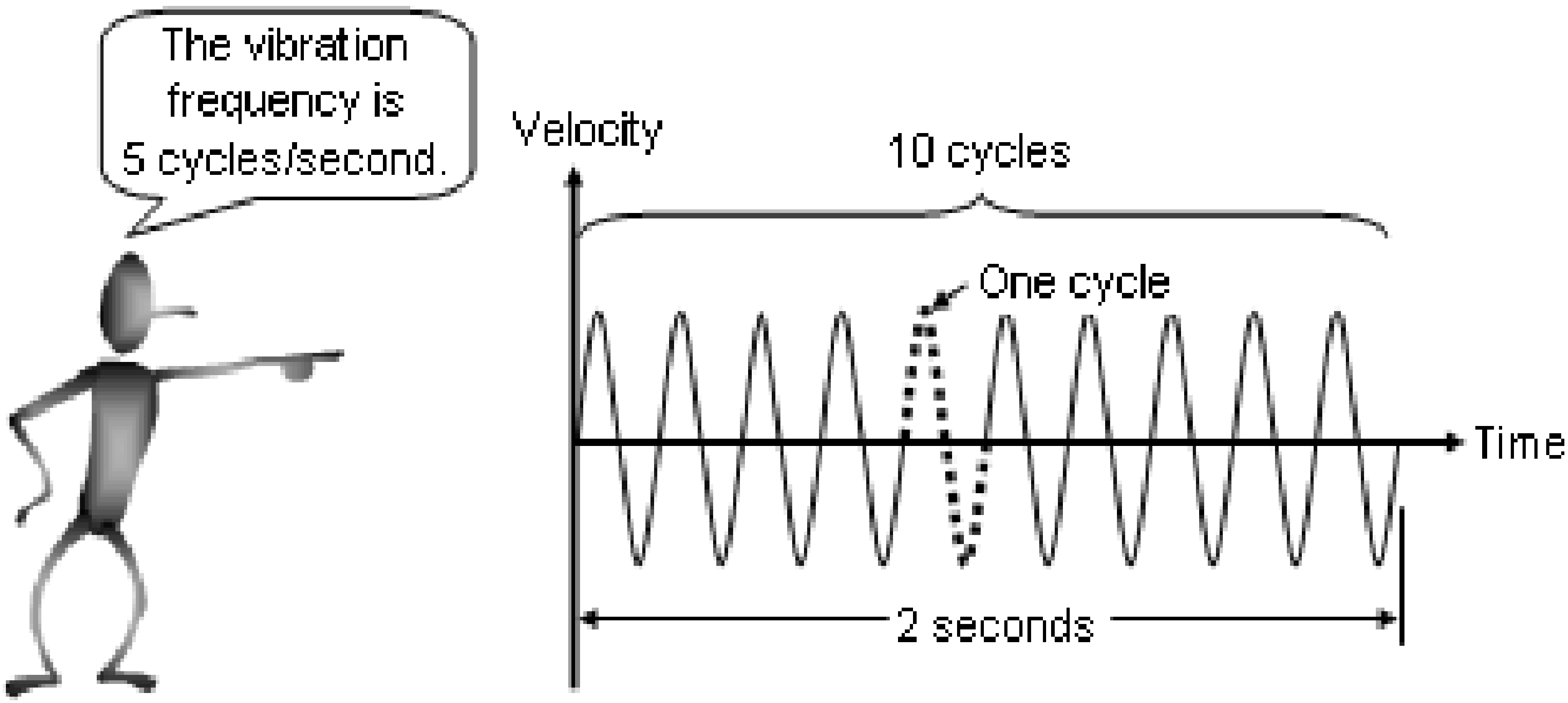
= 200 CYCLES/SECOND

= 200 Hz

= 200 CYC/SEC X 60 SEC/MIN

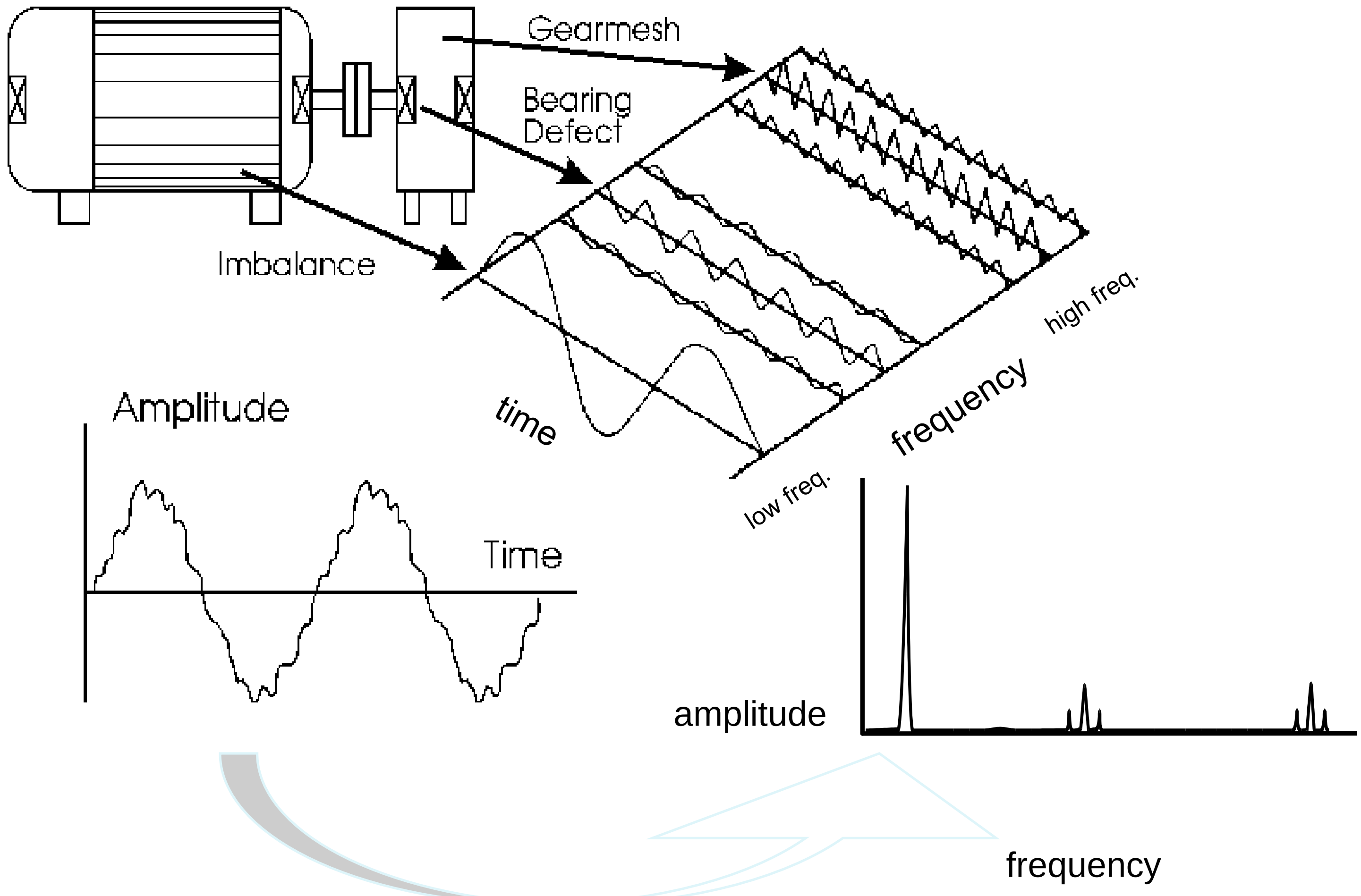
= 12,000 CPM

Relationship of time and frequency



What is the period or time?

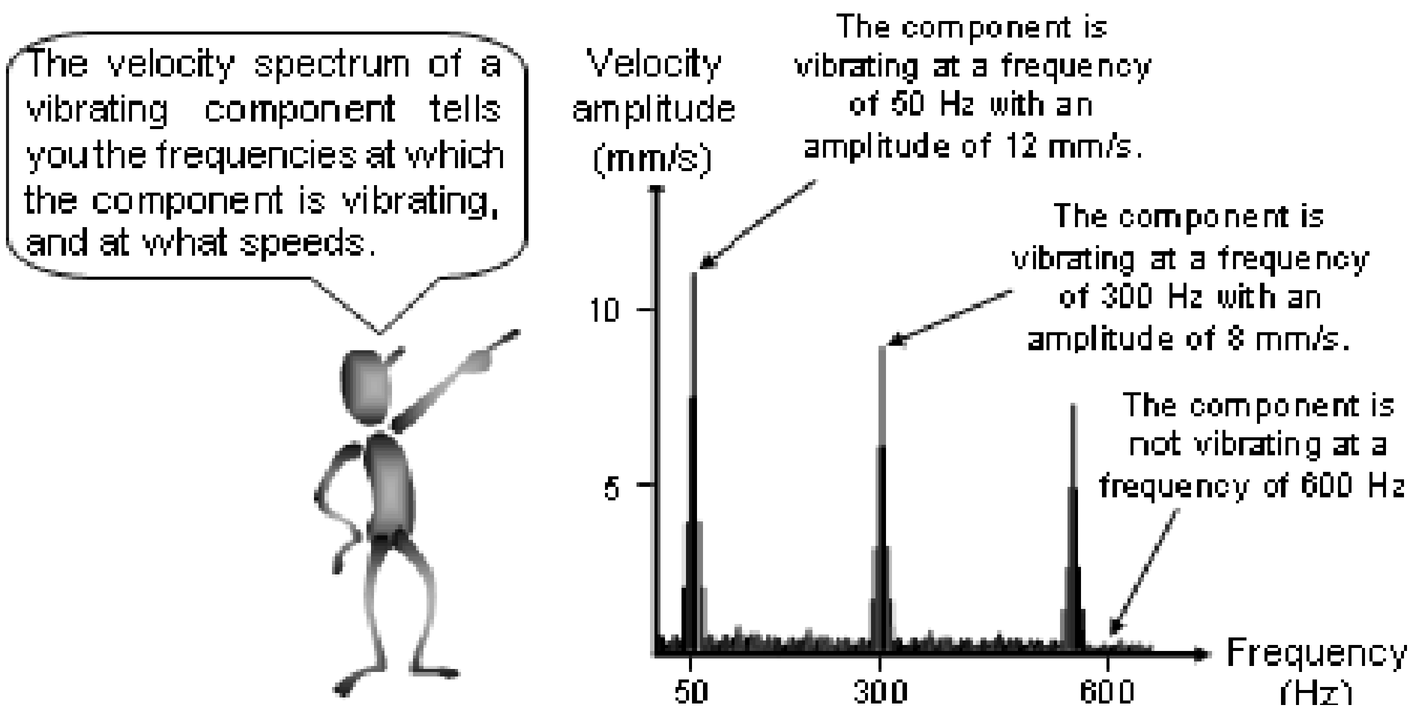
Combining Sources



Frequency – Spectrum

-The graphical display of the frequencies at which a machine component is vibrating, together with the amplitudes of the component at these frequencies.

- The information a spectrum contains depends on the **Fmax** and **resolution** of the spectrum.



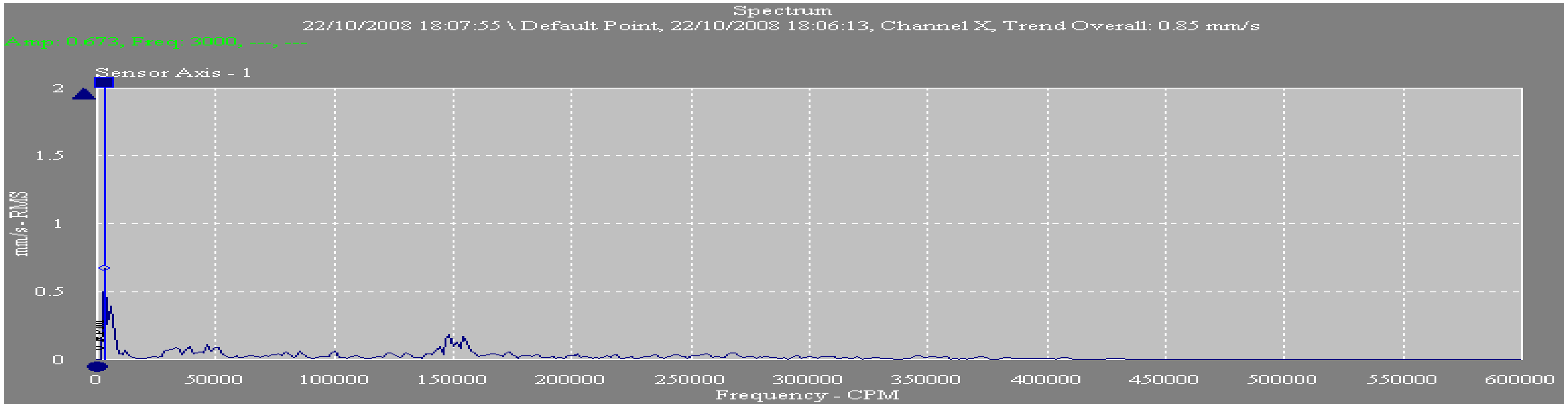
Defining FFT spectral parameters...

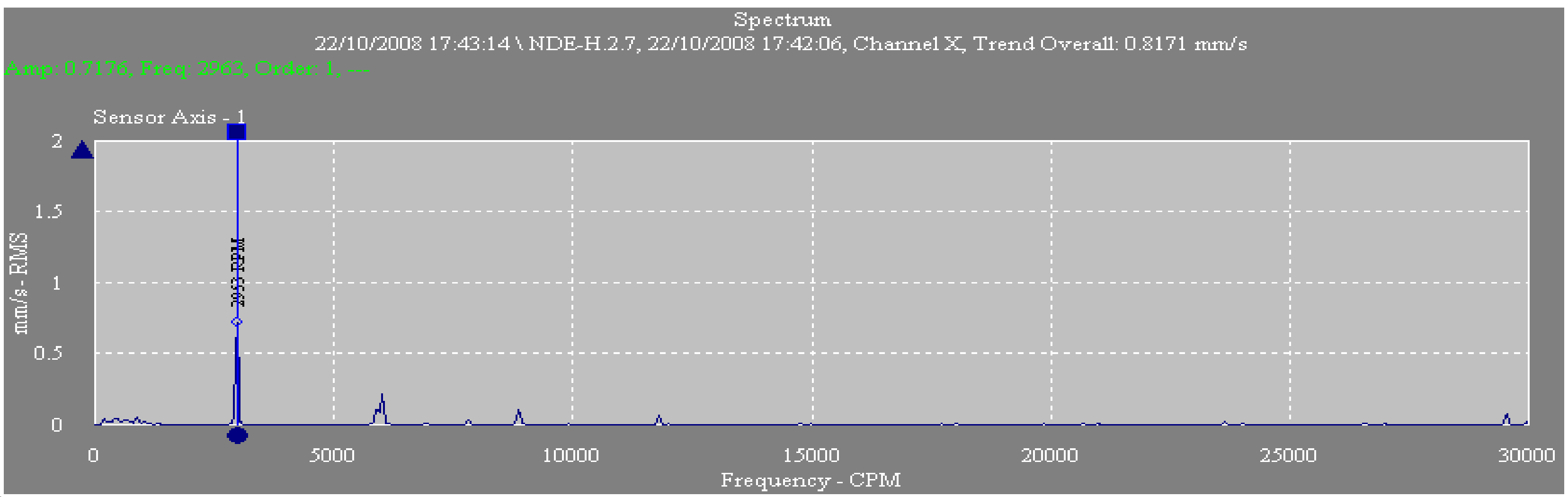
- **Maximum Frequency**: The *maximum* range of vibration frequencies to be analysed
- **Frequency Units**: Hz, CPM or Order
- **Number of Lines of Resolution**: The accuracy of displayed vibration frequencies
- **Number of Spectral Averages**: How many FFT's are taken and amplitude-averaged to minimise random and transient events

Selecting correct F_{max}

- Most important FFT decision
- Must be high enough to include all significant problem-related frequencies. We cannot afford to miss anything!
- The higher the F_{max}, the less accuracy between frequency components

Effect of improper F_{max}





FFT lines of resolution

- Determines frequency accuracy by setting the "sharpness" used in obtaining the FFT
- Typical FFT analysers offer choices of:
  - 25, 50, 100, 200, 400, 800, 1,600, 3,200, 6,400, and 12,800 lines
- Frequency range (0 to F_{max}) is divided equally by the number of these lines or bins

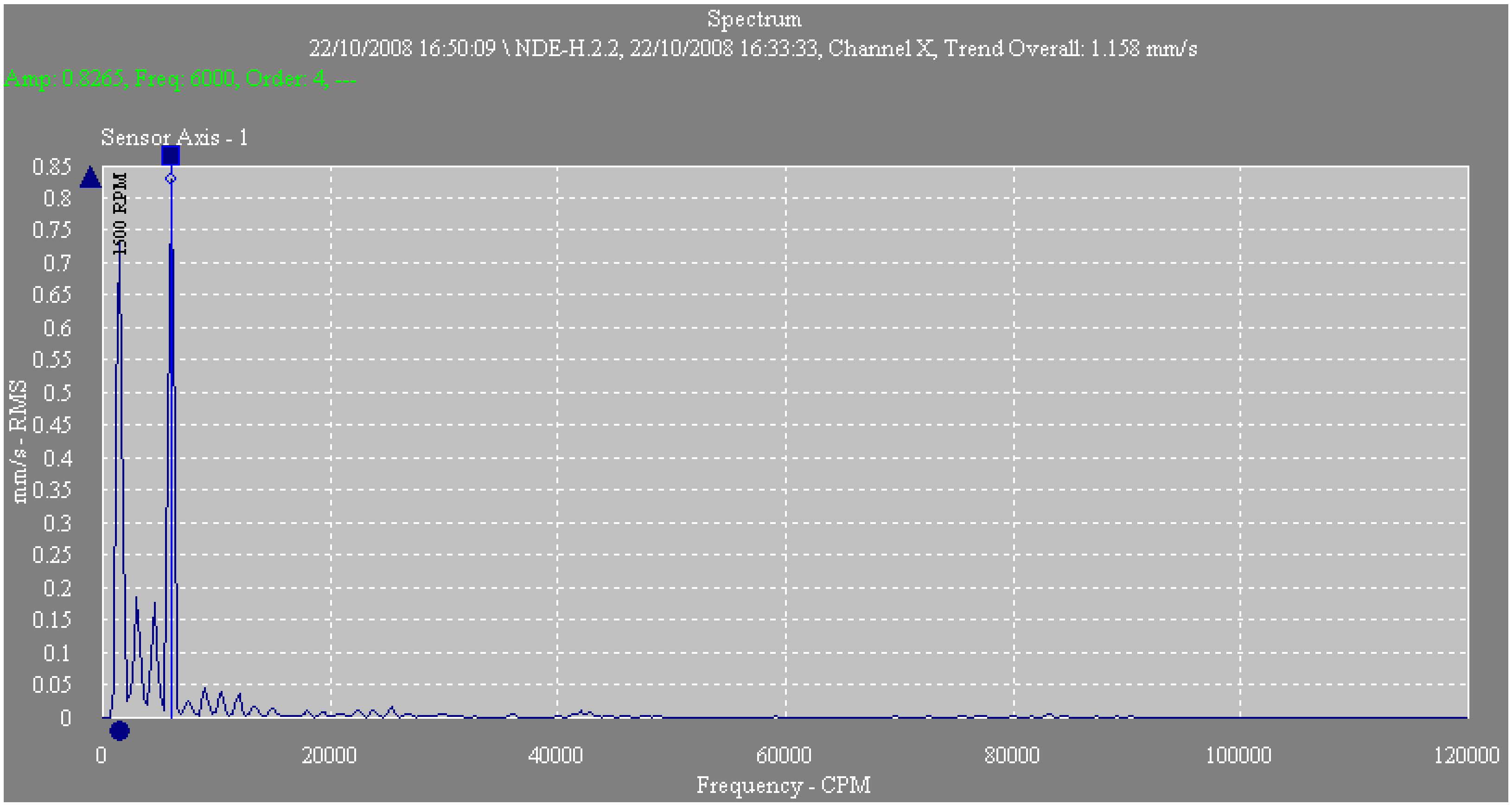
Frequency resolution

- For an F_{max} of 2,000 Hz (120,000 CPM) with 400 lines, the Resolution = 5 Hz (300 CPM) per bin

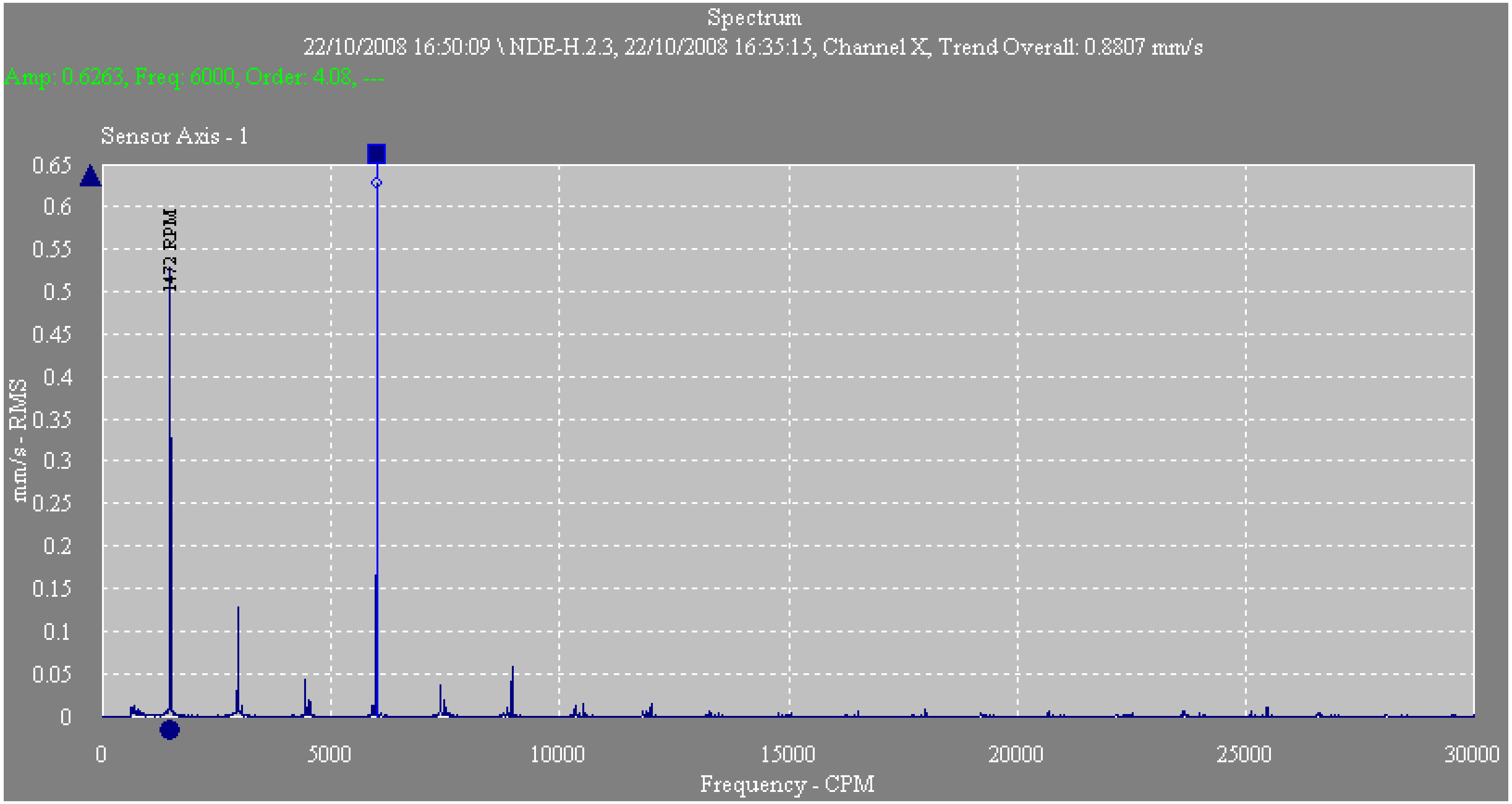
- Every vibration frequency present within a given 5 Hz (300 CPM) span will be averaged together and shown as one peak

- Thus, it is possible that more than one peak exists in a 5 Hz (300 CPM) span

400 lines, 0-12,000 cpm spectrum with "1,500 rpm" component



3,200 lines, 0–30K cpm spectrum shows actual 6K cpm component



Relationship between F_{max}, lines, and resolution

- Increasing F_{max} gives worse Resolution
- Decreasing F_{max} gives better Resolution
- Increasing Lines gives better Resolution
- Decreasing Lines gives worse Resolution
- The better the Frequency Resolution, the longer it takes to obtain the FFT reading and the more memory it requires to store

Spectral averaging

- More than one set of data is taken for a given FFT reading

- These sets of data are averaged together to help eliminate the influence of transient or random vibrations in the FFT that can confuse the data readings

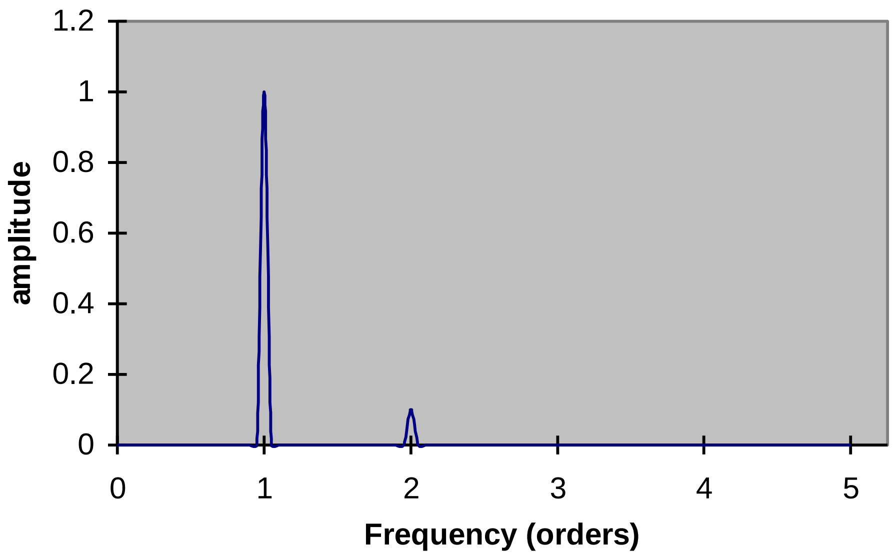
- The number of datasets is usually 2, 4, or 8

- Can go much higher as need arises

Basic Diagnosis

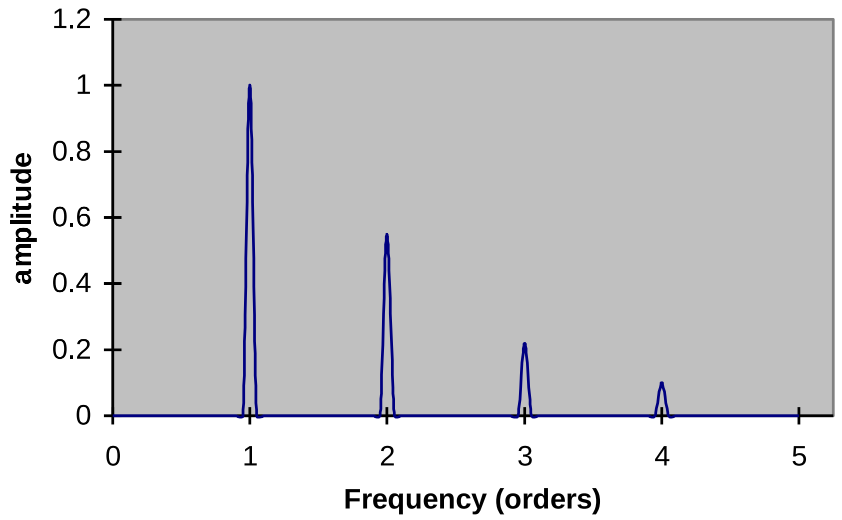
Unbalance Spectrum

- Single peak at running speed
- Little or no other vibration
- A "pure" example



Basic Diagnosis

- Misalignment Spectrum
  - Peak at running speed
  - Multiples of running speed



The Missing Link – Phase

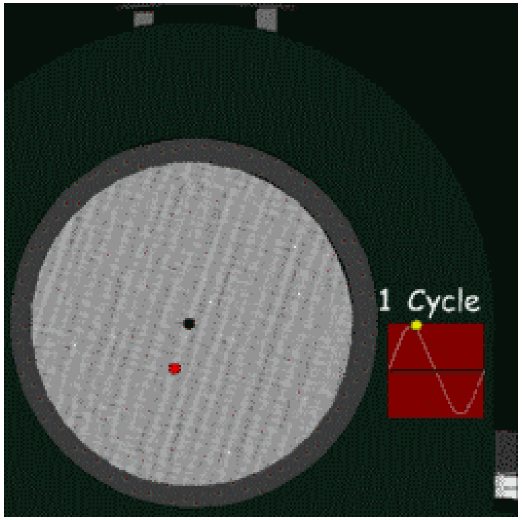
- Vibration frequency indicates the potential source of the problem
- Vibration amplitude indicates the severity of the problem.
- Phase indicates ***how*** a machine is moving

Phase

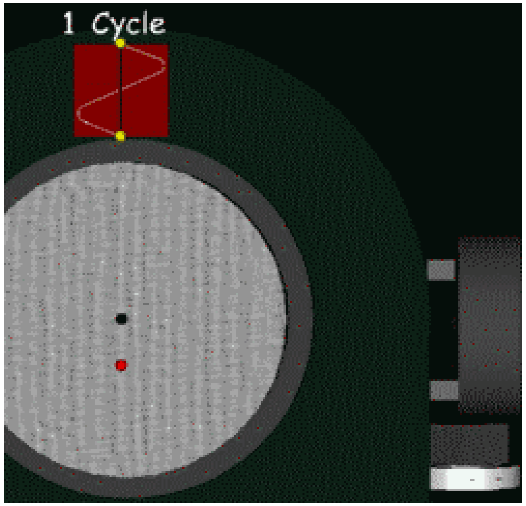
- The relationship of the movement of part of a machine to a reference – for example the position of the shaft as it rotates
- The relationship of the movement between one or more points on a machine

Vibration Phase

The relationship of the movement of part of a machine to a reference – for example the position of the shaft as it rotates



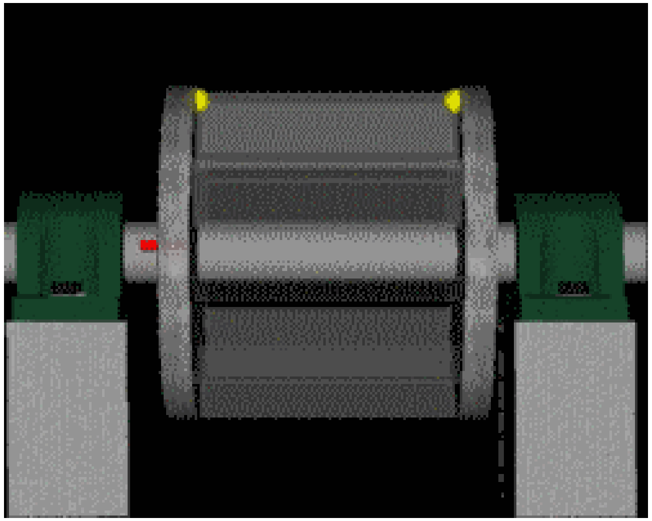
Vertical mounting



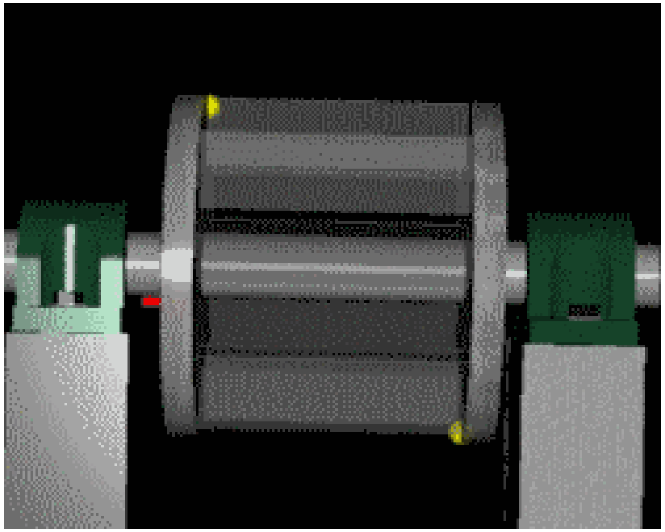
Horizontal mounting

Vibration Phase

The relationship of the movement between one or more points on a machine



In-phase



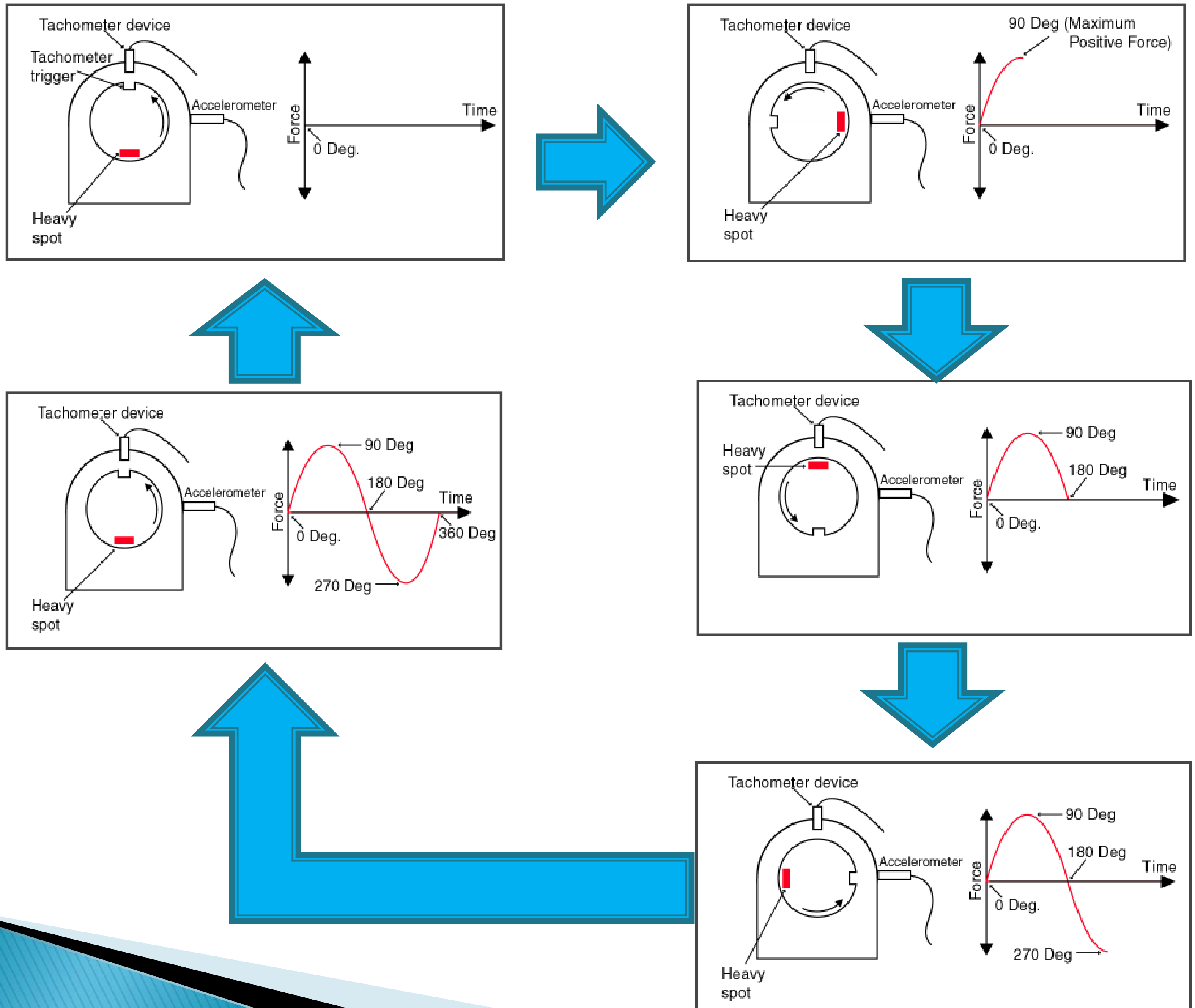
180 out-of-phase

Phase

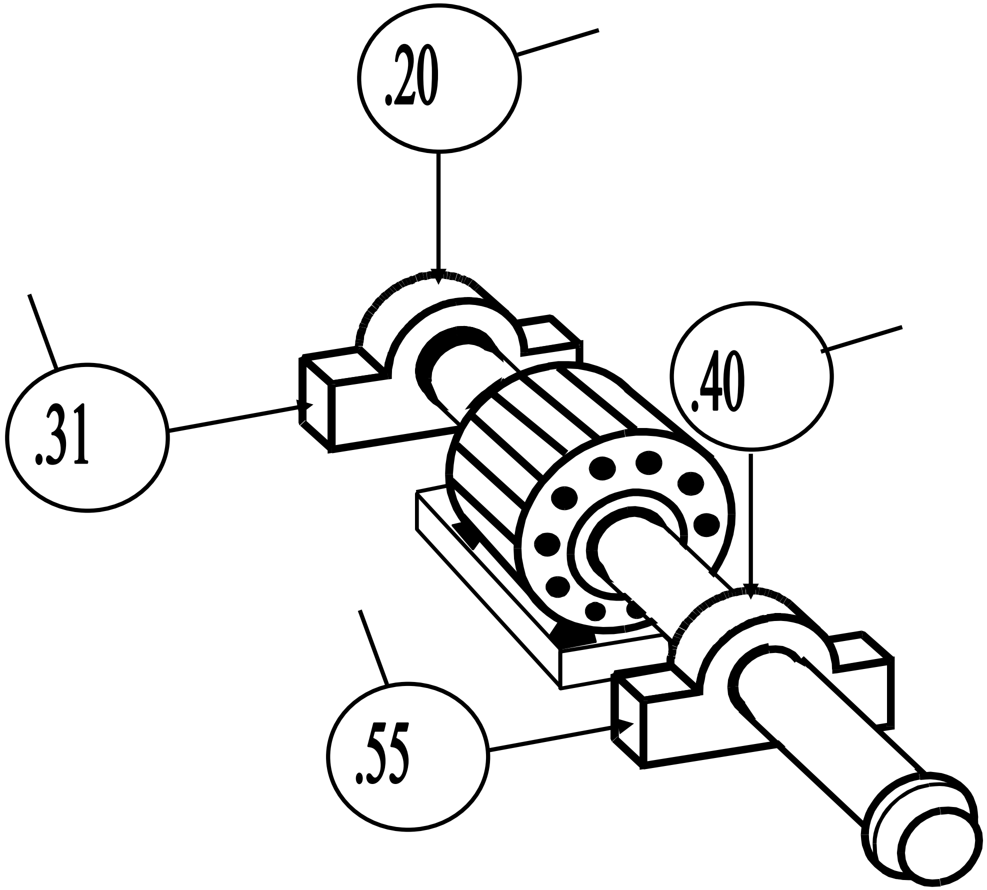
- Once we know “how” a machine is moving, we know WHY

- Amplitude and frequency provide 80% accuracy when performing a diagnosis or analysis – adding phase increases accuracy to better than 95%

Phase example



Phase as an Analysis Tool
Unbalance

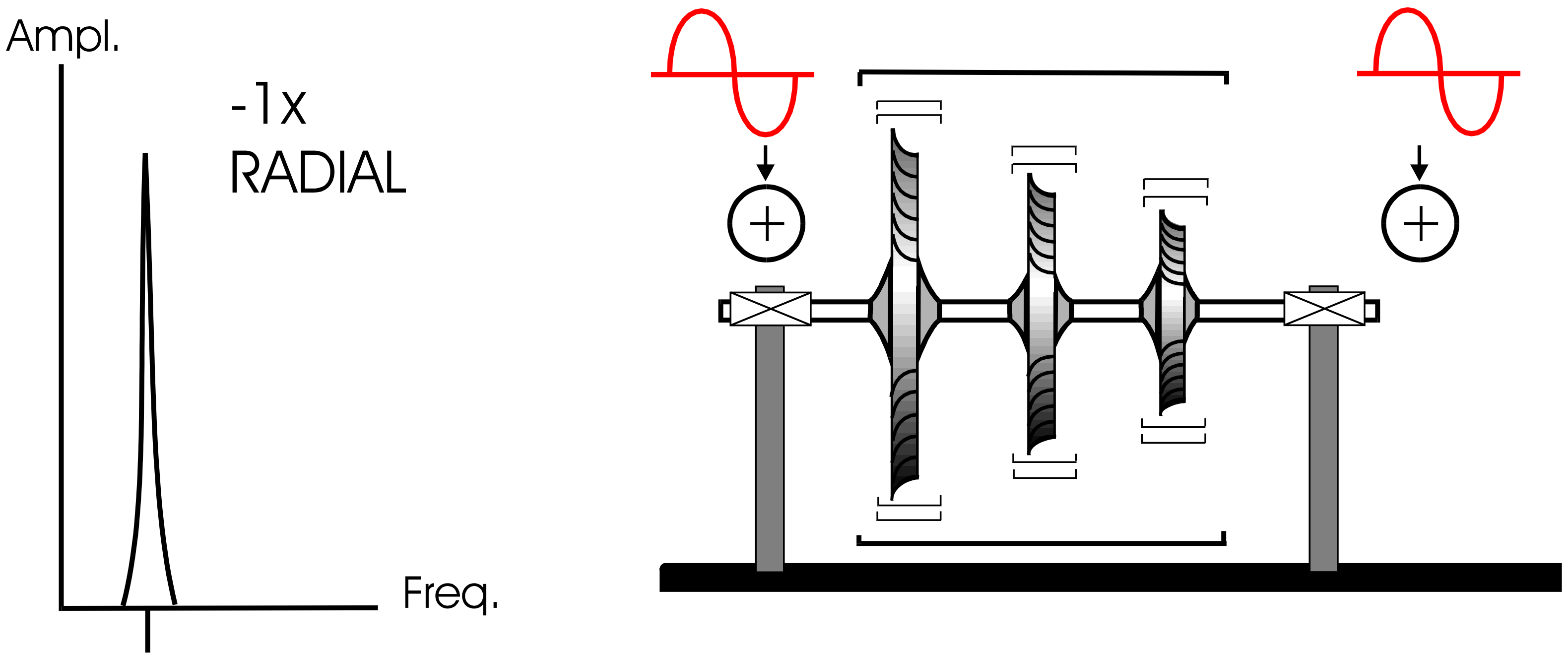


Sources of Vibration

Specific patterns in the spectral signatures are recognized as being related to specific machine problems.

▪ Misalignment	1x or 2x shaft speed
▪ Imbalance	1x
▪ Bent shaft	1x or 2x
▪ Looseness	2x to 10x
▪ Gear Mesh	number of teeth x RPM
▪ Bearing Defects	bearing defect frequencies

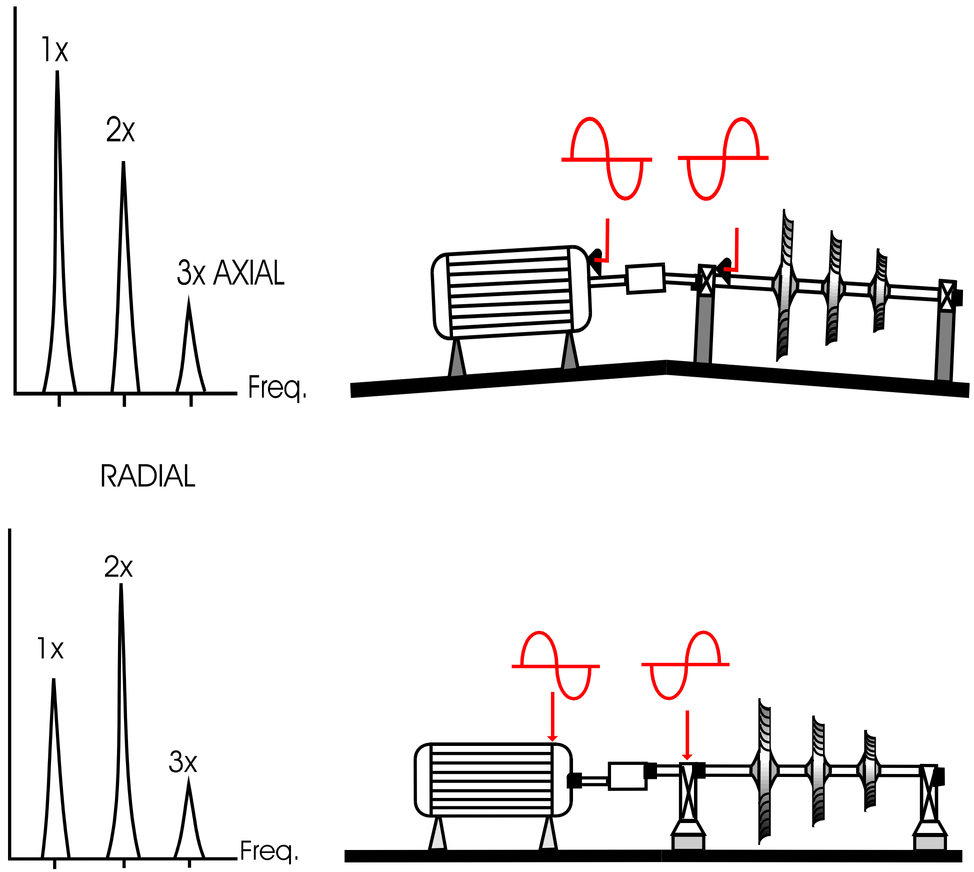
Mass Imbalance



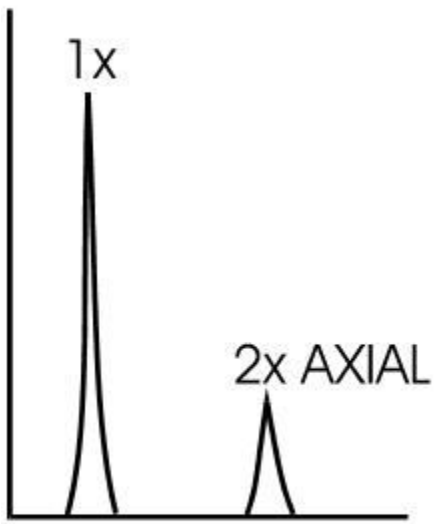
Misalignment

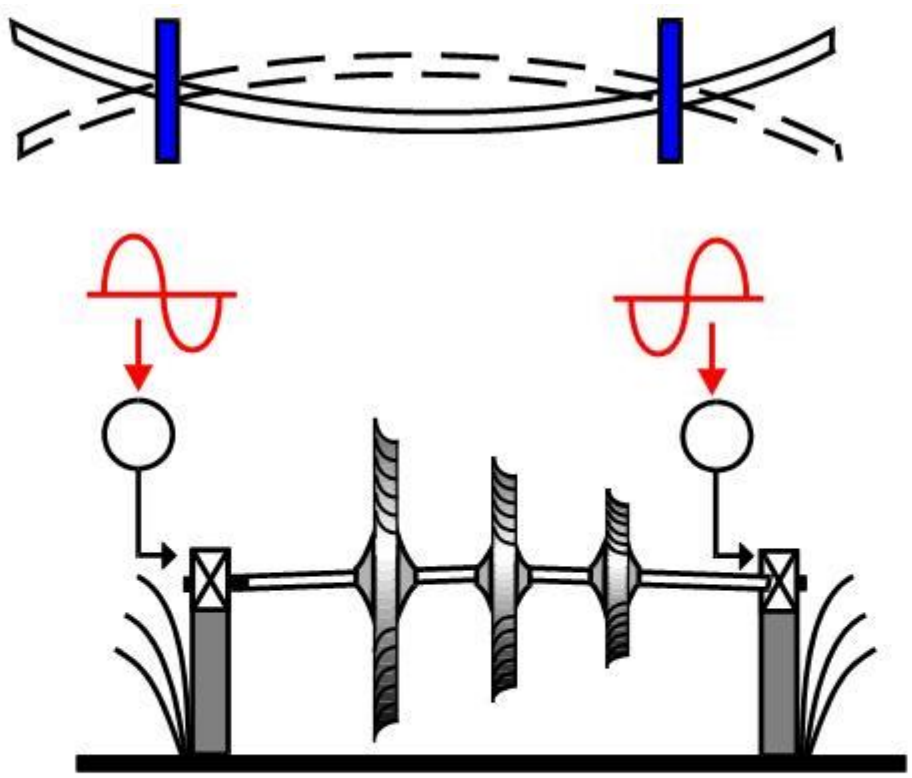
Angular Misalignment

Parallel Misalignment

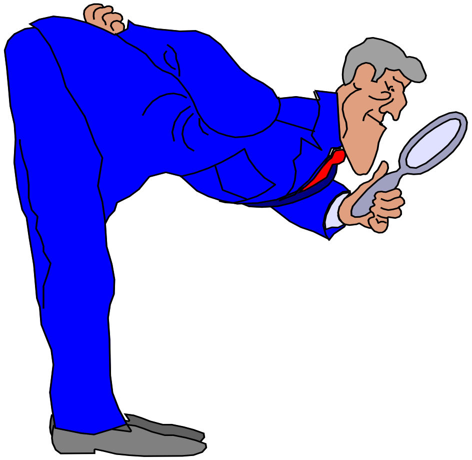


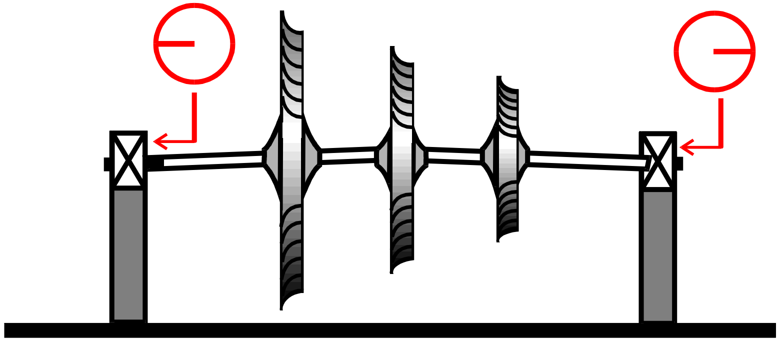
Bent Shaft

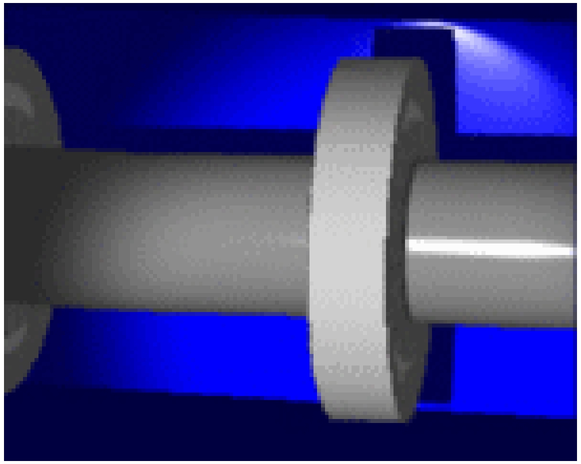


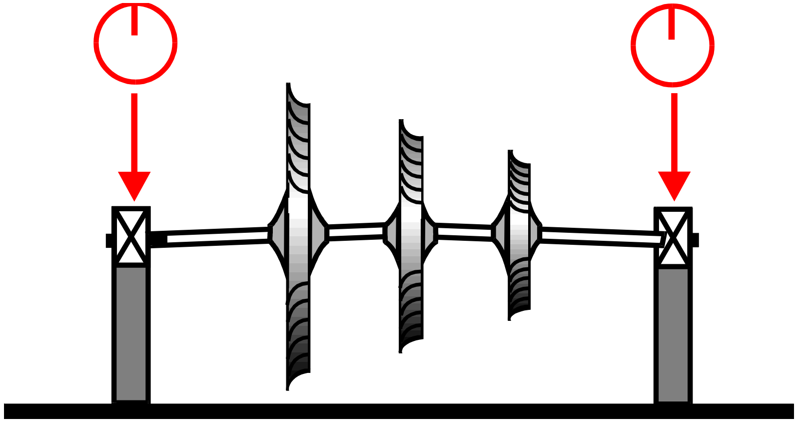


Bent Shaft – Diagnosis

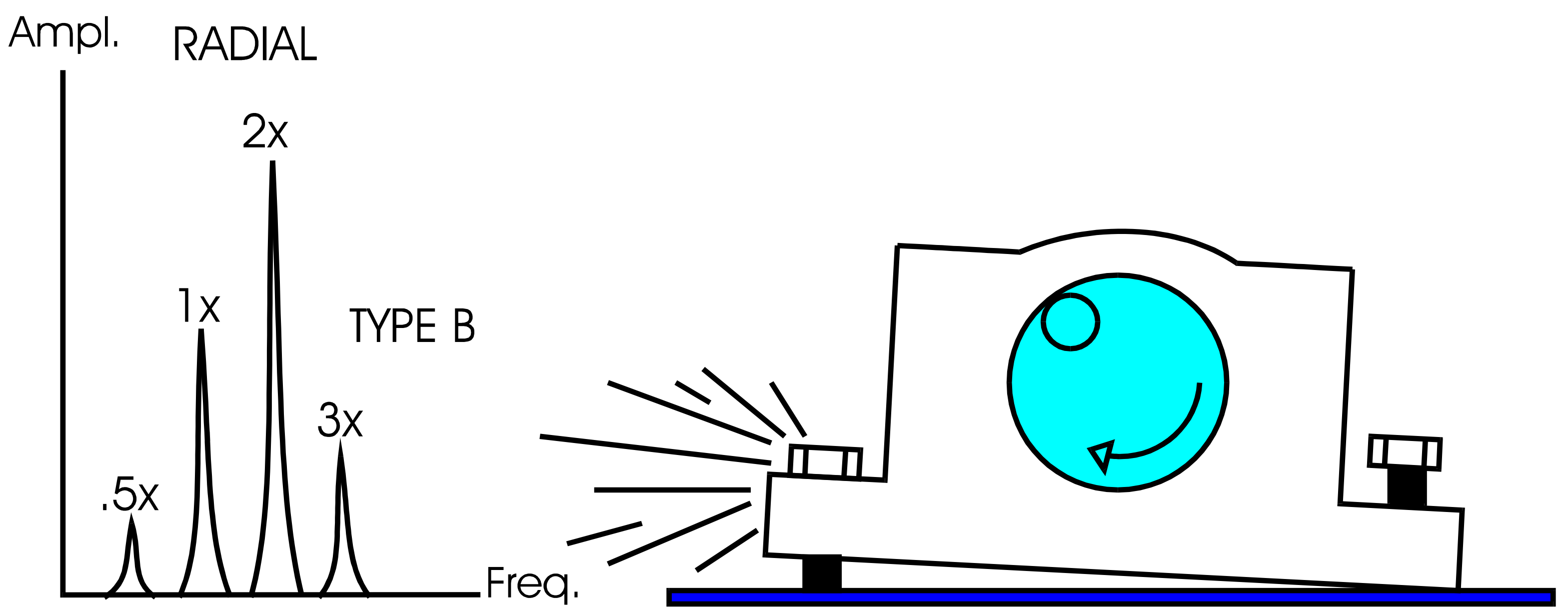








Mechanical Looseness

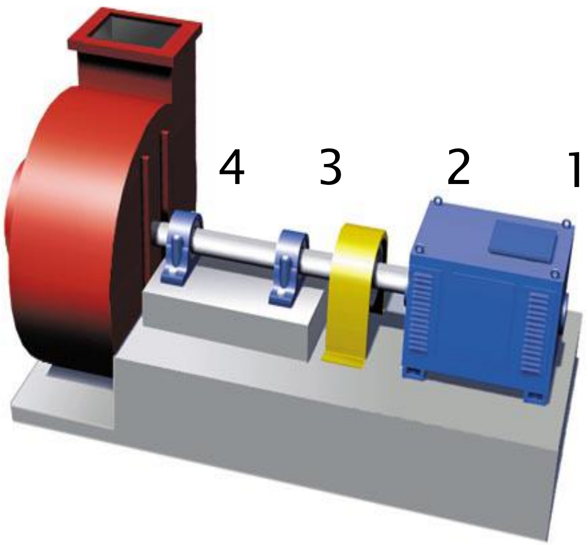


5 Typical Vibration Instrumentation

Objectives:

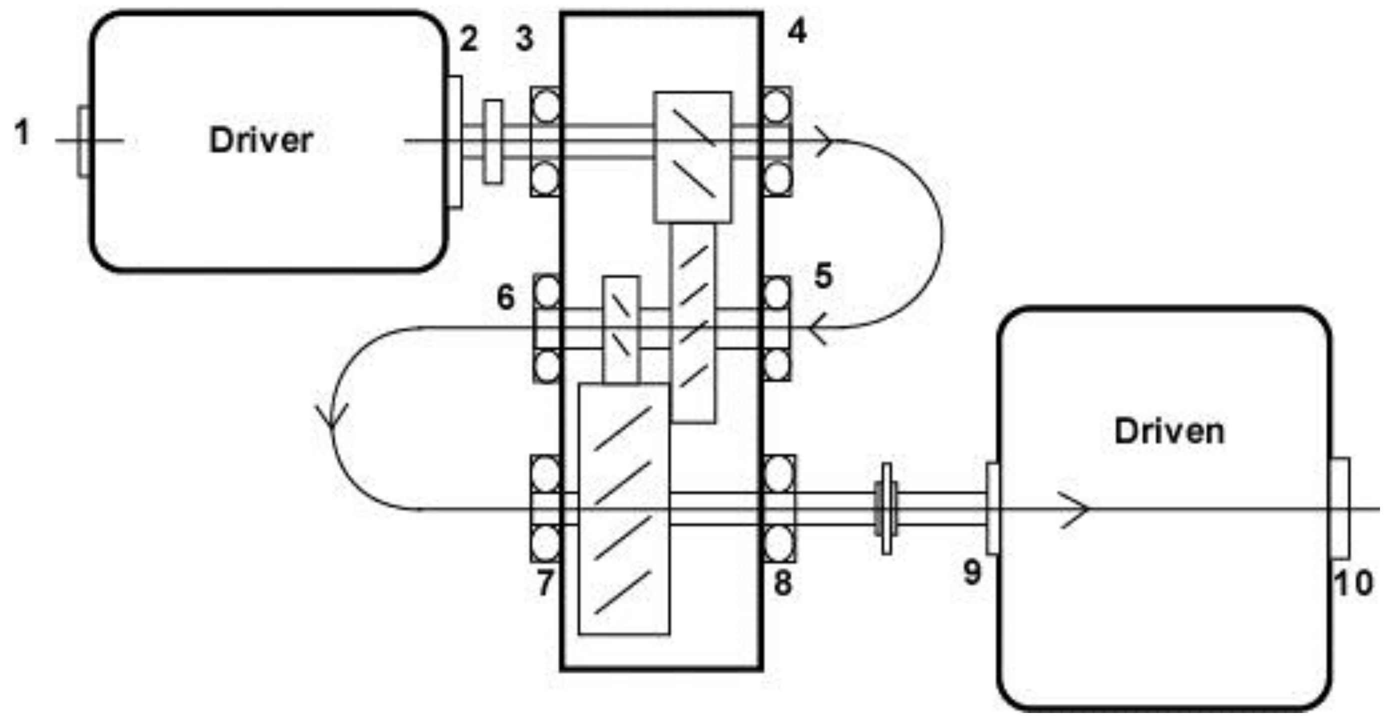
- Know the different type of vibration monitoring system
- Understand the application of different type of vibration transducers

Bearing Location



1	2	3	4
Motor Outboard Bearing	Motor Inboard Bearing	Driven Inboard Bearing	Driven Outboard Bearing
Motor Non-Drive End Bearing	Motor Drive End Bearing	Driven Drive End Bearing	Driven Non-Drive End Bearing

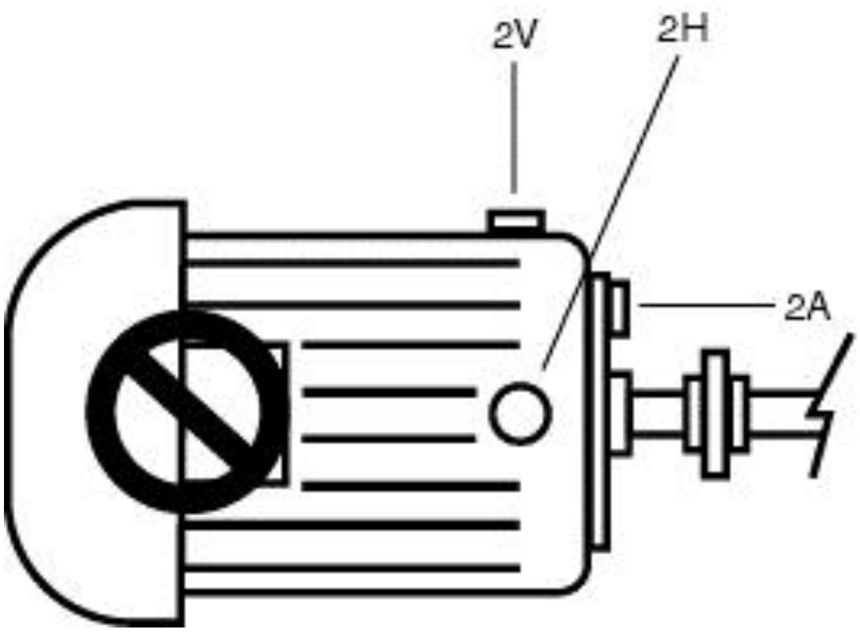
Measurement locations / identification



- Data collected at each bearing
- Measurement POINT numbering follows flow of power.

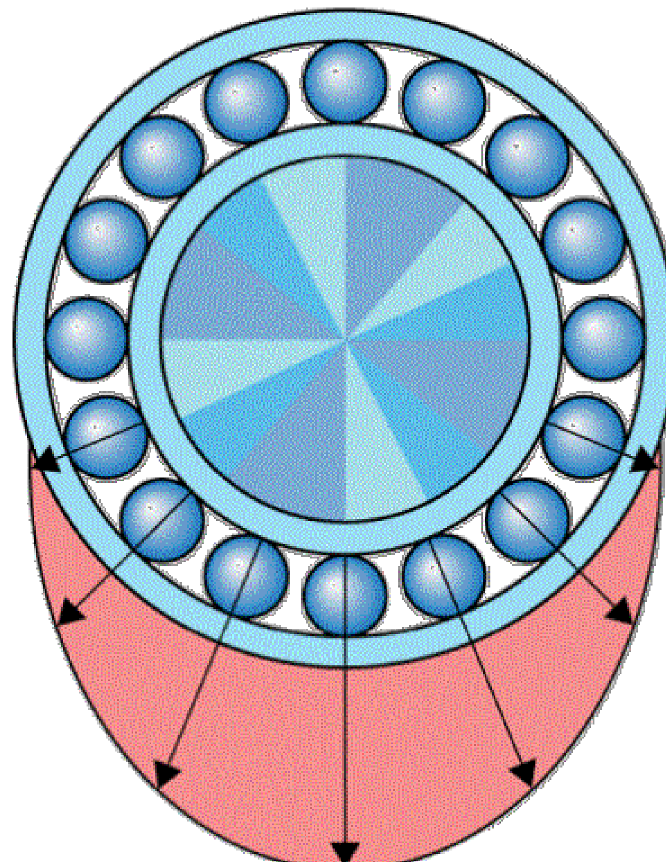
Motors with bell housing

- Limited access may mandate only one axial measurement per shaft plane in some field applications.
- Note that in this example, the correct numbering conventions (non-drive end being labeled #1, drive end labeled #2, etc.) are preserved, even though the #1 measurement POINT is not available for data acquisition.



Measuring Point Locations – Peakvue

- Measurements are most definitive when performed in the bearing's load zone
- Best results are obtained using permanently mounted transducers
- A common error is the taking of measurements using flat surfaced, rare earth magnets on rounded machinery surfaces

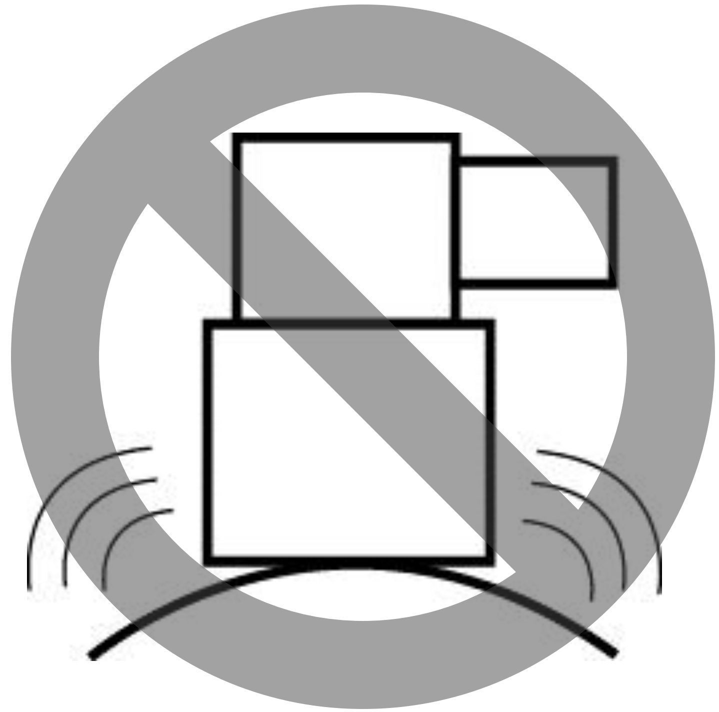


gravity defining the bearing's load zone

Measurement location

- Wrong – flat transducer magnets mounted on uneven surfaces allow excessive transducer freedom, resulting in non-repeatable data

- Consistency is imperative to a successful program



Consistency

Consistency is imperative to a successful program.

- Consistent sensor placement (location)
- Consistent sensor contact angle
- Consistent machine speed
- Consistent surface condition for sensor placement
- Use of extension rods and hand-held probes do not promote consistency

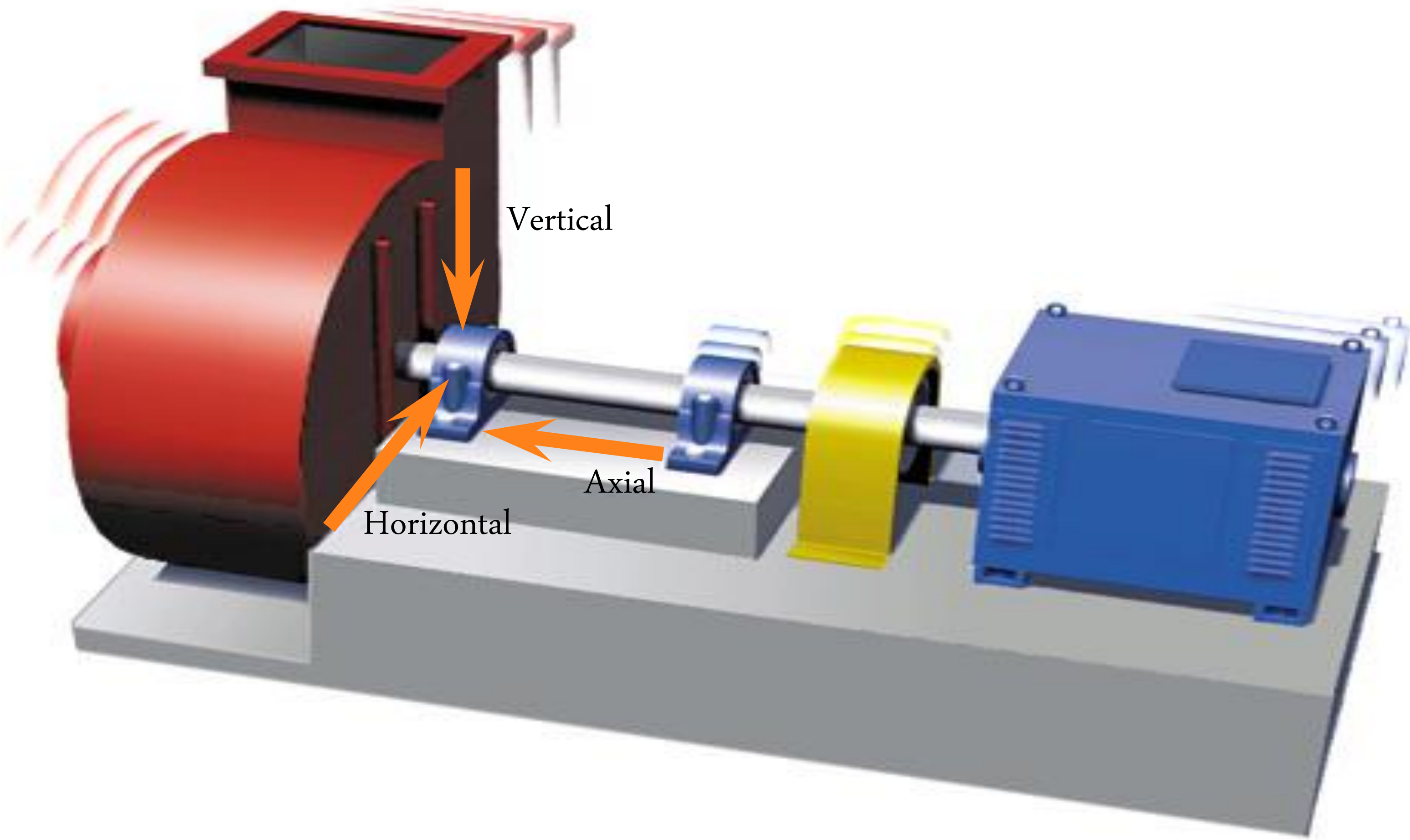
Problems encountered when using magnetic mounted sensors:

- non-ferrous machinery frame (magnet will not cling)
- not taking data at exactly the same location
- heat exchanger fins obstructing probe access
- poor access to optimum measurement POINT location

Measurement locations on machinery

- Horizontally-mounted machinery: a measurement should be taken in the horizontal and vertical planes of each bearing, plus a minimum of one axial position for each shaft in a multiple-shaft system
- Vertically mounted pumps and machinery should have a sample position measured radially on each bearing (horizontal position), preferably displaced 90° from the pump's discharge plane
- **Maintain distance from motor's electrical termination connection**

Shaft Orientation



ISO 2372 Vibration Diagnostic Table (Horizontal Shaft)

	Excessive **Horizontal** Vibration Indicates:	Excessive **Vertical** Vibration Indicates:	Excessive **Axial** Vibration Indicates:	Excessive **Structural** Vibration Indicates:	Notes
Imbalance	YES	NO	NO	NO	Horizontal > Axial
Misalignment	NO	YES	YES	NO	Axial > Horizontal
Looseness	YES	YES	NO	YES	Vert. $\geq$ Horizontal
Electrical Faults Measured as Vibration					To detect an electrical problem: Turn off machine power and monitor vibration. If the vibration immediately drops, the problem is electrical.

YES = ISO 2372
Unsatisfactory - Unacceptable Levels

NO = ISO 2372
Good - Satisfactory Levels.

ISO 2372 Vibration Diagnostic Table (Overhung – Horizontal Shaft)

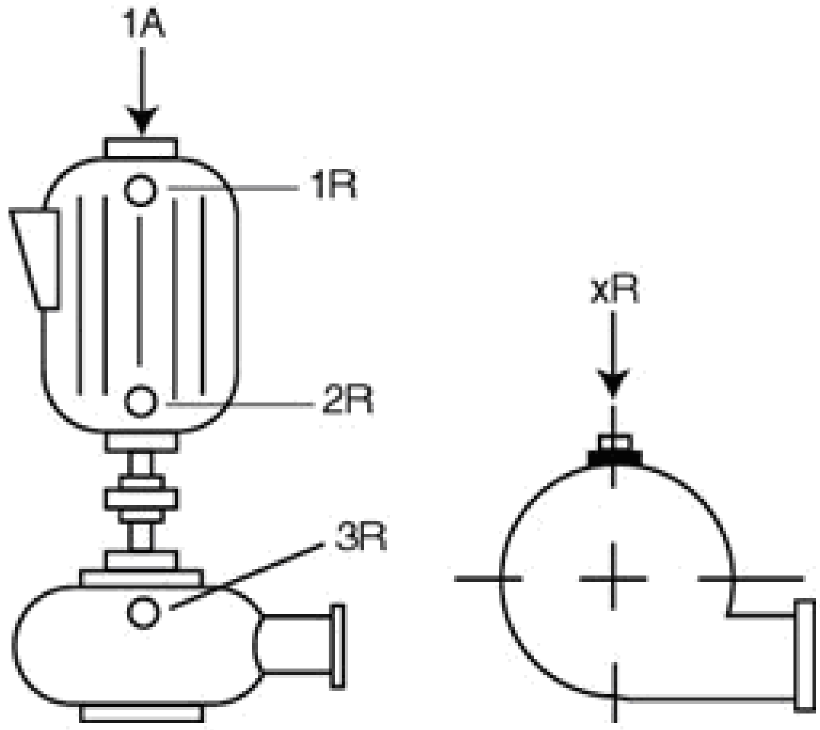
	Excessive **Horizontal** Vibration Indicates:	Excessive **Vertical** Vibration Indicates:	Excessive **Axial** Vibration Indicates:	Excessive **Structural** Vibration Indicates:	Notes
Imbalance	YES	NO	YES	NO	Hor. & Axial > Vert
Misalignment	YES	NO	YES	NO	Hor. & Axial > Vert
Looseness	YES	YES	NO	YES	Vert. ≥ Horizontal
Electrical Faults Measured as Vibration					To detect an electrical problem: Turn off machine power and monitor vibration. If the vibration immediately drops, the problem is electrical.

On an overhung machine, imbalance and misalignment may display similar characteristics. Use phase measurements to differentiate between the two.

YES = ISO 2372
Unsatisfactory - Unacceptable Levels

NO = ISO 2372
Good - Satisfactory Levels.

Vertically Mounted Equipment



ISO 2372 Vibration Diagnostic Table (Vertical Shaft)

	Excessive **Radial 1** Vibration Indicates:	Excessive **Radial 2** Vibration Indicates:	Excessive **Axial** Vibration Indicates:	Excessive **Structural** Vibration Indicates:	Notes
Imbalance	YES	NO	NO	NO	Radial > Axial
Misalignment	YES	NO	YES	NO	Axial > Radial
Looseness	YES	NO	NO	YES	
Electrical Faults Measured as Vibration					To detect an electrical problem: Turn off machine power and monitor vibration. If the vibration immediately drops, the problem is electrical.

Radial 1 and Radial 2 positions differ by 90 degrees.

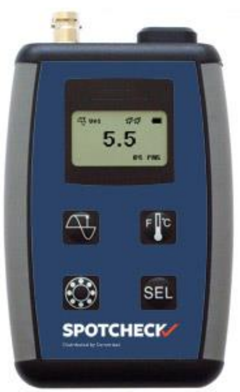
YES = ISO 2372
Unsatisfactory - Unacceptable Levels

NO = ISO 2372
Good - Satisfactory Levels.

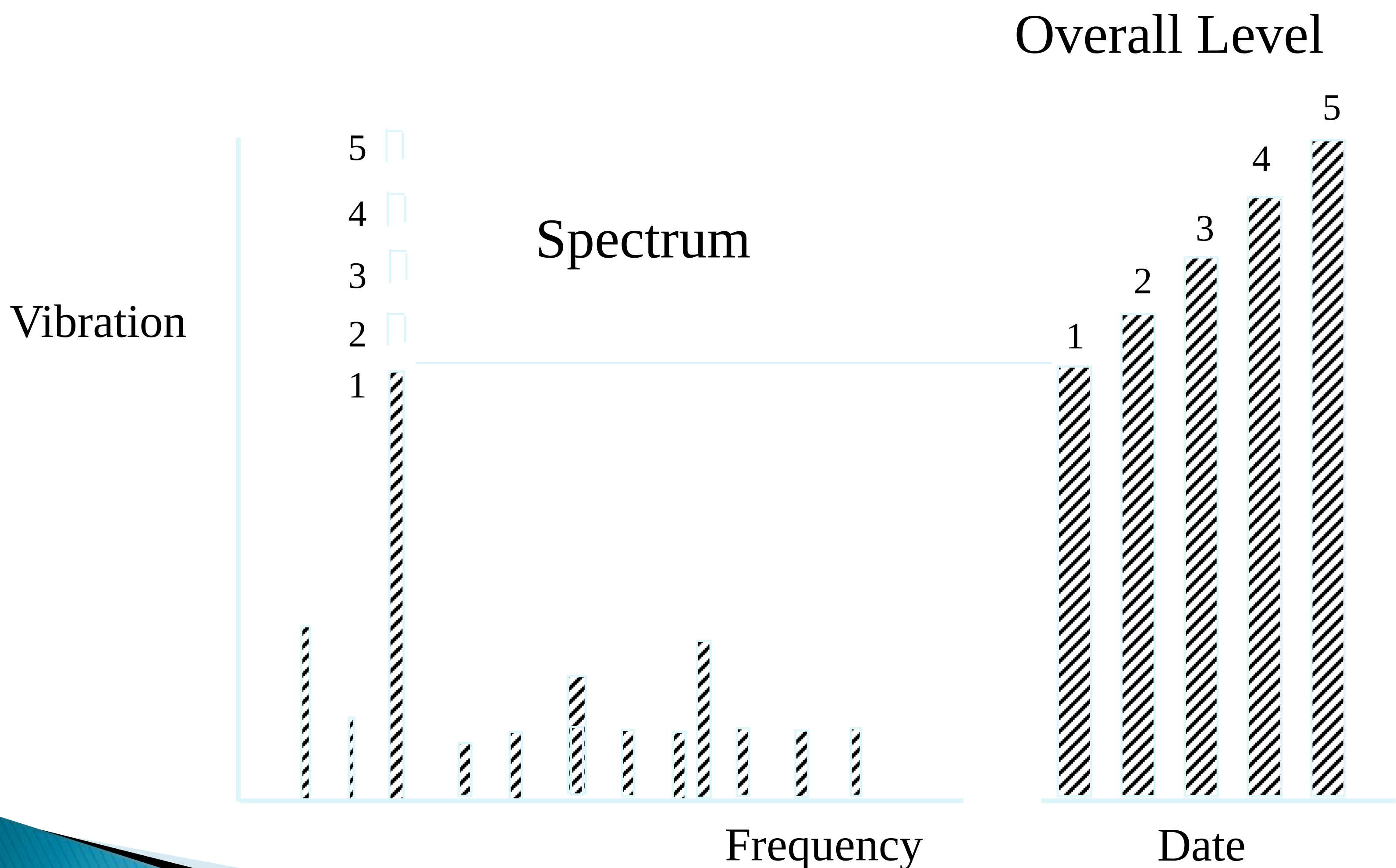
Choosing Your Instrumentation

- What do you want to achieve?
- What is your present and future Budget for equipment & Training?
- Person power? Knowledge level?
- Number of machines to be monitored?
- Type of machines to be monitored?
- Environment?

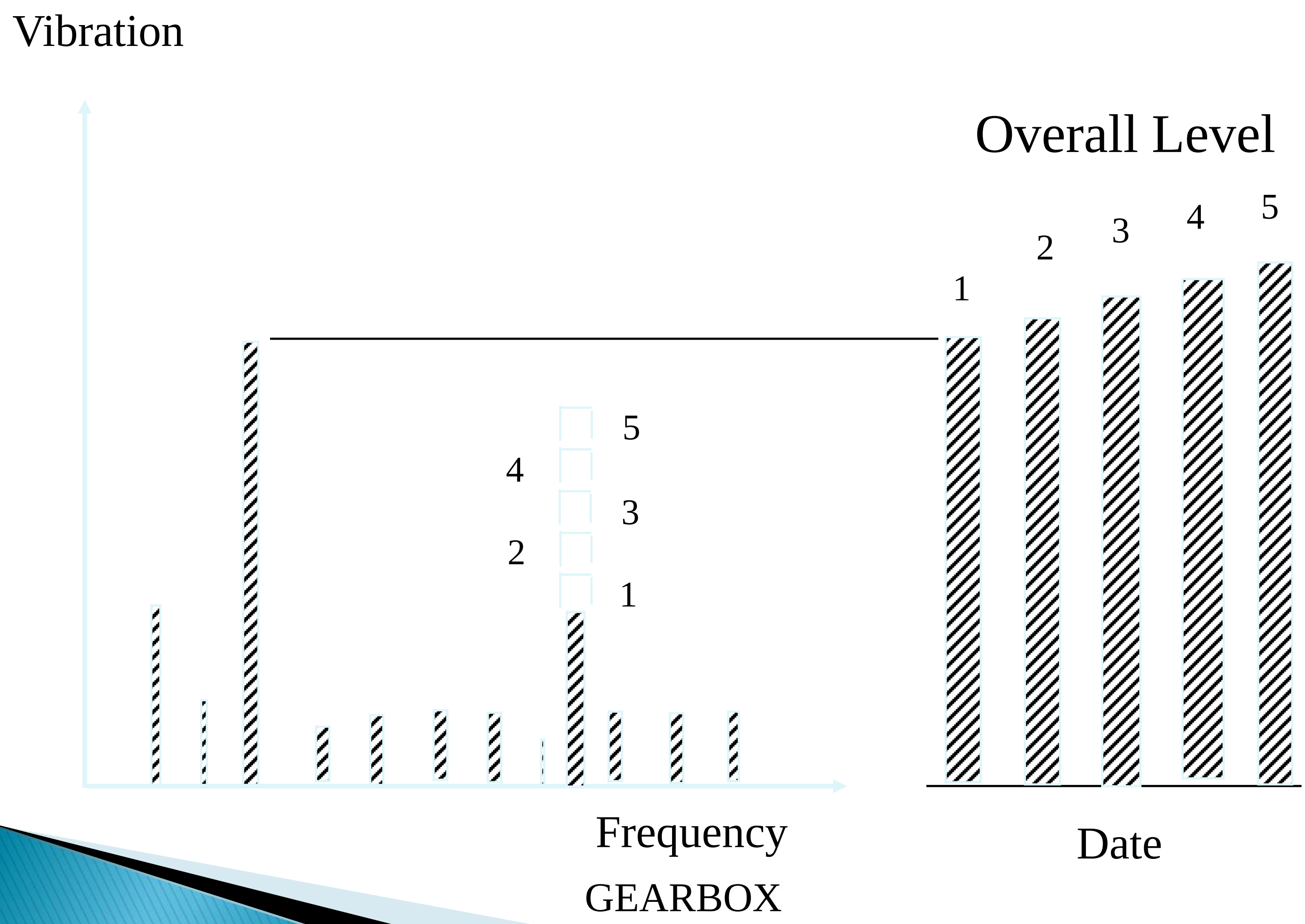
Vibration Meters



Increase in vibration due to unbalance



Limitations of Measuring Overall Vibration Only



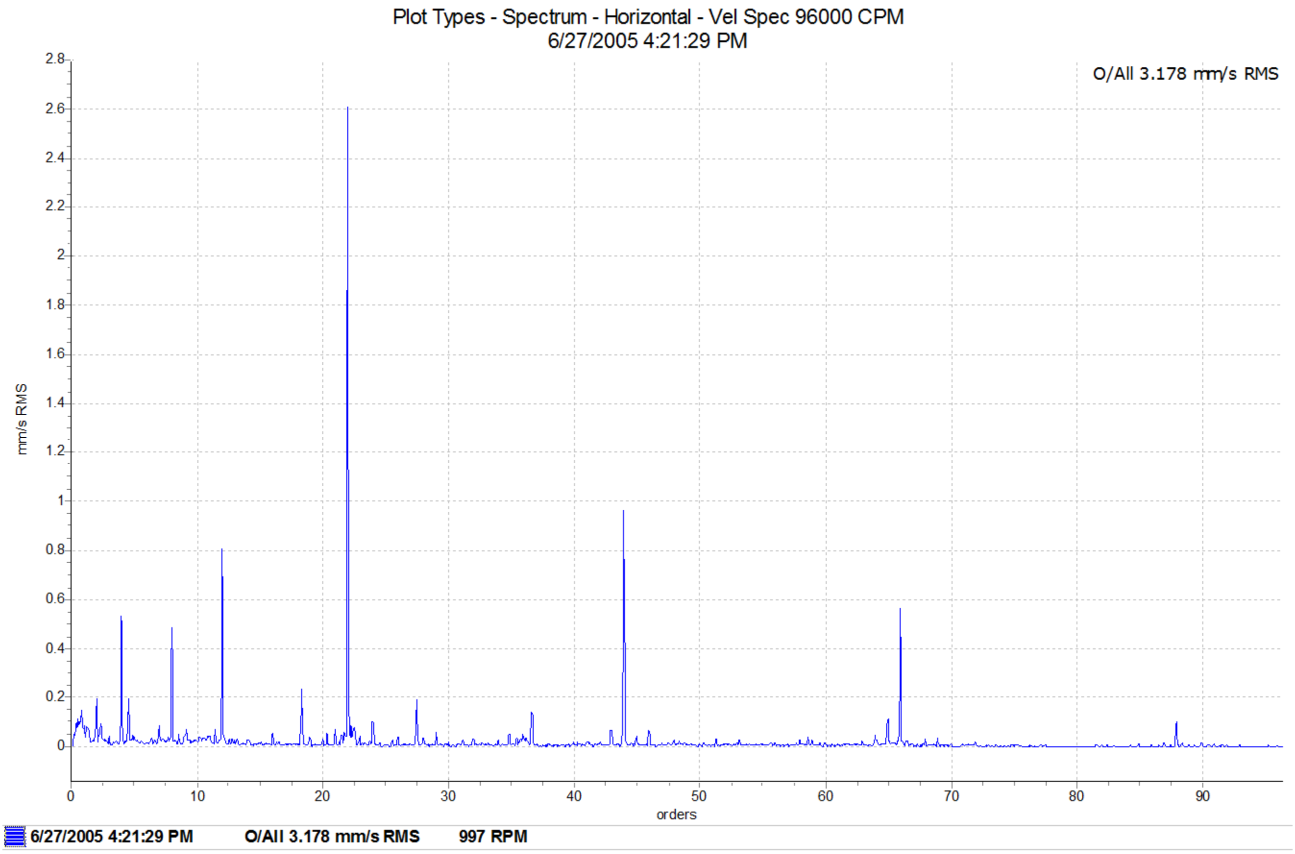
Criteria for Instrument Comparison

- Portability
- Relative cost
- Ease of use
- Frequency & Dynamic range
- Measurement parameters
- Operation & Display types
- Transducer types
- Reference and/or Strobe light
- Software available

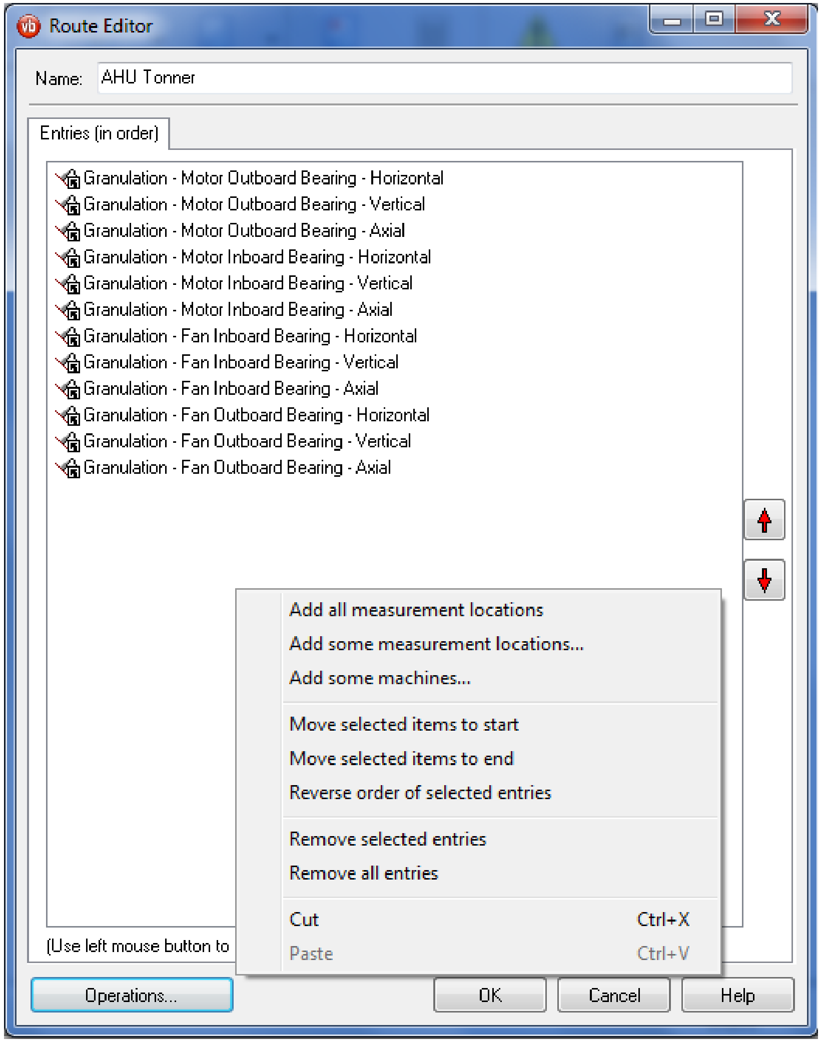
Portable Vibration Analyzer

- Data collector and software
- Data upload/download
- Can attach to permanent or roving transducers
- Database management
- Route management
- Data display
- Data reports

The computer and software



The route or tour



The exception report

Exception Report

Site:	Commtest - Factory Default
Folder:	Example
Issued:	1/9/2013 3:32:55 AM

Machine: **Alarm Types**	Danger

Alarm Types - Peak - Vertical - Demod (2-10kHz) 1000 Hz
650 Hz Warning by 119.9% (0.001172 g 0-pk) (Warning)
650 Hz Danger by 110.1% (0.005449 g 0-pk) (Danger)
Alarm Types - Numeric Alarm - Keypad Entry - Vibration Vel (mm/s)
Alert, < 3.5 mm/s, > 4 mm/s Alert (Alert)
Alarm Types - Waveform Alarms - Vertical - Vel Wfm 800 ms
Waveform True Pk-Pk Danger by 100.6% (1.409 mm/s) (Danger)
Alarm Types - Envelopes - Vertical - Vel Spec 200 Hz
Alarm Envelope, Alert, Spec, Velocity, 0.252 - 5.039 orders Exceeded by 110.9% (Alert)
Alarm Types - Bands - Vertical - Vel Spec 800 Hz
1X Danger by 134.1% (8.044 mm/s RMS) (Danger)

Machine: **Gear Assessment**	Danger

Gear Assessment - 3-G/Box In DE - Horizontal - Vel Spec 1600 Hz
Overall Alert by 116.7% (6.859 mm/s RMS) (Alert)
VR5 Warning by 147.7% (7.383 mm/s RMS) (Warning)
VR3.15 Warning by 234.4% (7.383 mm/s RMS) (Warning)
Primary GMF Danger by 109.8% (6.582 mm/s RMS) (Danger)
Gear Assessment - 3-G/Box In DE - Vertical - Vel Spec 1600 Hz
Primary GMF Danger by 129.6% (8.746 mm/s RMS) (Danger)
Fundamental Bearing Defect Frequencies Alert by 106.3% (1.145 mm/s RMS) (Alert)
Overall Danger by 110.8% (8.957 mm/s RMS) (Danger)
VR5 Warning by 204.2% (10.21 mm/s RMS) (Warning)

On-Line Systems

- "**On-Line**" does not necessarily mean "**online**" as in "connected to internet" (although today many On-Line systems are online!).
- "On-Line System" is a general term for a permanently installed monitoring system.
- Depending on system vendor, an "On-Line System" or "Monitor System" can be a **protection** system, or a **surveillance** system, or both.

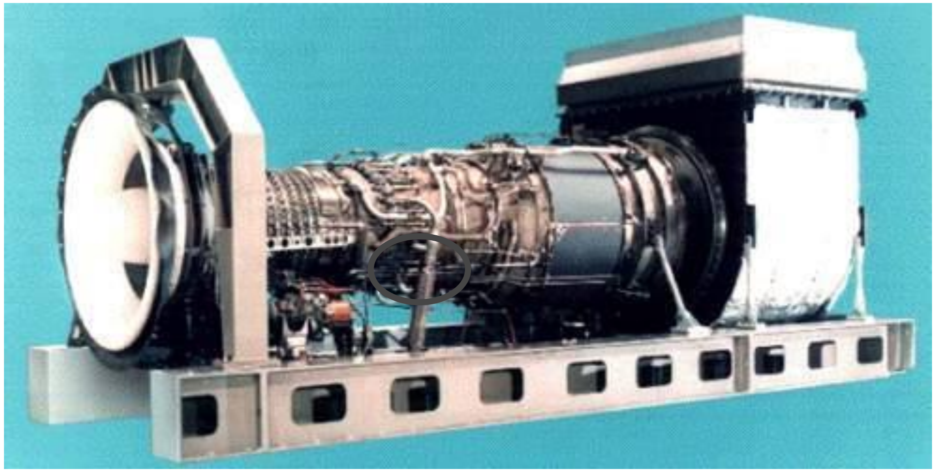
Machine Protection System

Reactive
- Vibration is a symptom.
- Short Term Perspective.

Continuous measurement.
- On-line systems.
- Simple vibration measurement.
- Automatic shutdown.

<u>Prevent</u> Catastrophic Failure

API-670 Standard



Machine Surveillance System

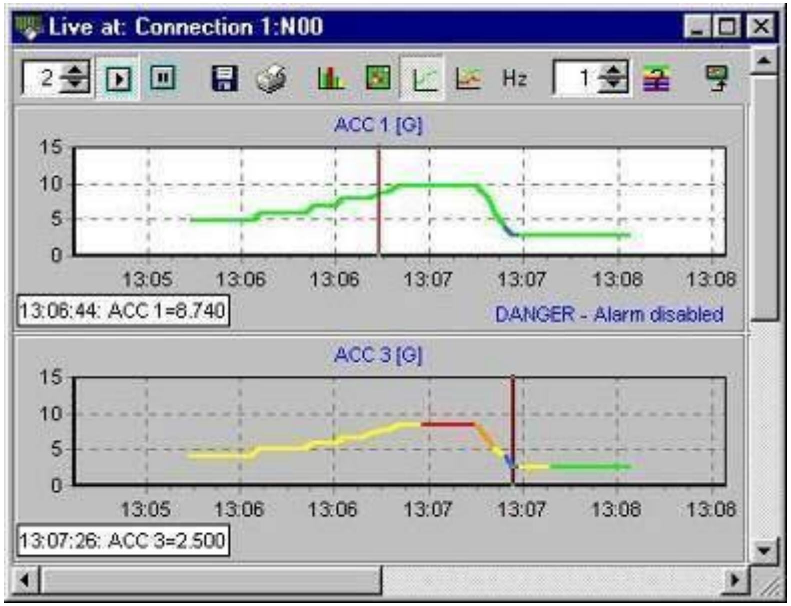
Predictive

- Vibration is a symptom.
- Long Term Perspective.

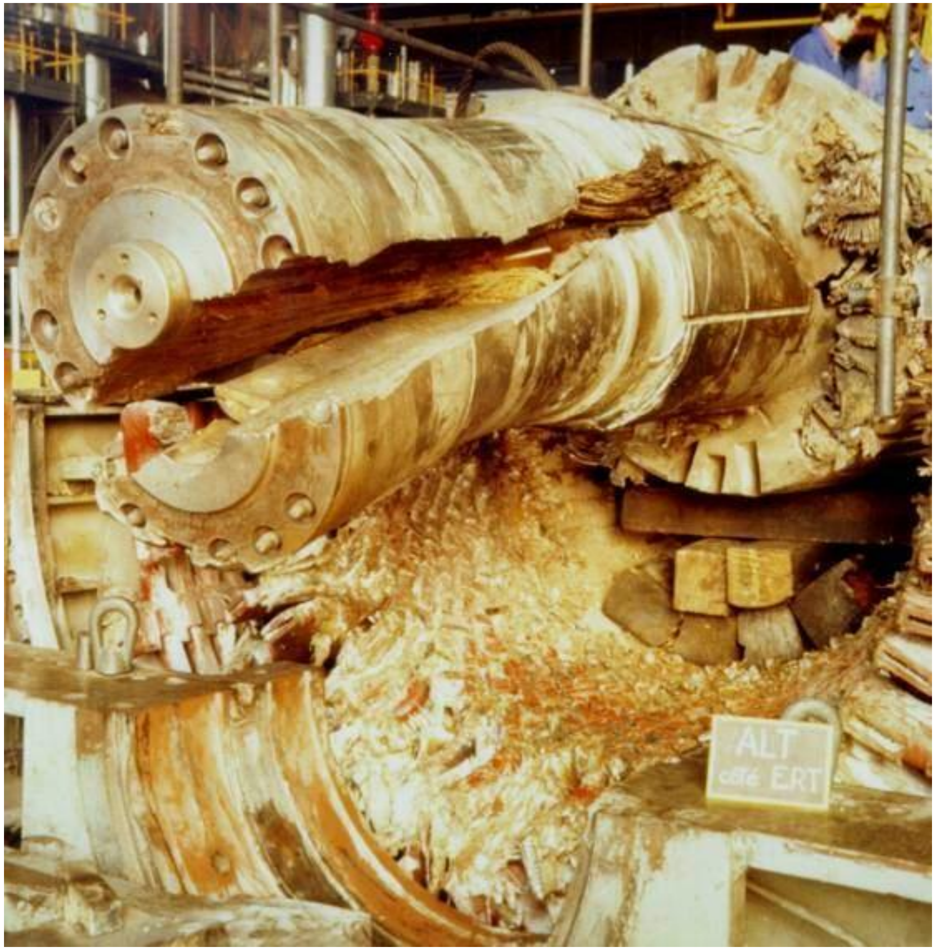
Periodic measurement

- Offline or Online systems.
- Complex vibration measurement.
- Manual warning.

Predict Catastrophic Failure



How do I know it works?



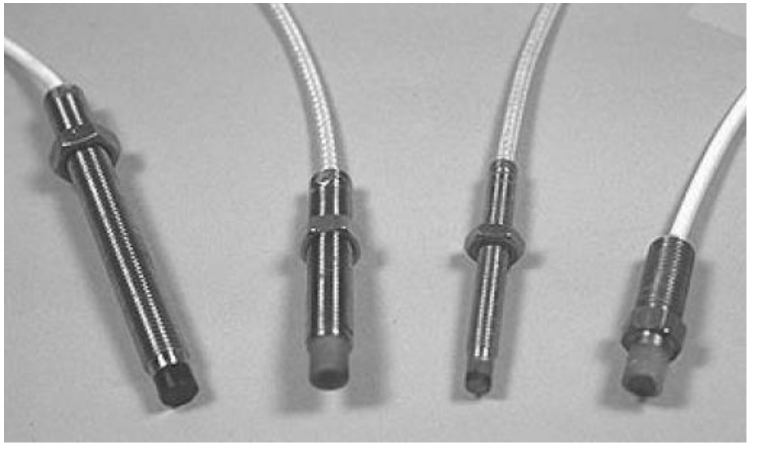
- If it is a protection function, it is less about reducing cost, and more about preventing this..
- With a surveillance system, the avoidance of future cost is the driver..

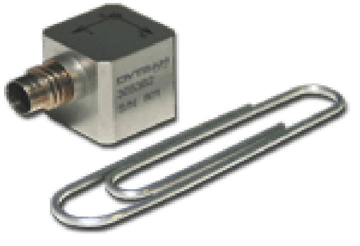
Vibration Transducers

- Accelerometers
- Velocity transducers
- Eddy current displacement probes

Transducers/sensors

- Sense and convert mechanical motion into a scaled electrical signal
- Are placed at strategic points on machines to monitor condition



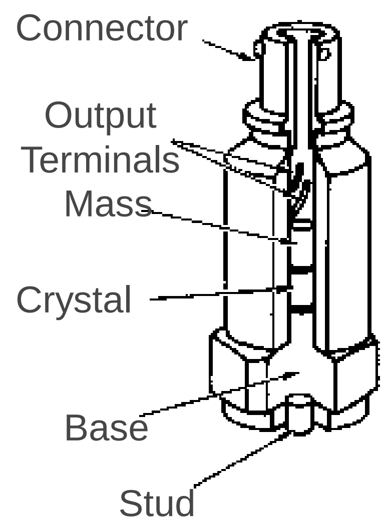


Transducer Selection Consideration

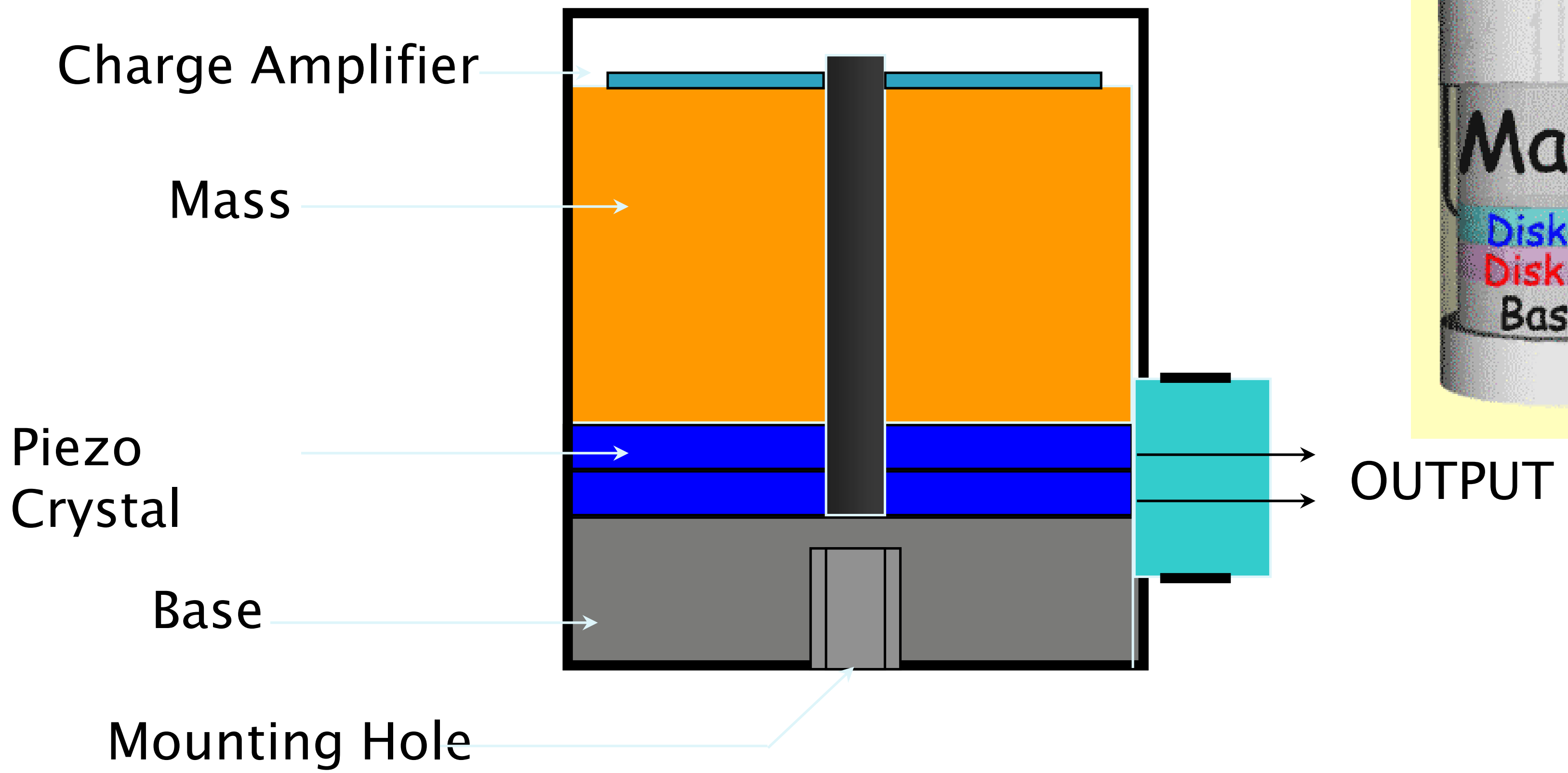
- Unit of Measurement: Displacement, Velocity, Acceleration
- Type of Bearings: Journal or Rolling Element Bearing
- Speed of Machine, or Dominant Frequency to be Measured
- Temperature of Mounting Point: High-temp transducer is more expensive!
- Cable Length, Strength of Signal
- Installation Requirements: Mounting type, Bracket design, Clearances, Limitation, etc.
- Relative Mass of Casing and Rotor: Foundation stiffness, transmissibility
- Machine Limitation/Past Problems
- Unusual Installation Problems: Environmental factors e.g. corrosive, extreme temp
- User Experiences: Plant personnel experience on transducer installation

Accelerometers

- Rugged Devices
- Operate in Wide Frequency Range (Near 0 to above 400 kHz)
- Good High Frequency Response
- Some Models Suitable For High Temperature
- Require Additional Electronics



Typical accelerometer



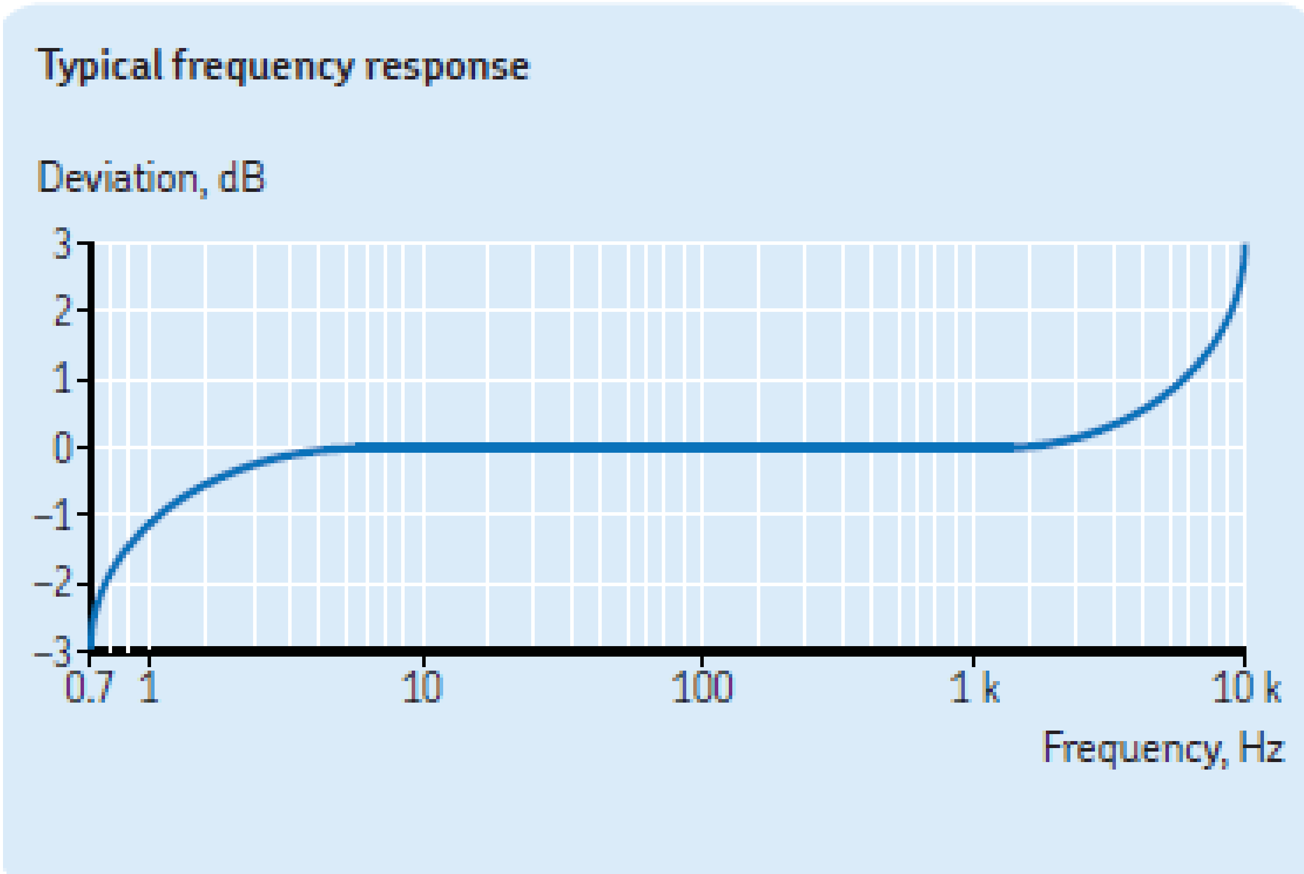
Accelerometer Advantages

- Measures Casing or Structural Absolute Motion
- Easily Attached to Machinery, Piping, Baseplates or Structures
- Flat Phase Response Throughout Transducer Operating Range
- Solid State Electronics with Rugged and Reliable Construction
- Special Units Available for High Temperature Applications (>1,200°F)

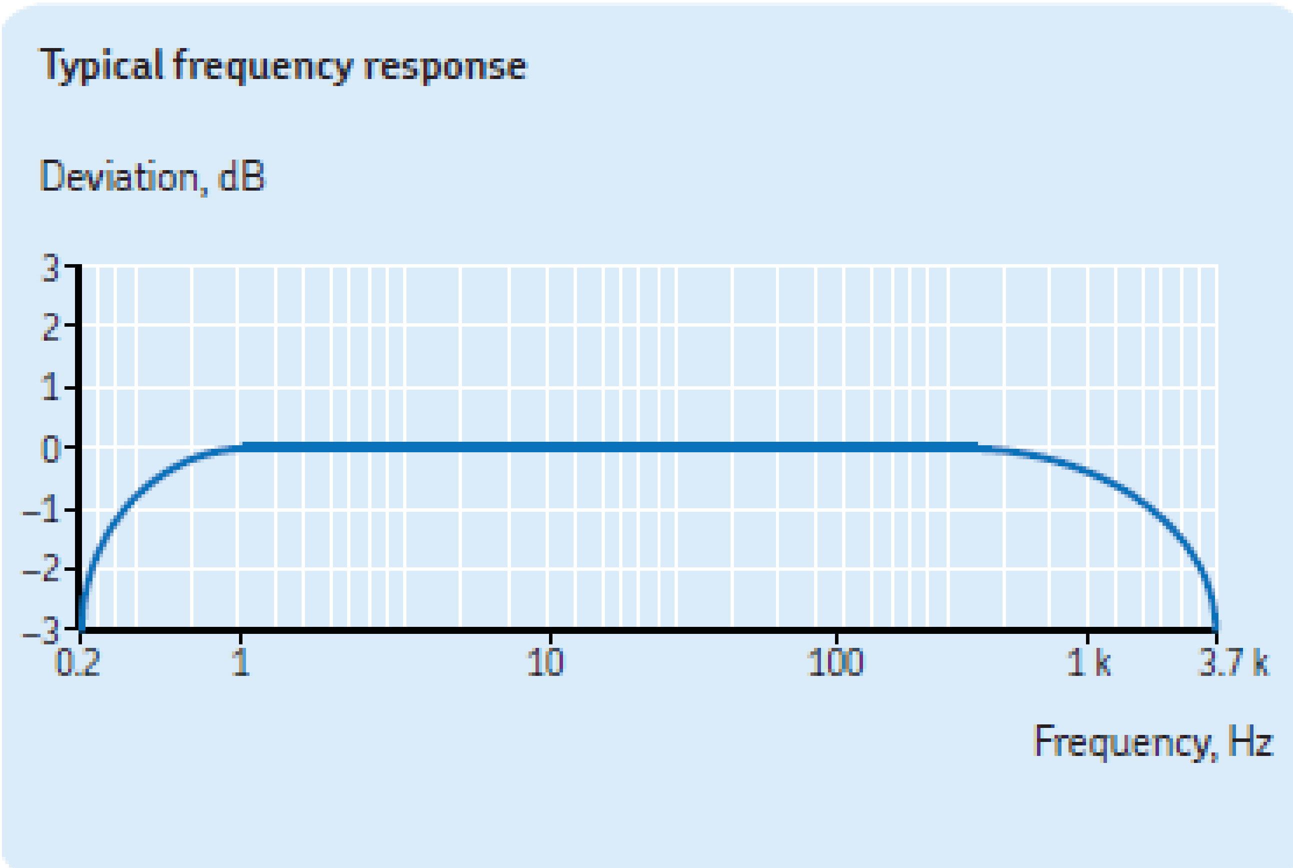
Accelerometer Disadvantages

- Sensitive to Mounting Technique and Surface Condition
- Unable to Measure Shaft Vibration or Position
- Transducer Cable Sensitive to Noise, Motion, and Electrical Interference
- Double Integration Often Suffers from Low Frequency Noise

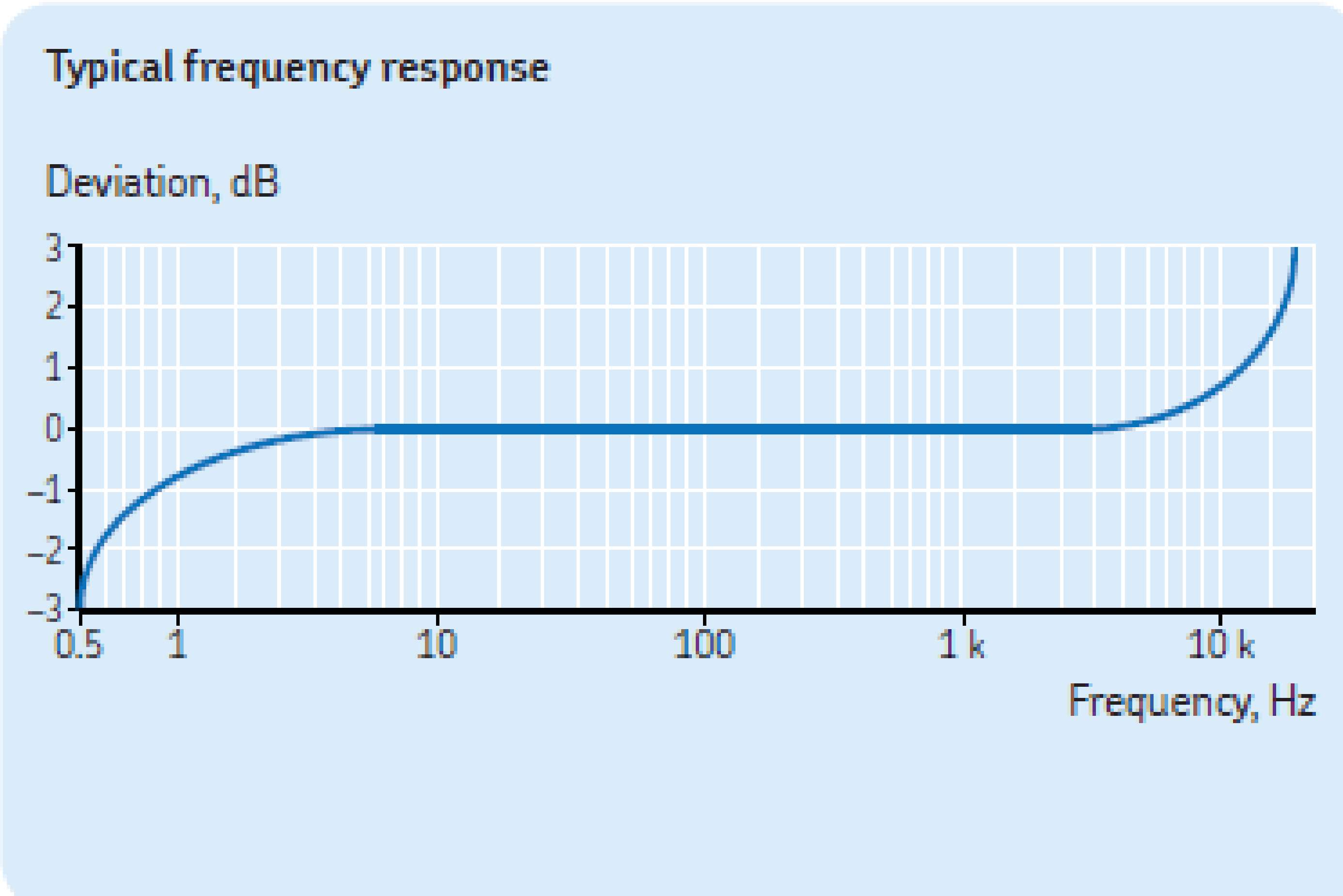
Frequency Response – General Purpose Accelerometer



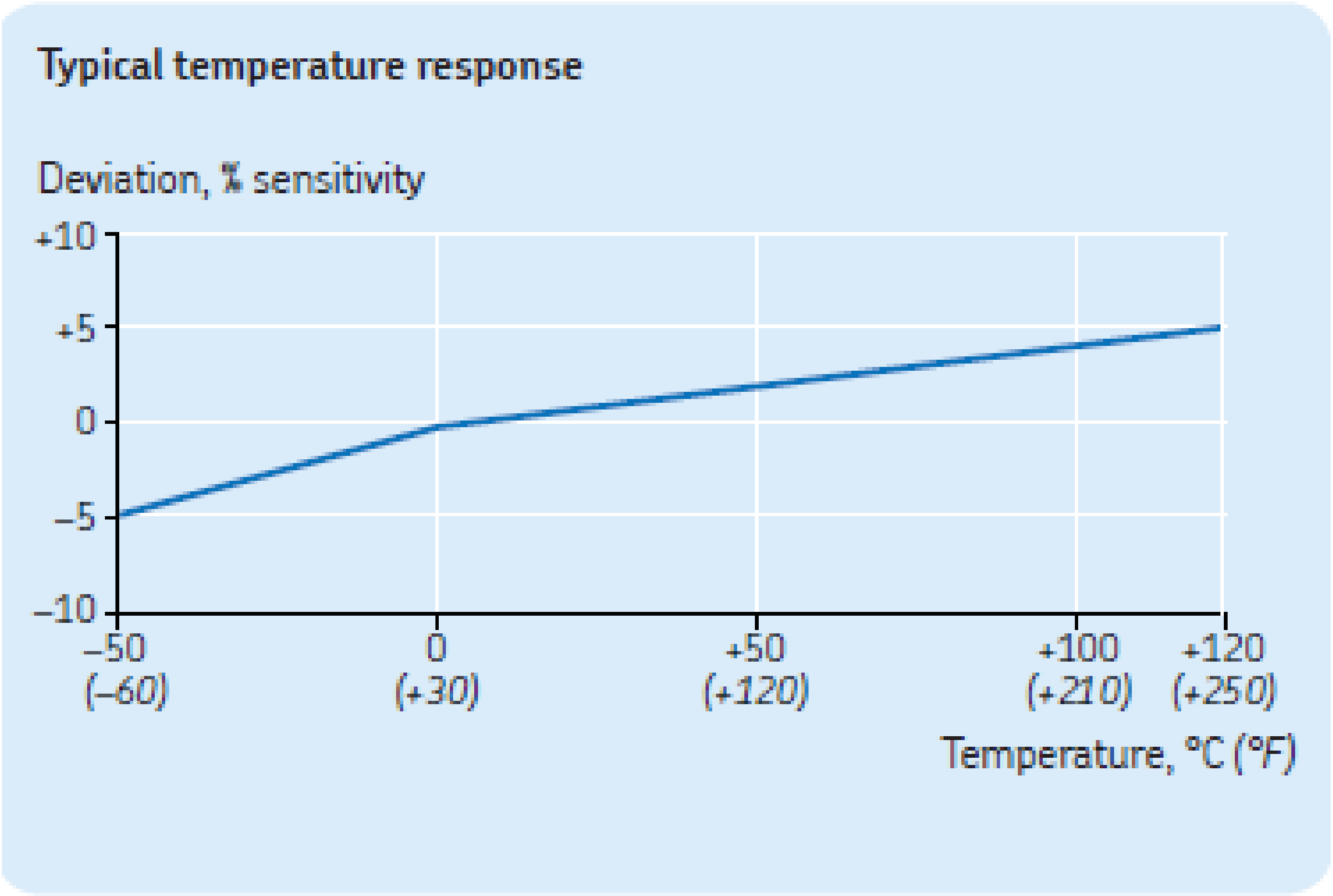
Frequency Response – Low Frequency Accelerometer



Frequency Response – High Frequency Accelerometer

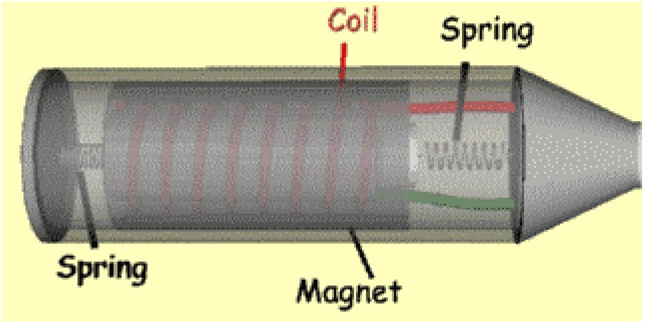


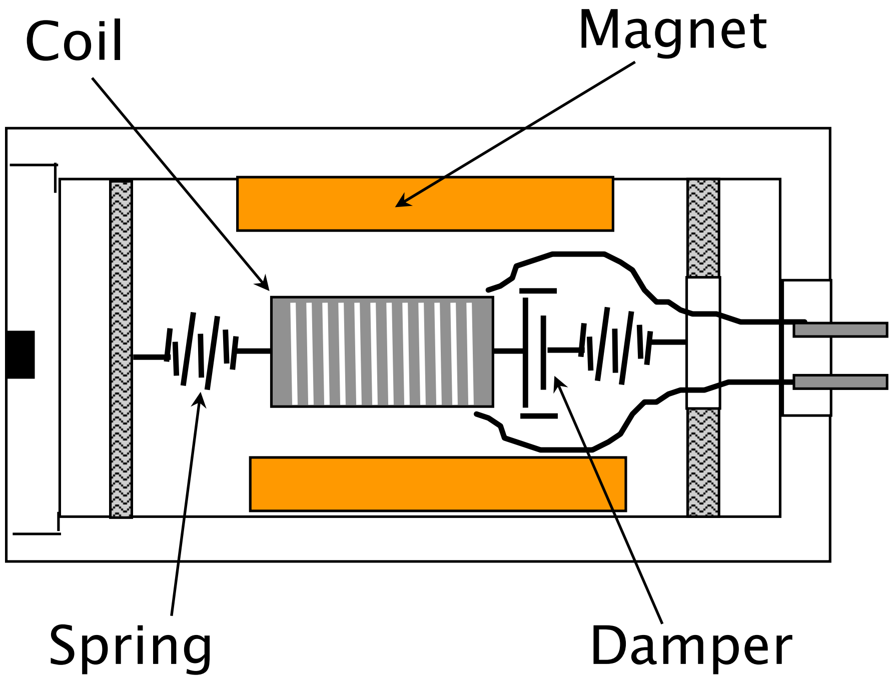
Typical Temperature Response



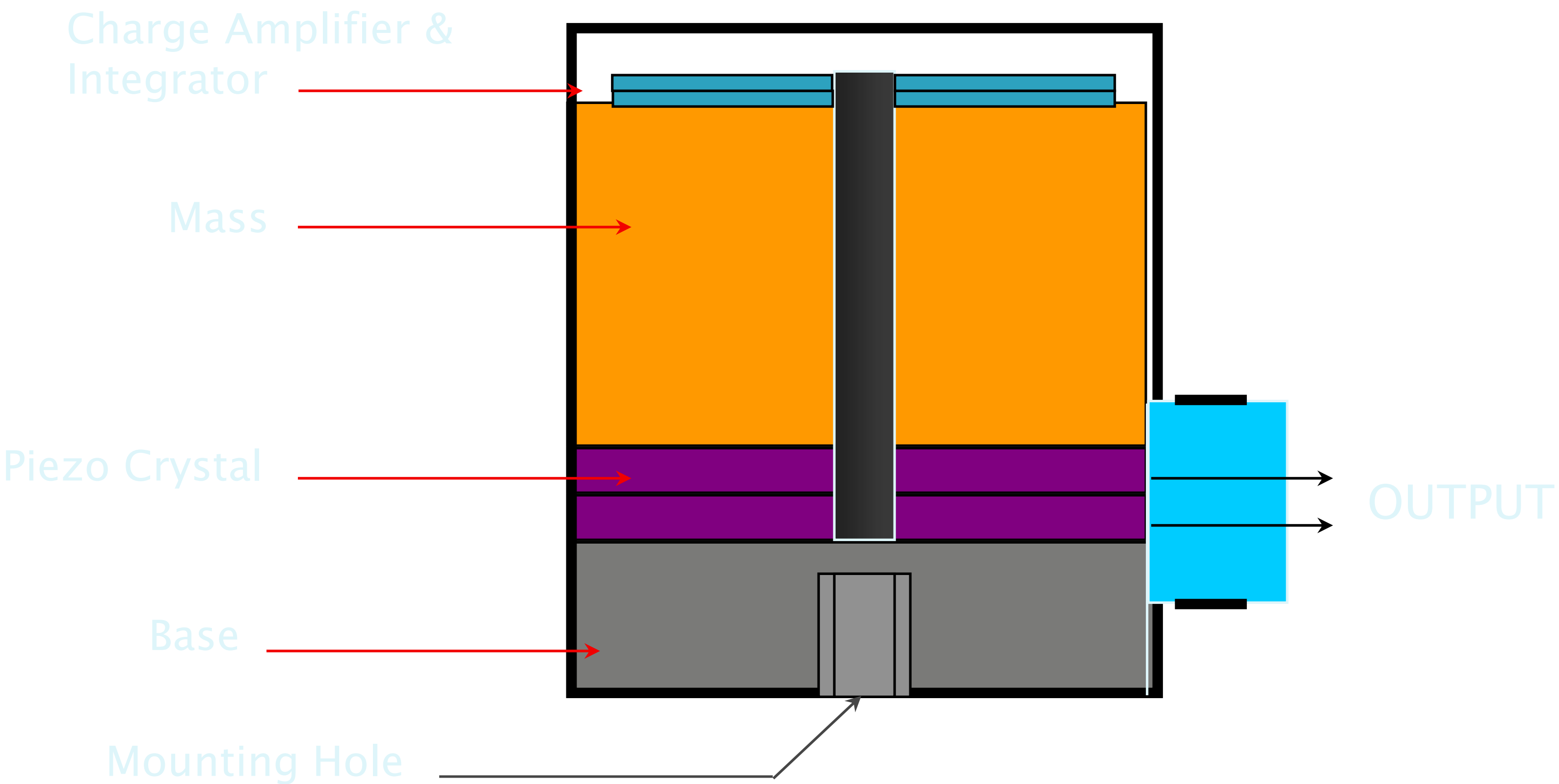
Velocity transducer

- Large
- Low natural frequency
- Limited frequency range
- Easily damaged





Velomitor



Charge Amplifier &
Integrator
Mass
Piezo Crystal
Base
Mounting Hole
OUTPUT

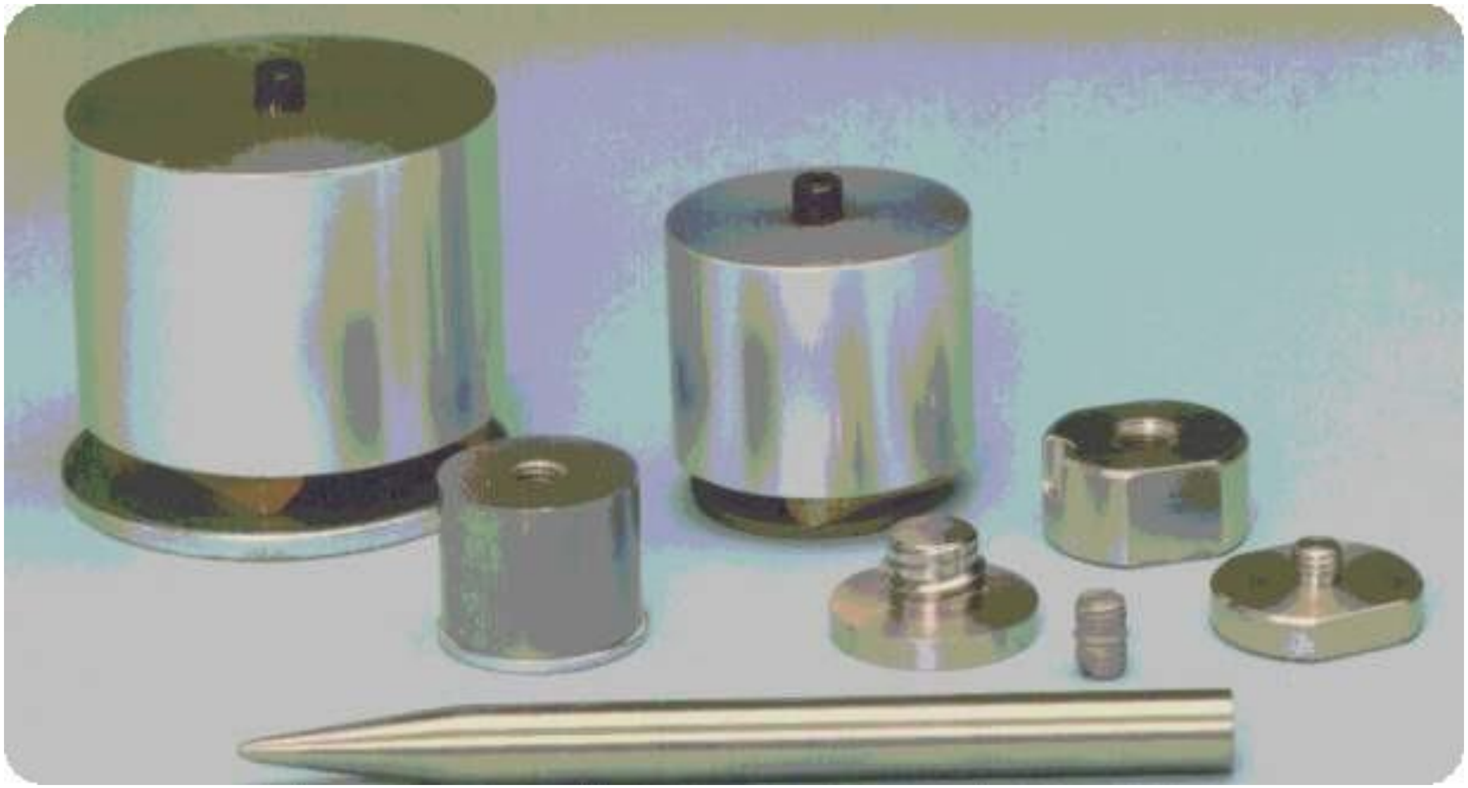
Velocity Advantages

- Measures Casing Absolute Motion
- Easily Attached to Machinery Externals, Piping, Baseplates or Structures
- Good Signal Response Between 900 and 90,000 CPM (15 and 1,500 Hz)
- No Special Wiring Required
- Available in Several Configurations

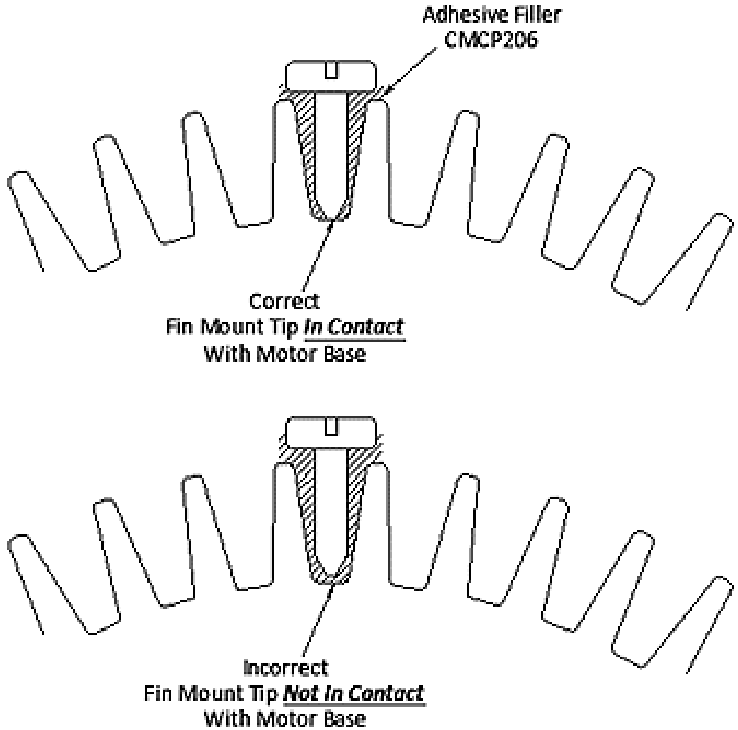
Velocity Disadvantages

- Sensitive to Mounting Fixture and Transducer Orientation
- Unable to Measure Shaft Vibration or Position
- Poor Signal Response Below 900 CPM (15 Hz) Above 90,000 CPM (1.5 KHz)
- Operates Above Transducer Natural Frequency of 600 CPM (10 Hz)
- Potential for Failure due to Fatigue of Moving Internal Parts
- Temperature Sensitive, Typical Upper Limit of 250°F, Lower Limit of 30°F

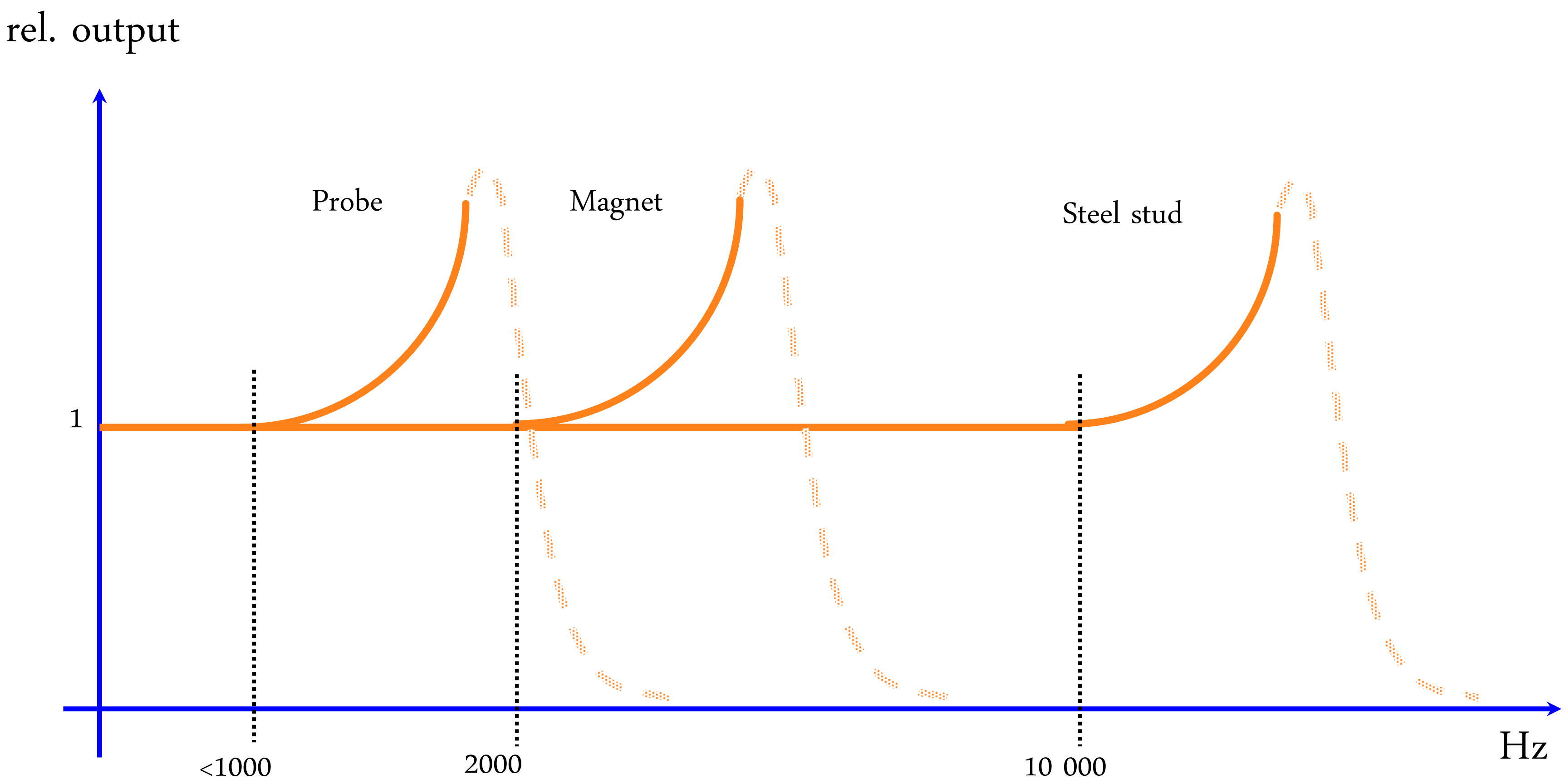
Sensor mounting methods



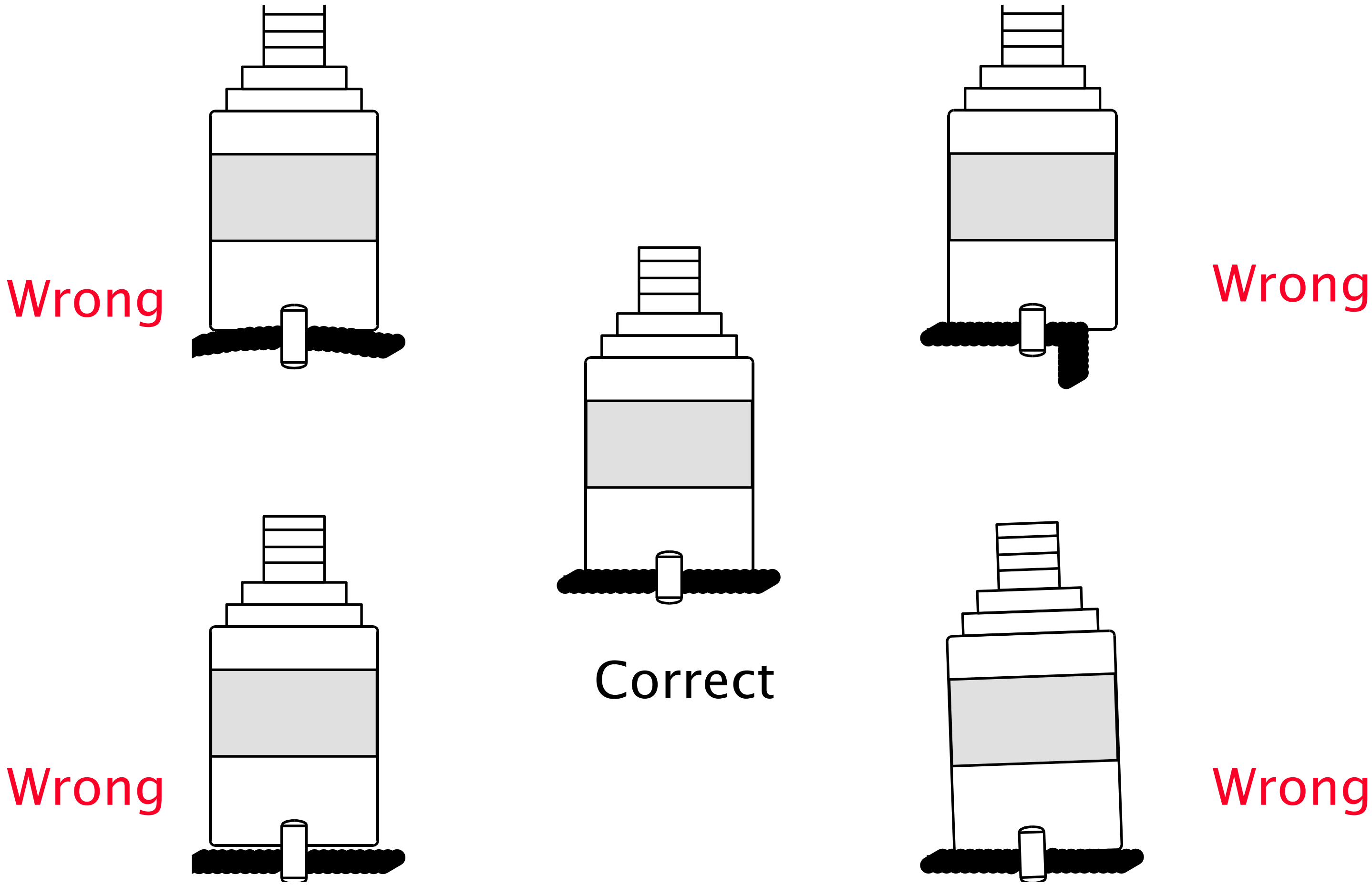
Motor Fin Mounting



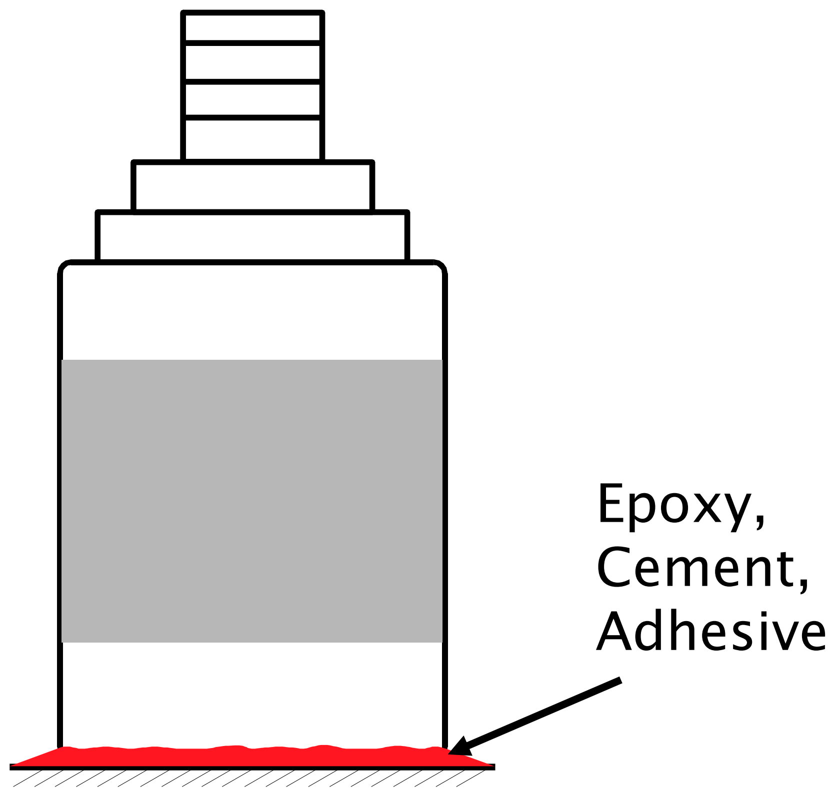
Mounting techniques



Screw mounting

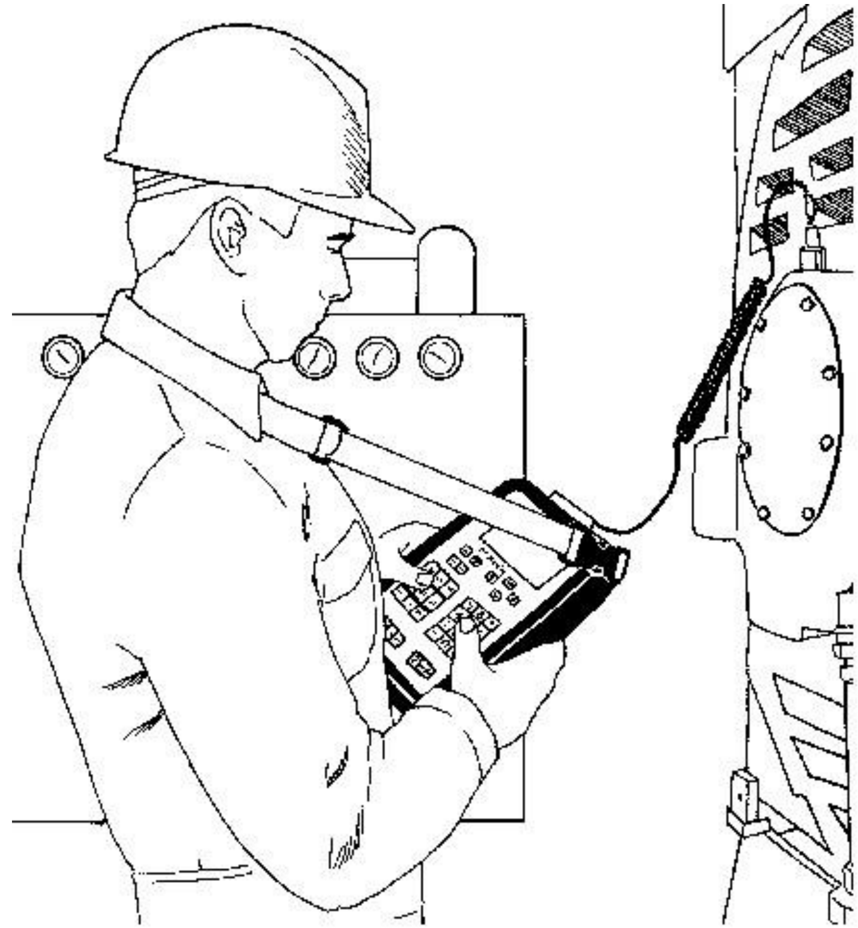


Direct adhesive cement mounting



Magnetic mounting base

- Convenient means of providing a quick or temporary mount
- Reduces frequency response rating by approximately 50% vs. stud mounting



Sensor disks for magnetic mounting

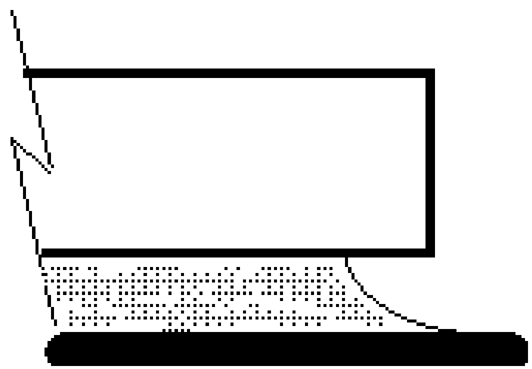
Sample Disk
(overhead view)

Sample Disk
(side profile)

Note adhesive fillet between
machine surface and sample disk

Mounting sensor disks (adhesive fillets)

Good

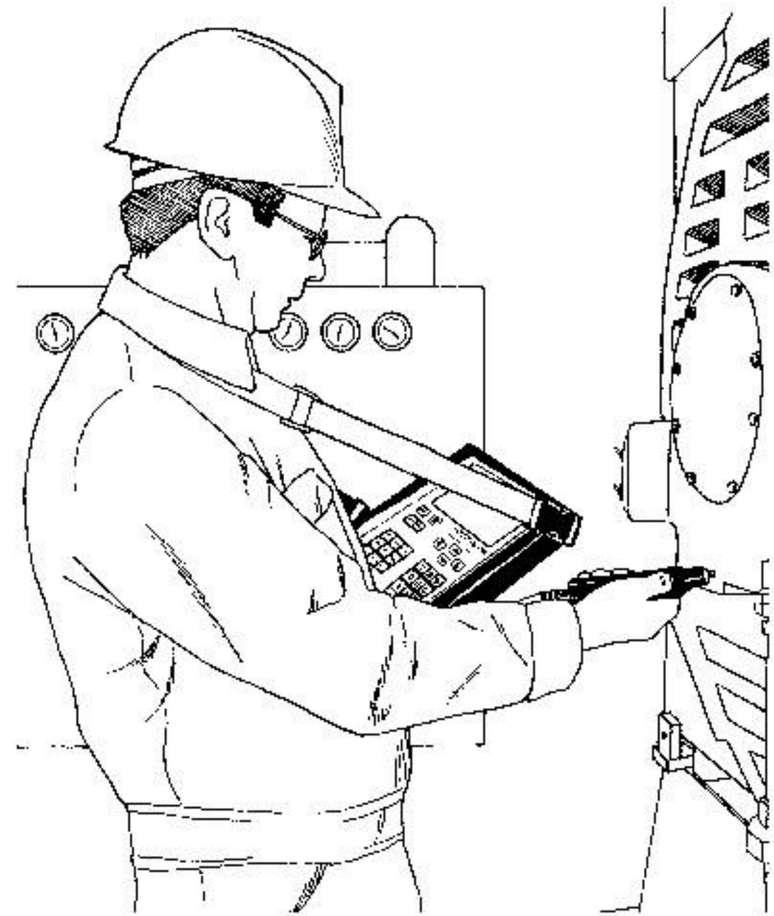


Bad

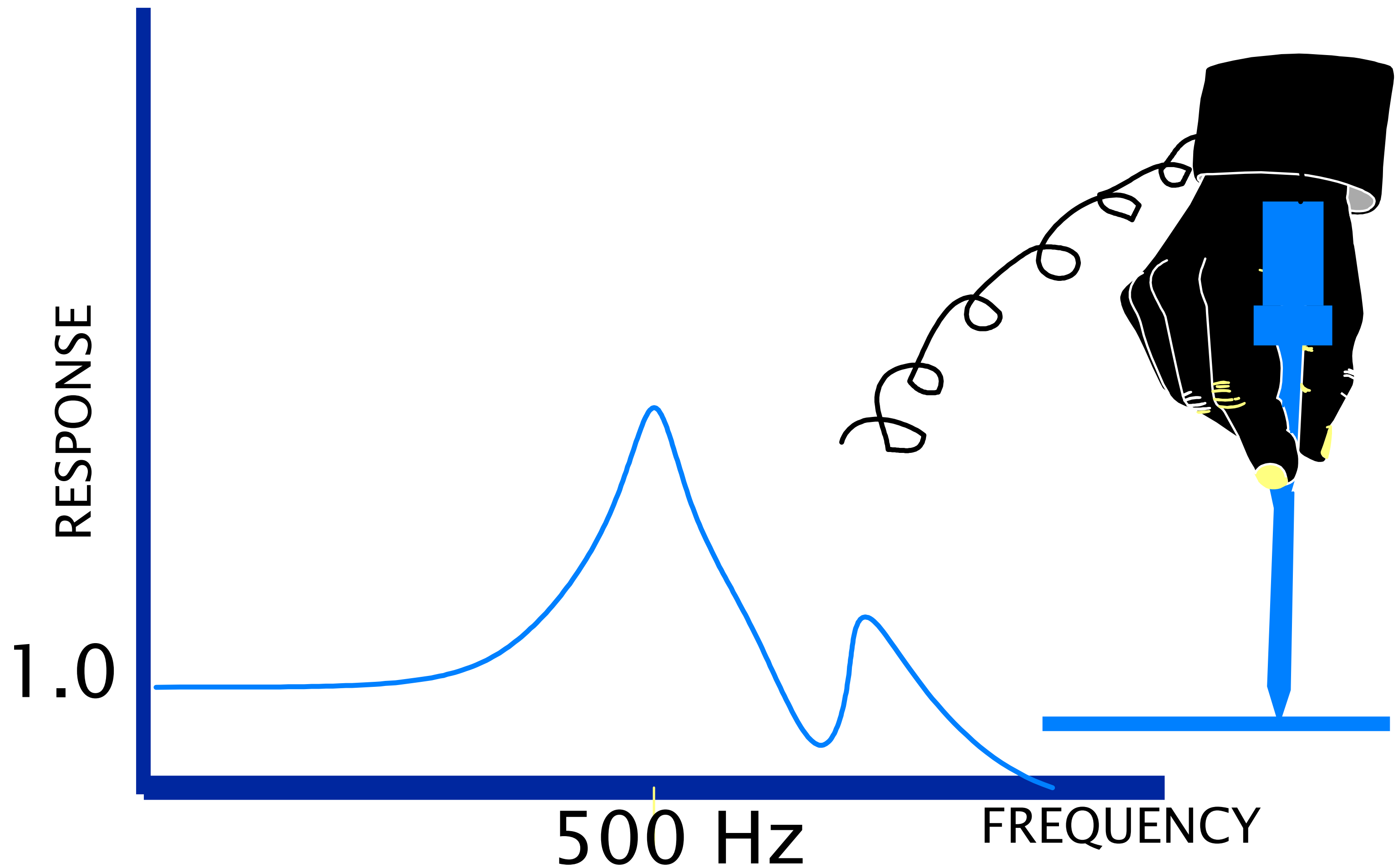
Concave fillet allows oil to leach under disk, promoting failure

Handheld/Probe mounting

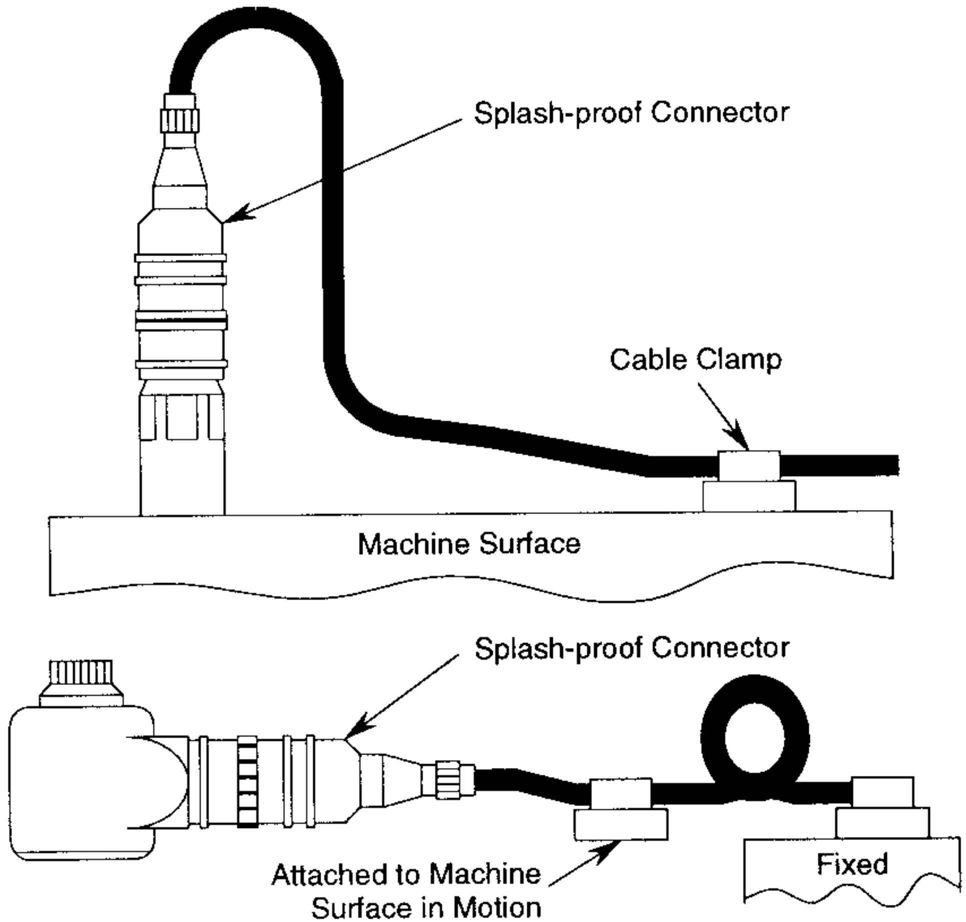
- Rapid and convenient
- Subject to many sources of error
- Use only as a last resort



Handheld probe – typical response

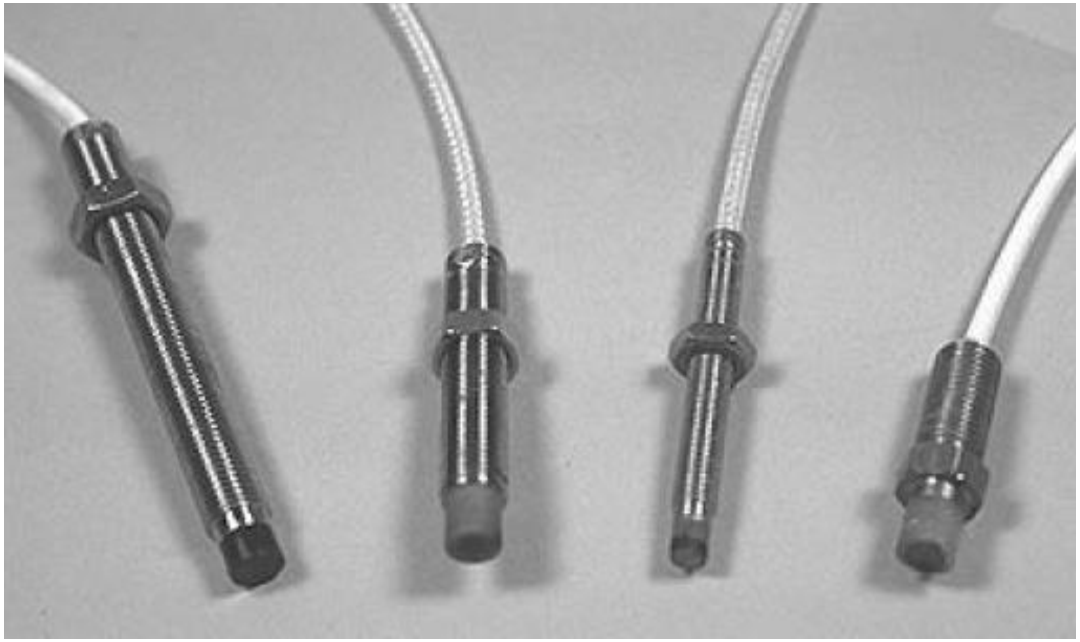


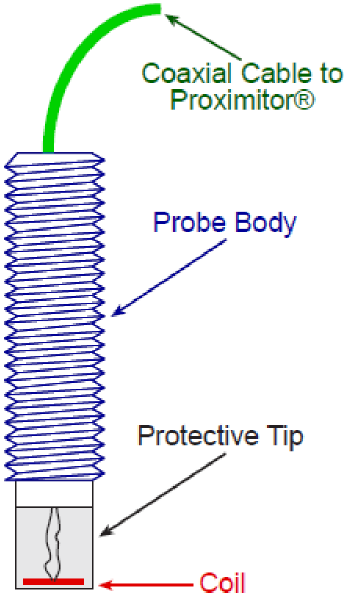
Cable attachments



Displacement Probe

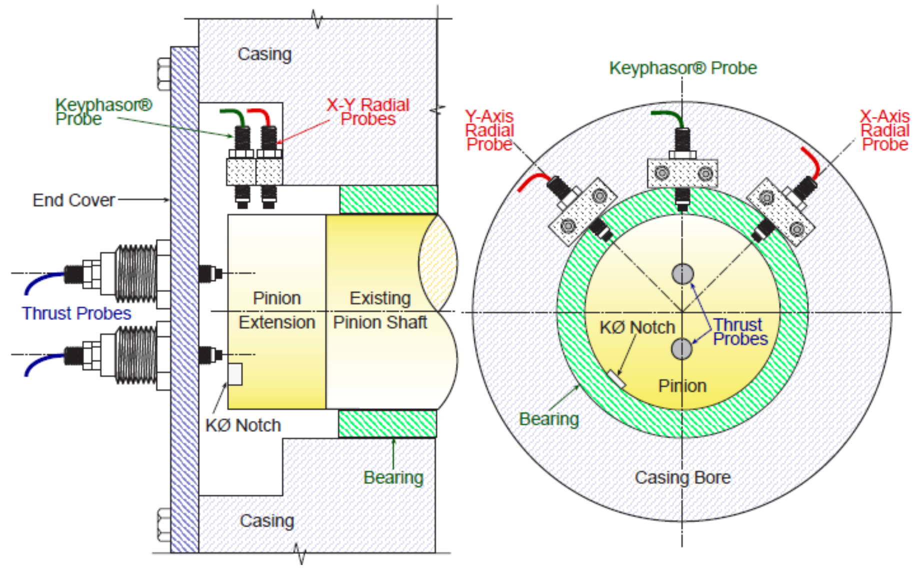
Probe, Extension Cable, Proximitor®



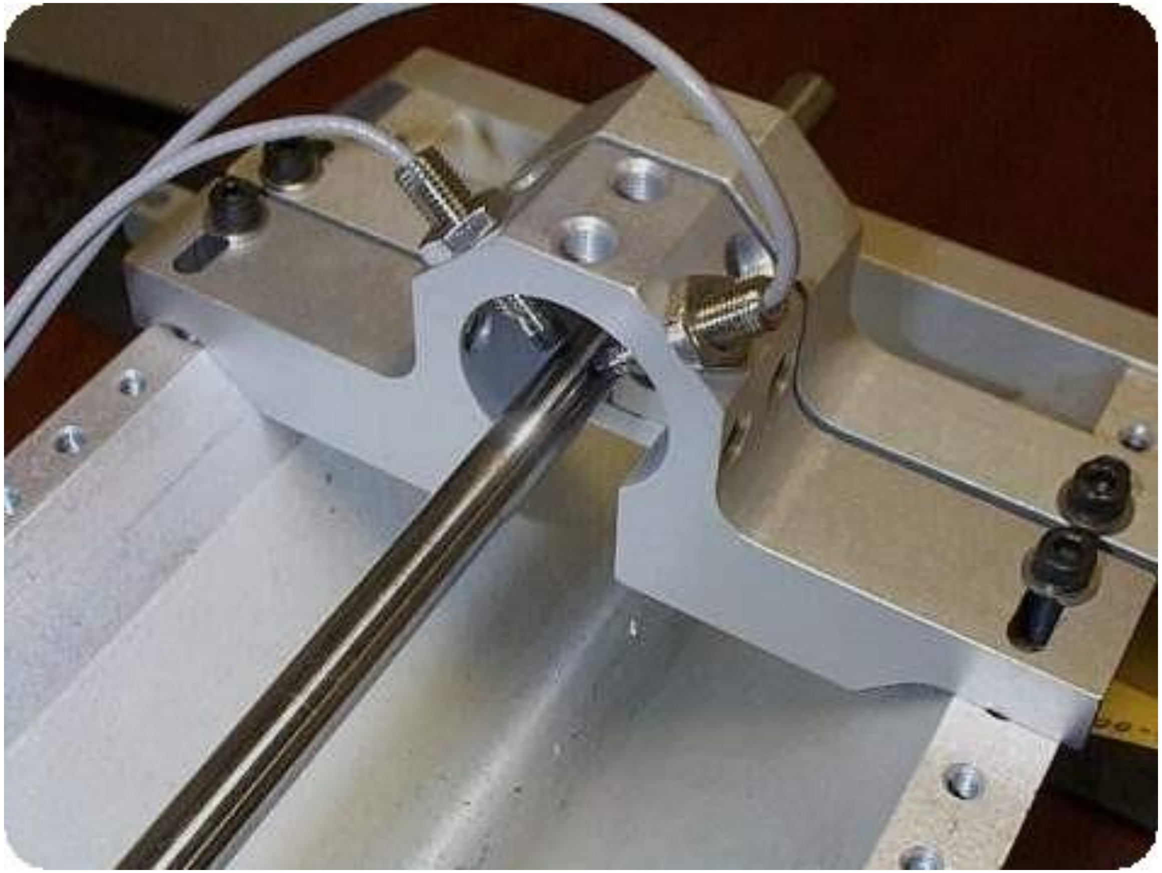


Displacement/eddy current probe

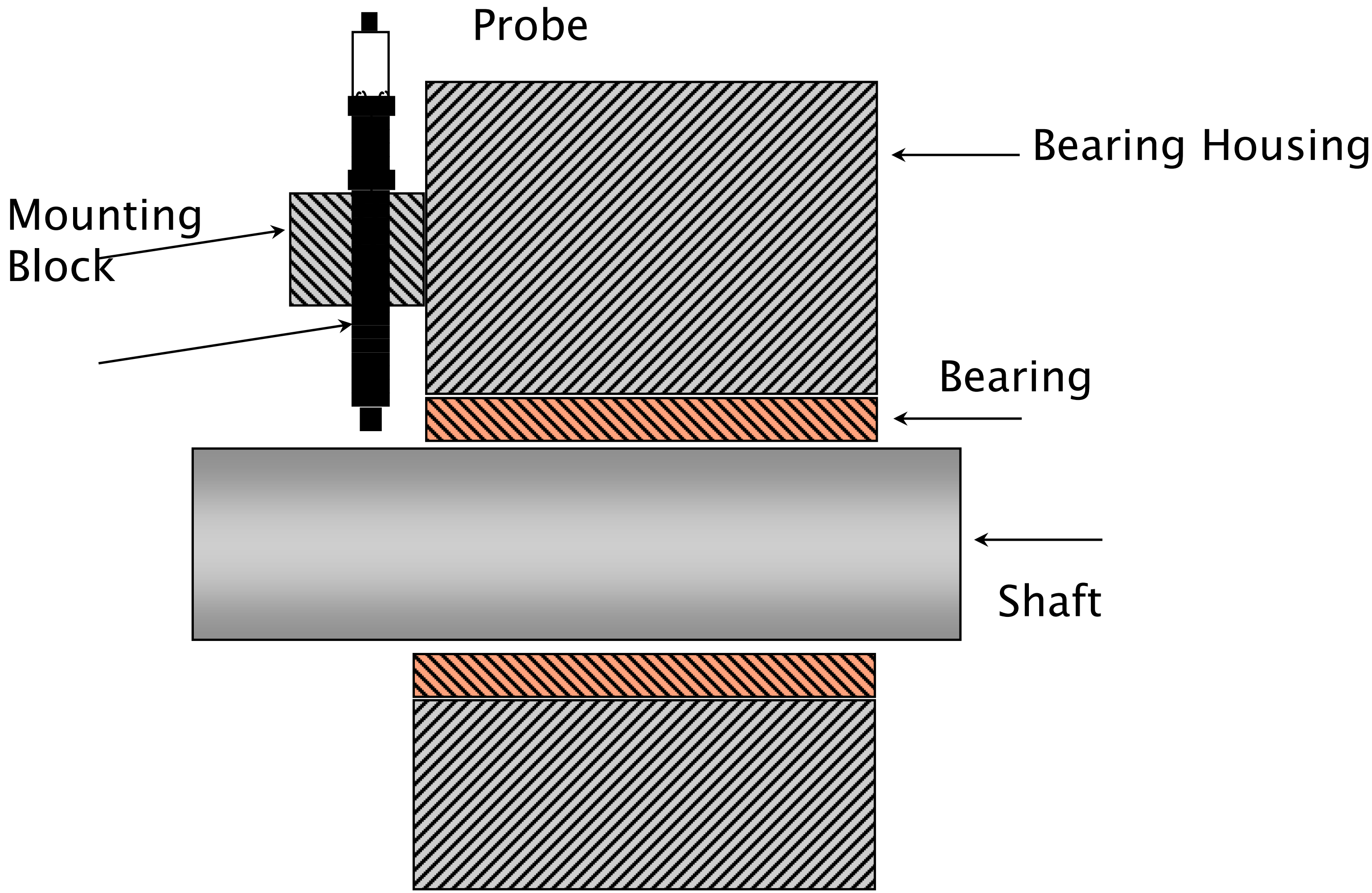
- Measures relative distance between two surfaces
- Accurate low frequency response
- Limited high frequency sensitivity
- Requires external power source



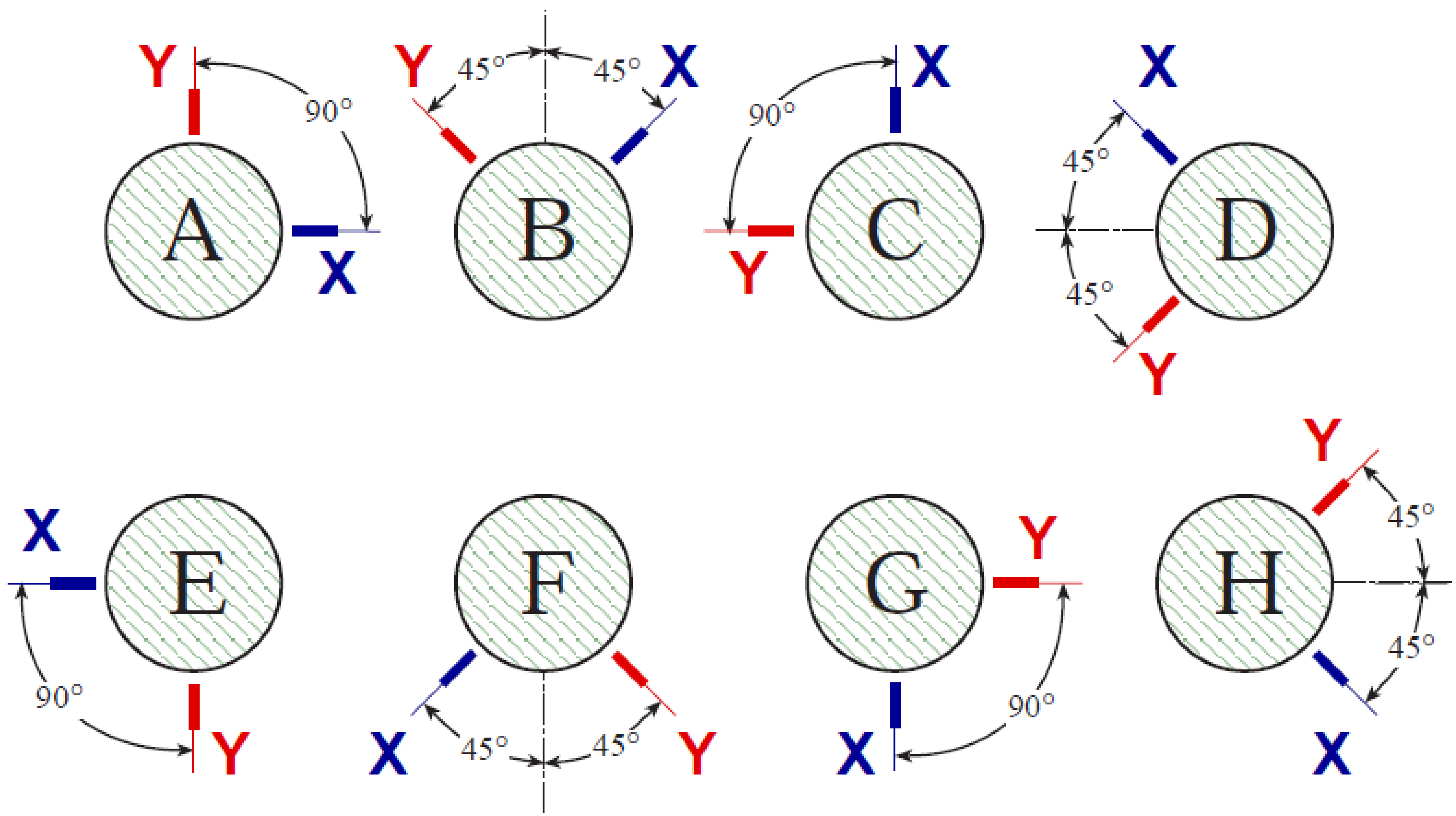
Eddy-current probe configuration



Eddy probes



Radial Probe Angular Identification



Proximity Probe Advantages

- Measures Shaft Static Position – DC Component
- Measures Shaft Dynamic Motion – AC Component
- Excellent Signal Response Between DC and 90,000 CPM (1.5 kHz)
- Flat Phase Response Throughout Transducer Operating Range
- Simple Calibration
- Solid State Electronics
- Rugged and Reliable Construction
- Available in Many Physical Configurations
- Suitable for Installation in Harsh Environments
- Multiple Machinery Applications for the Same Transducers

Proximity Probe Disadvantages

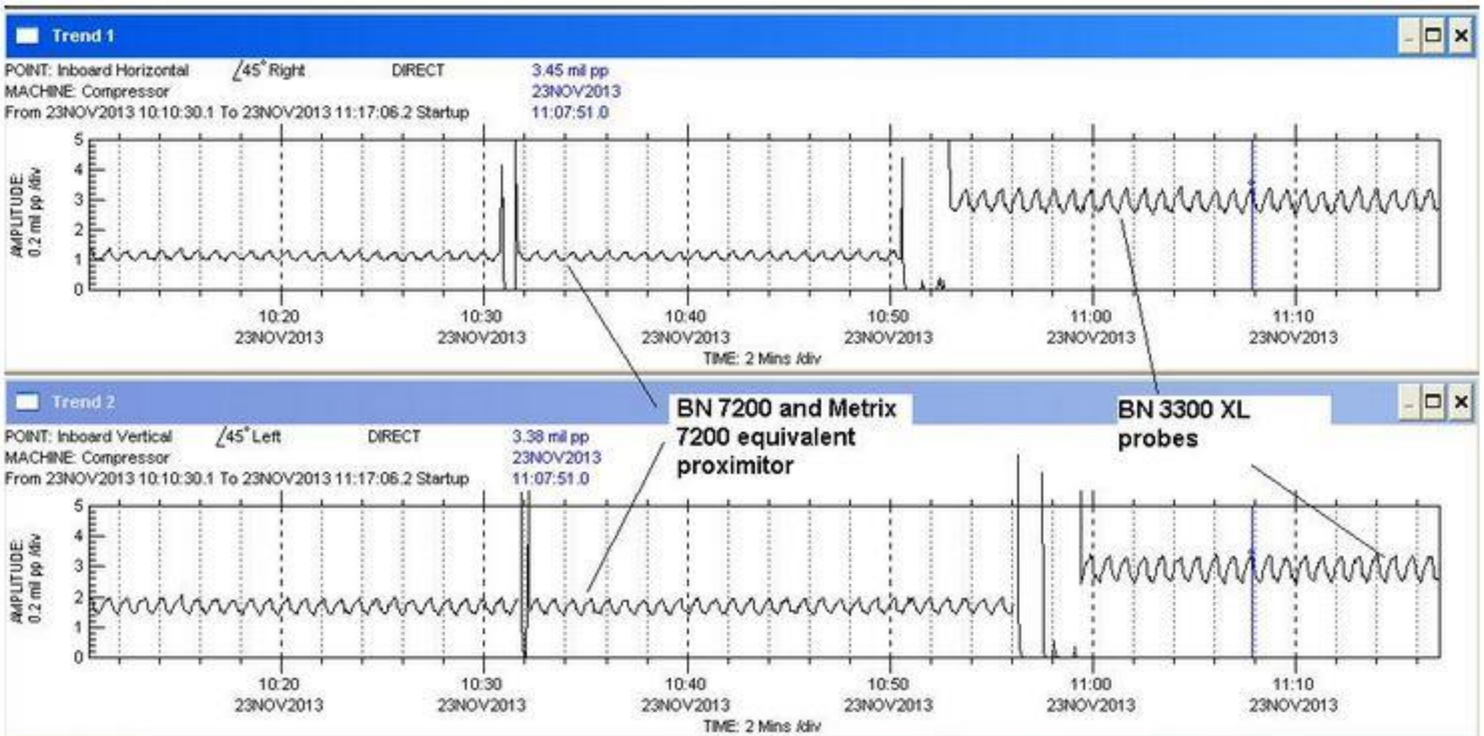
- Sensitive to Surface Imperfections and Magnetism
- Sensitive to Material Properties
- Shaft Surface must be Conductive
- Low Dynamic Signal Response Above 90,000 CPM (1.5 kHz)
- External Power Source Required
- Correct Probe to Proximitor® Cable Impedance Must Be Maintained (e.g. 5 or 9 meters)
- Sensitive to Interference from Adjacent Proximity Probes – Cross-talk!
- Sensitive to Probe Mounting Bracket Resonance(s)
- Potentially Difficult to Install

Probe Sensitivity with Different Metals

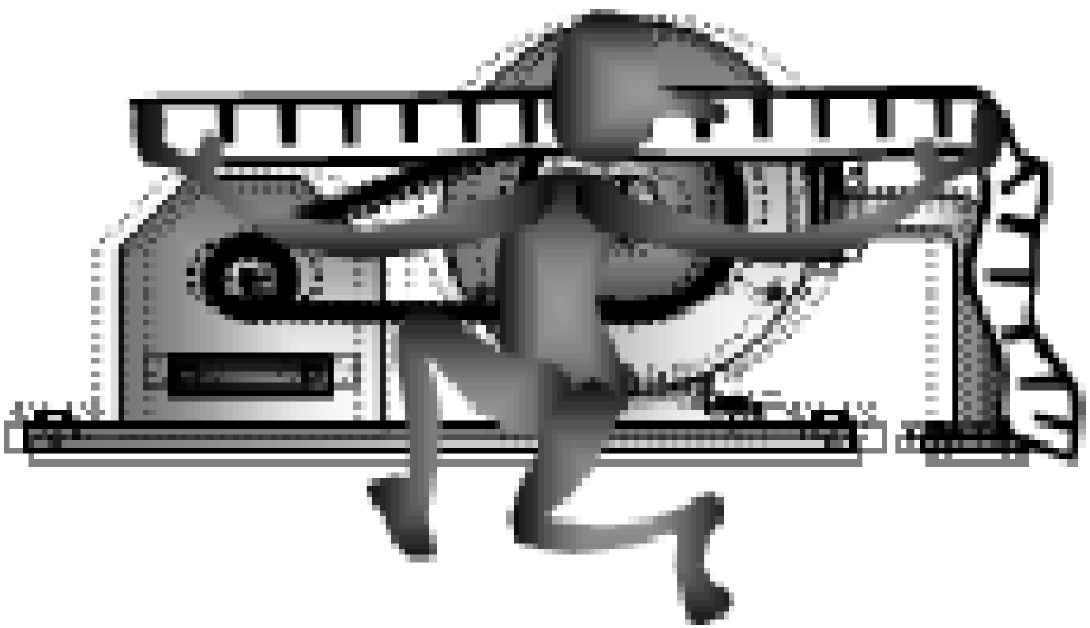
Material	Probe Voltage Sensitivity
Copper	380 millivolts/Mil
Aluminum	370 millivolts/Mil
Brass	330 millivolts/Mil
Tungsten Carbide	290 millivolts/Mil
Stainless Steel	250 millivolts/Mil
Steel — 4140 or 4340	200 millivolts/Mil

Effect of Incompatible Displacement Probe System

Measurement Point	Vibration Reading (mils, pk-pk)		DC Gap Voltage (VDC)	
	BN 7200 and Metrix	BN 3300 XL	BN 7200 and Metrix	BN 3300 XL
XVI-407A	1.45	3.359	-7.34	-11.86
XVI-407B	1.82	3.325	-9.09	-10.25



6 How is Machine Vibration Measured?



Objectives:

- Know equipment information
- Identify operating mode
- Understand Vibration Monitoring and Analysis Process
- Understand how vibration sensors should be mounted
- Determine how measurement parameters should be set
- Take vibration measurement in a systematic way

Machinery Management

Vibration Analysis requires *information!*

- Shaft Running Speed
- Bearing Type/ Bearing Number
- Number of impeller blades
- Number of Gear Teeth
- Pulley Diameter
- Belt Number
- etc…

Bearing types

Journal bearing

- cylinder surrounding the shaft, filled with some form of lubricant
- lubricant is the medium supporting the shaft, allowing no metal-to-metal contact and providing a completely frictionless environment
- disadvantage is an instability, which manifests itself as oil whirl and oil whip
  - leads to high friction levels, which overheat the bearing, leading to rapid destruction of the bearing, rotor journal, and machine seals

Rolling element bearing

- contain an inner race, an outer race, the rolling element, and a cage to support and guide the rolling elements
- components are in much closer contact than in journal bearings
- due to their tighter clearances, provide less vibration damping, and although they are one of the most precisely machined parts, have a limited lifetime

Failure modes

Journal bearings

- tend to exhibit lower order faults (unbalance, misalignment, excessive clearances, cracked shafts, loose rotating parts, preload)
- damping, due to presence of lubricant in bearing load zone and bearing geometry, tends to be high
- Nearly all failure modes associated with bearing and rotating shaft are analyzed with time domain and lower order frequency domain analysis

Rolling element bearings

- tend to initially produce vibration signals in higher frequency ranges
- higher order frequency domain analysis, with time domain analysis as a backup
- amplification factors usually high due to tighter clearances
- damping low due to limited amount of lubricant present and close clearances within bearing load zone

Operating Mode

- Steady State
- Transient
- Slow Roll
- Stopped

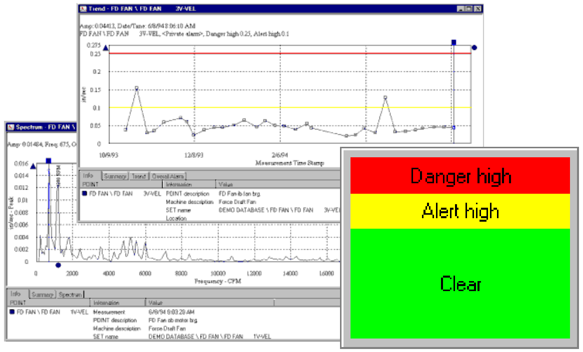
Typical Vibration Monitoring and Analysis Process

Condition Monitoring Software

Download the configured measurement POINTs to analyzer

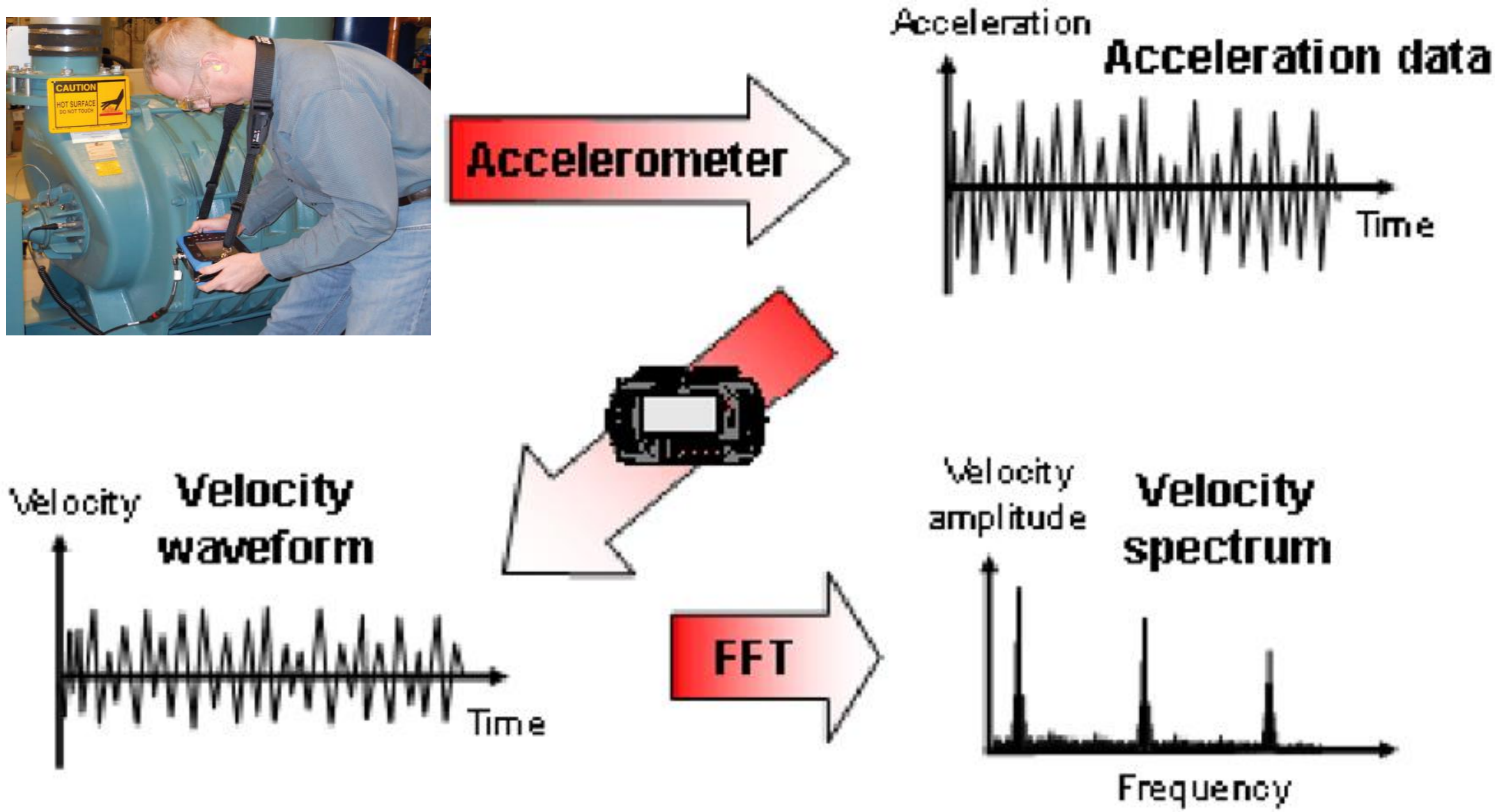
Field Data Collection

Upload collected data to the database

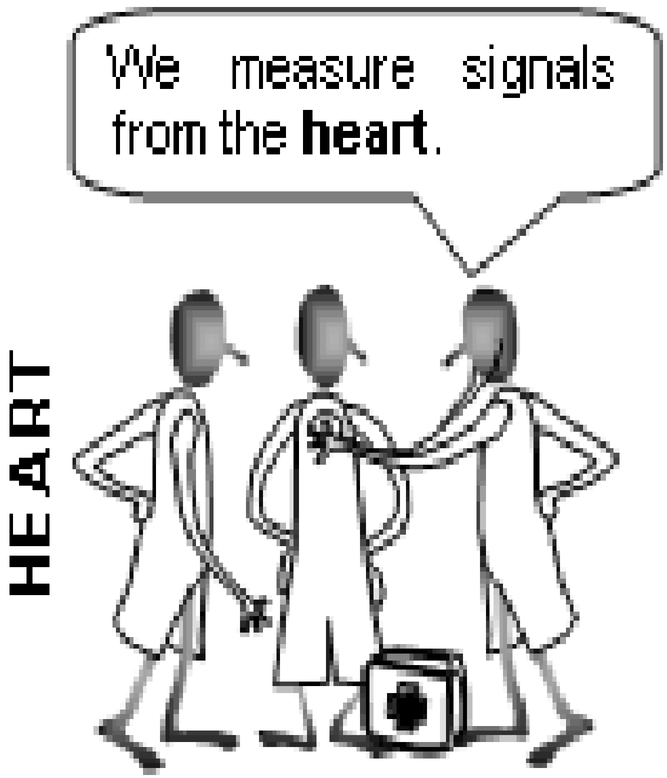


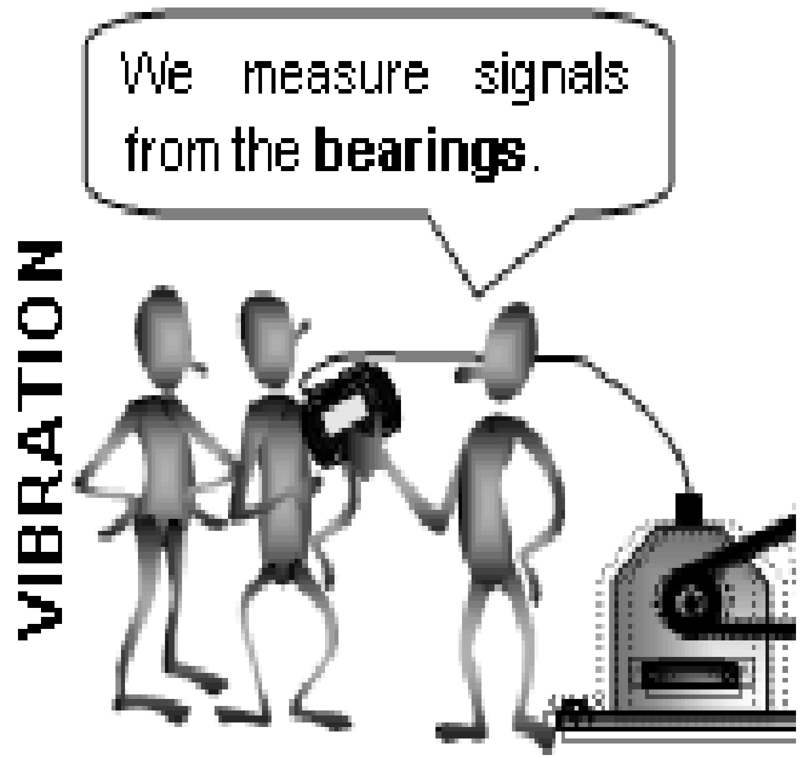
Use Condition Monitoring Software to identify equipment that exceeded alarm limits and to conduct analysis on the vibration data

How Does The Instrument Work?

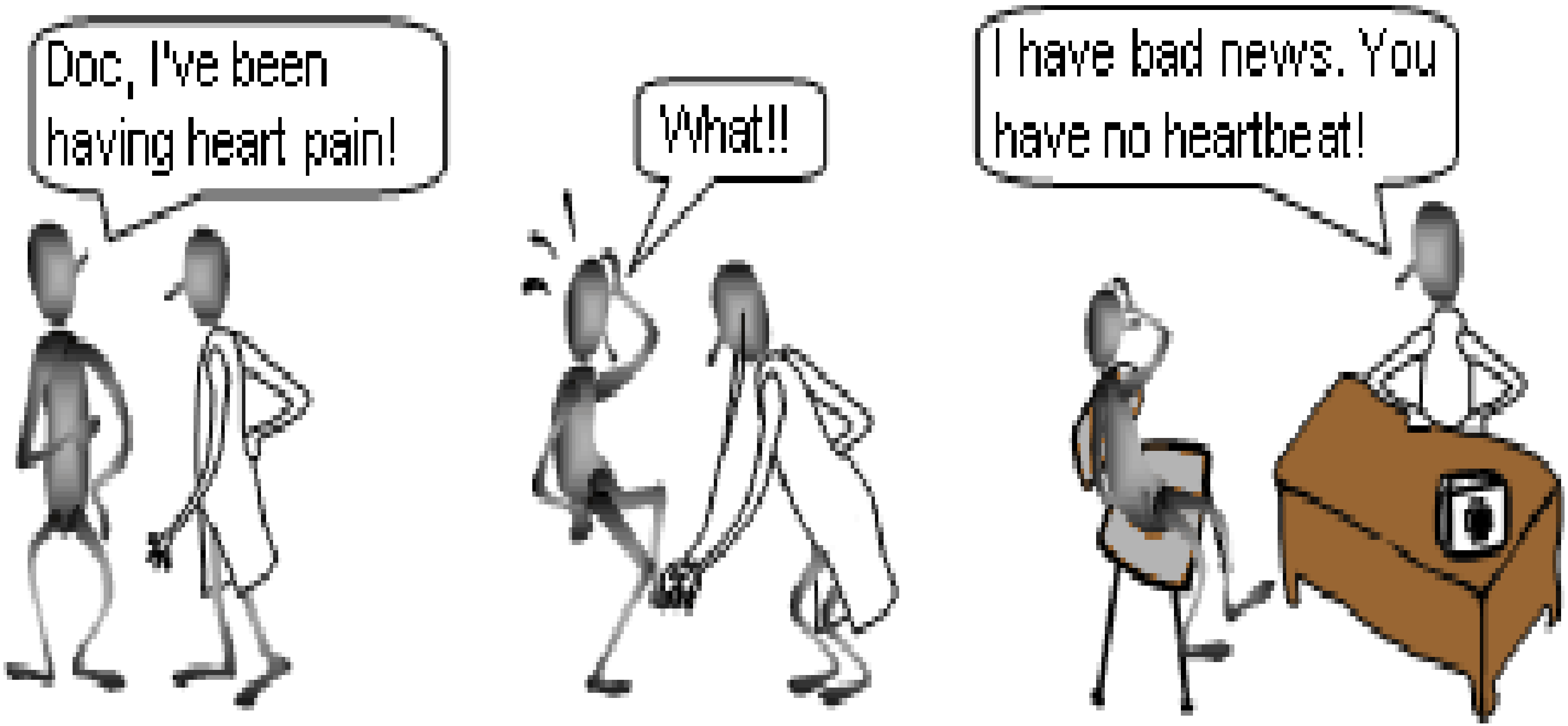


How is the Accelerometer Mounted?

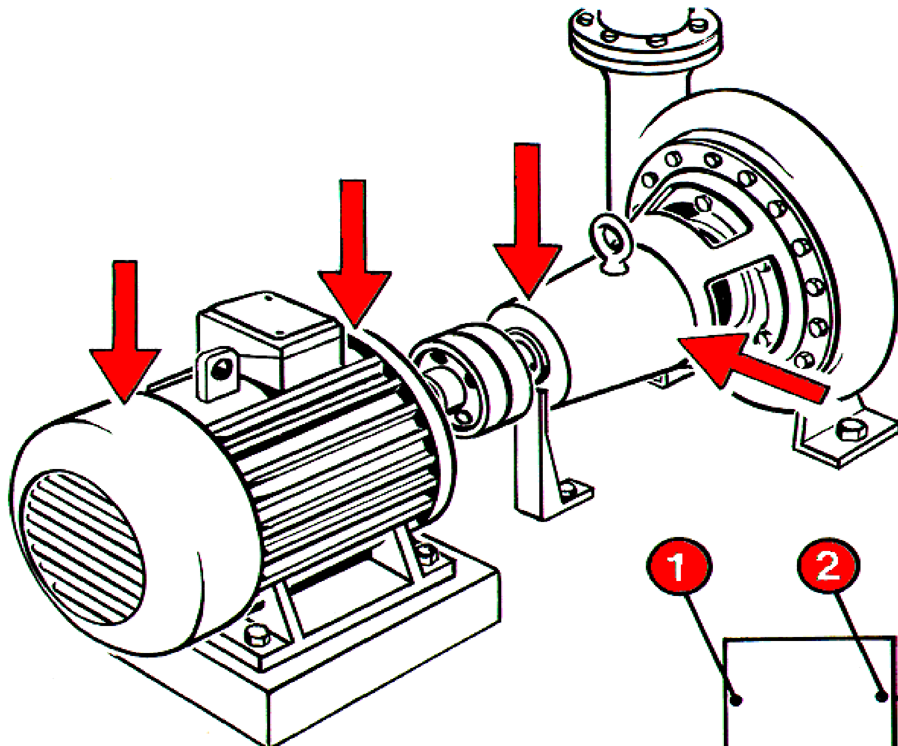


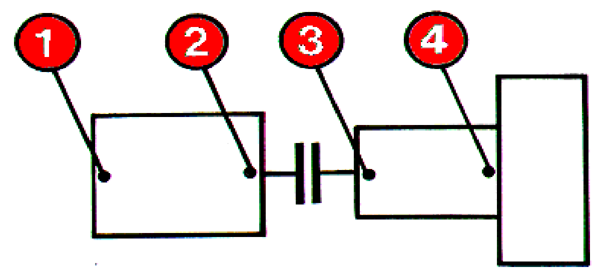


Mount as close as Possible to the Bearing

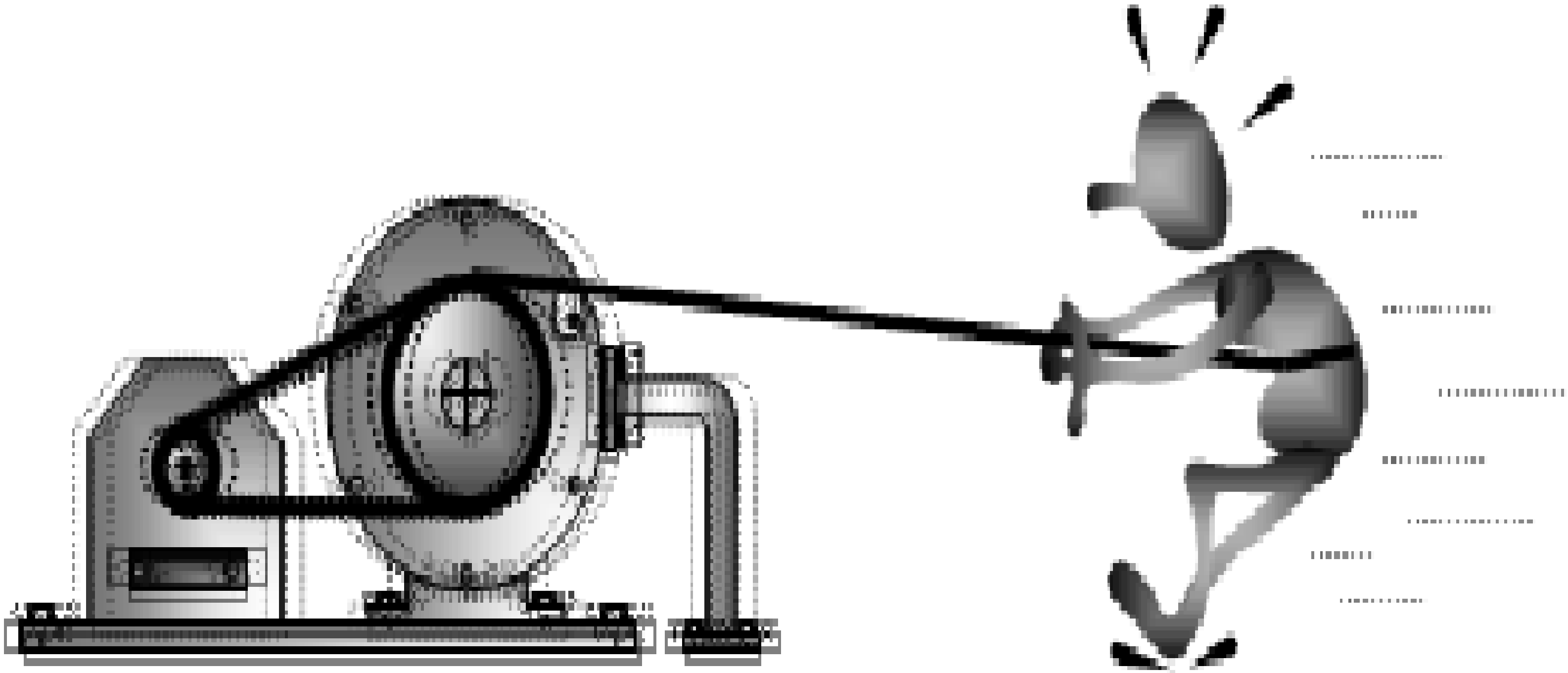


Know the Bearing Location

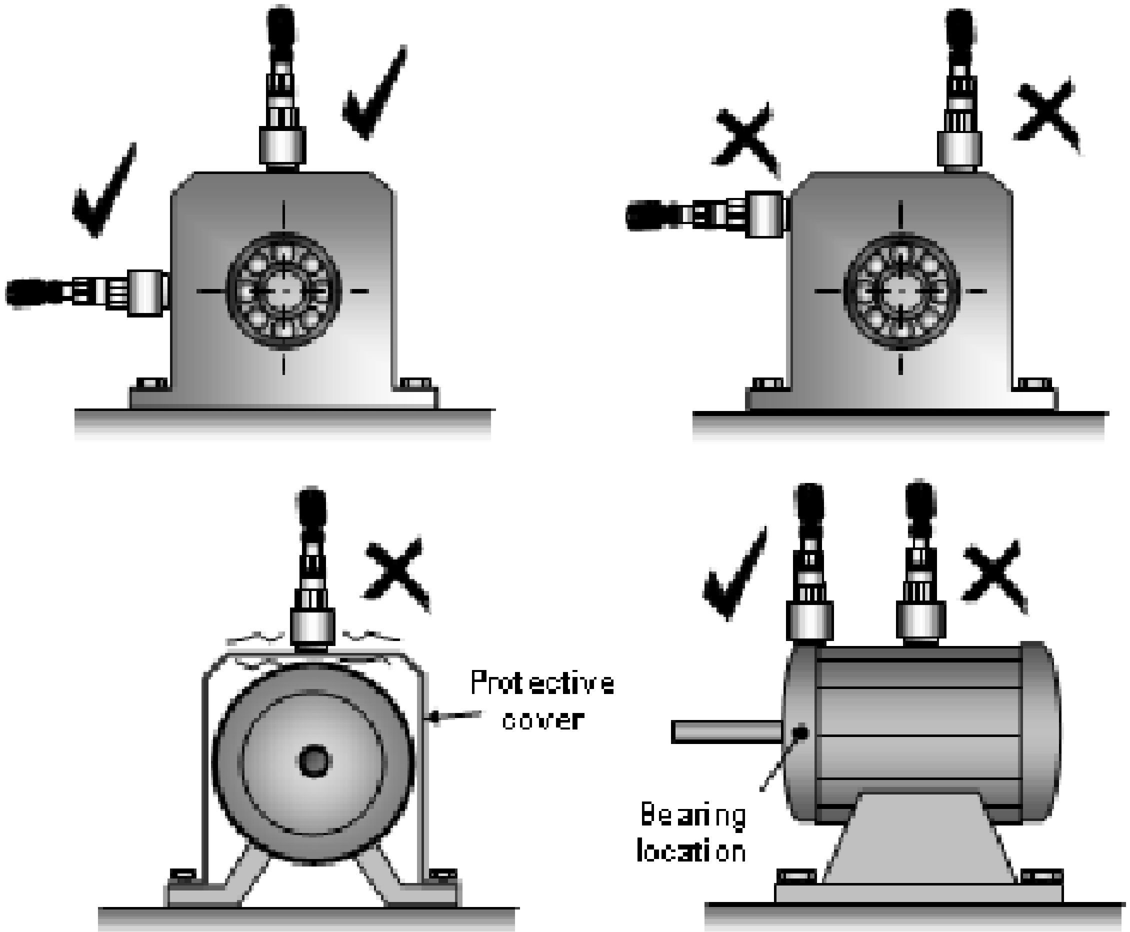




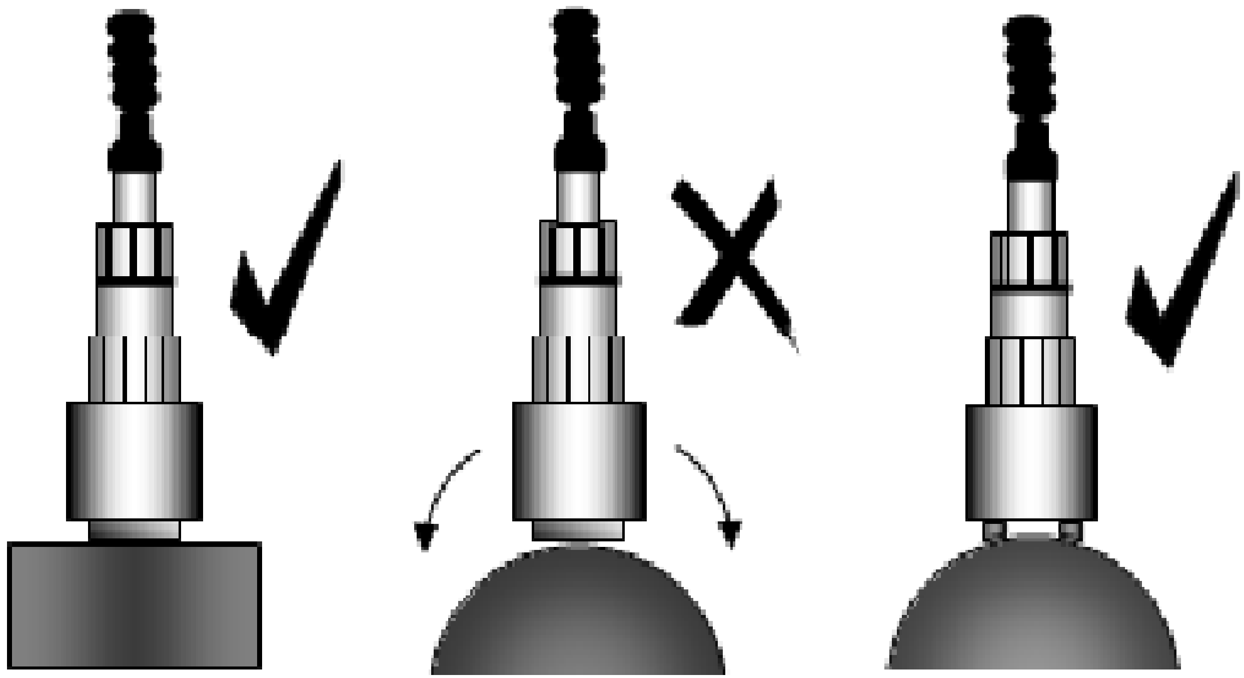
Take care of personal safety



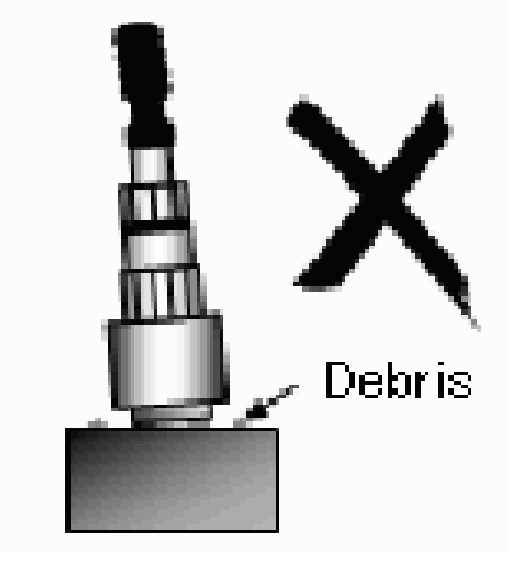
Mount on the Centerline of Bearing



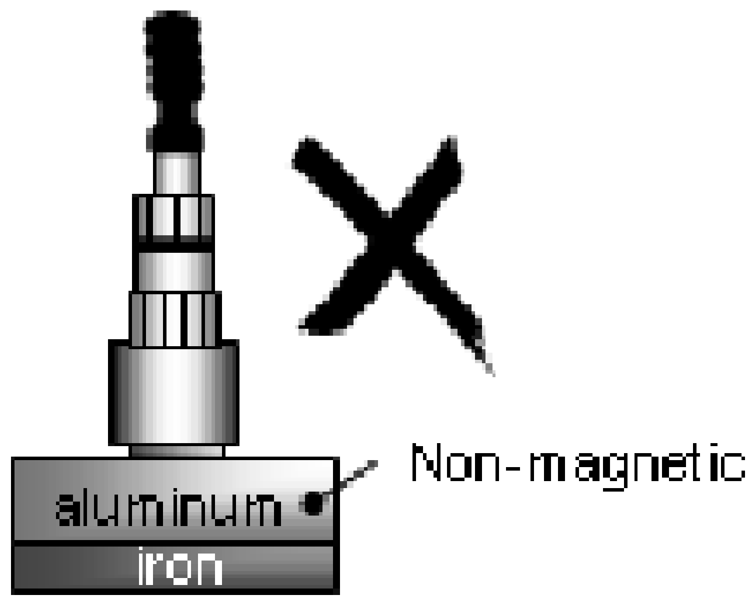
Make sure the accelerometer is firmly attached



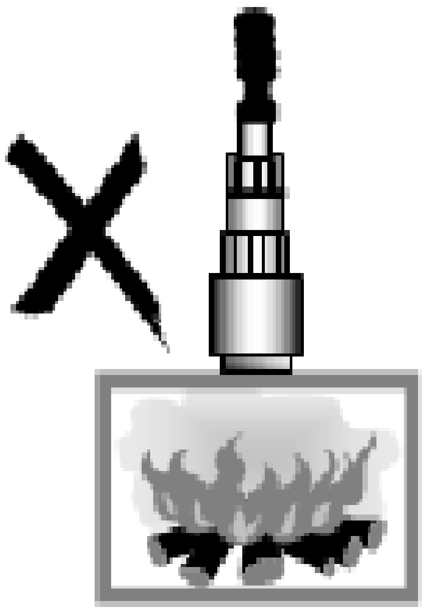
Must be free of debris, rust, and flaking paint

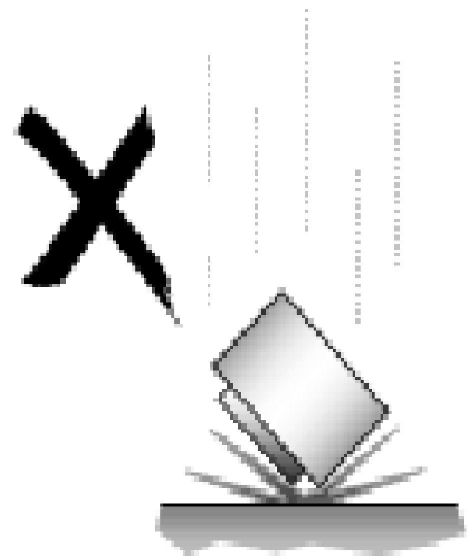


Mounting surface must be truly magnetic

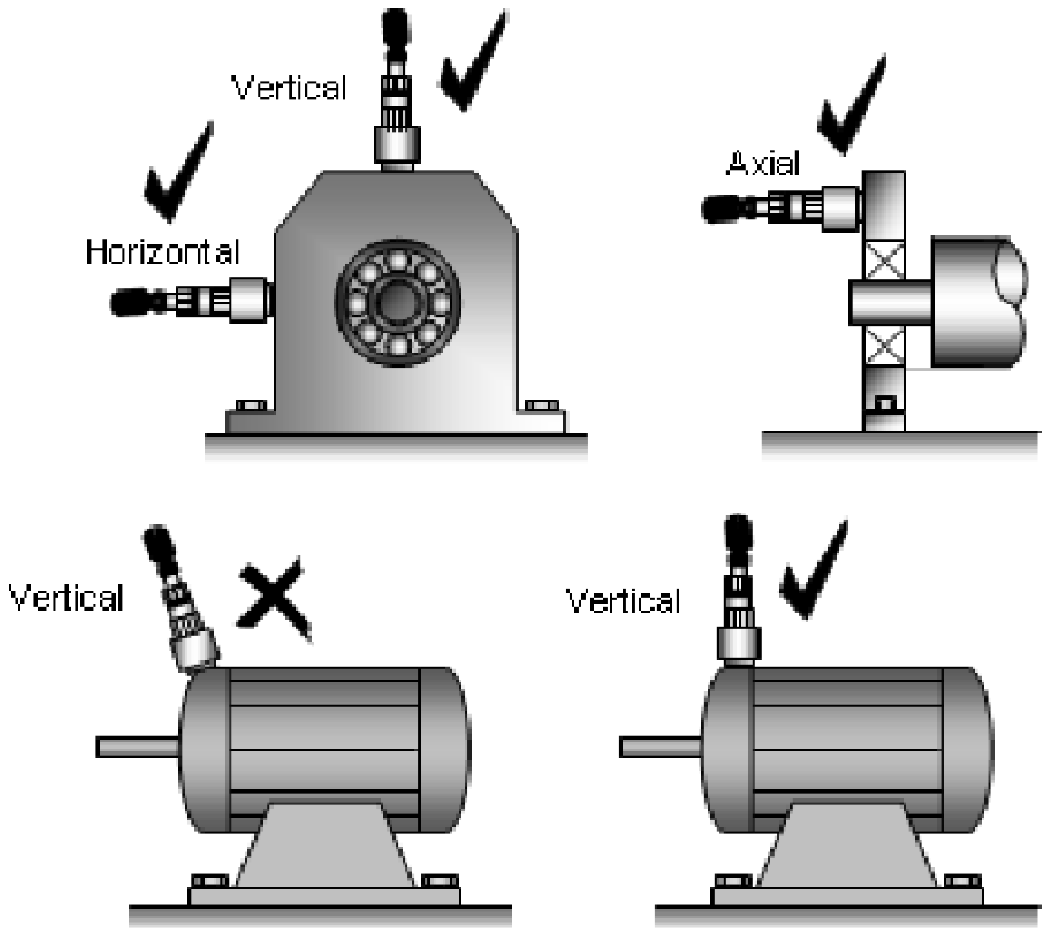


Magnetic mounting should not be dropped or heated

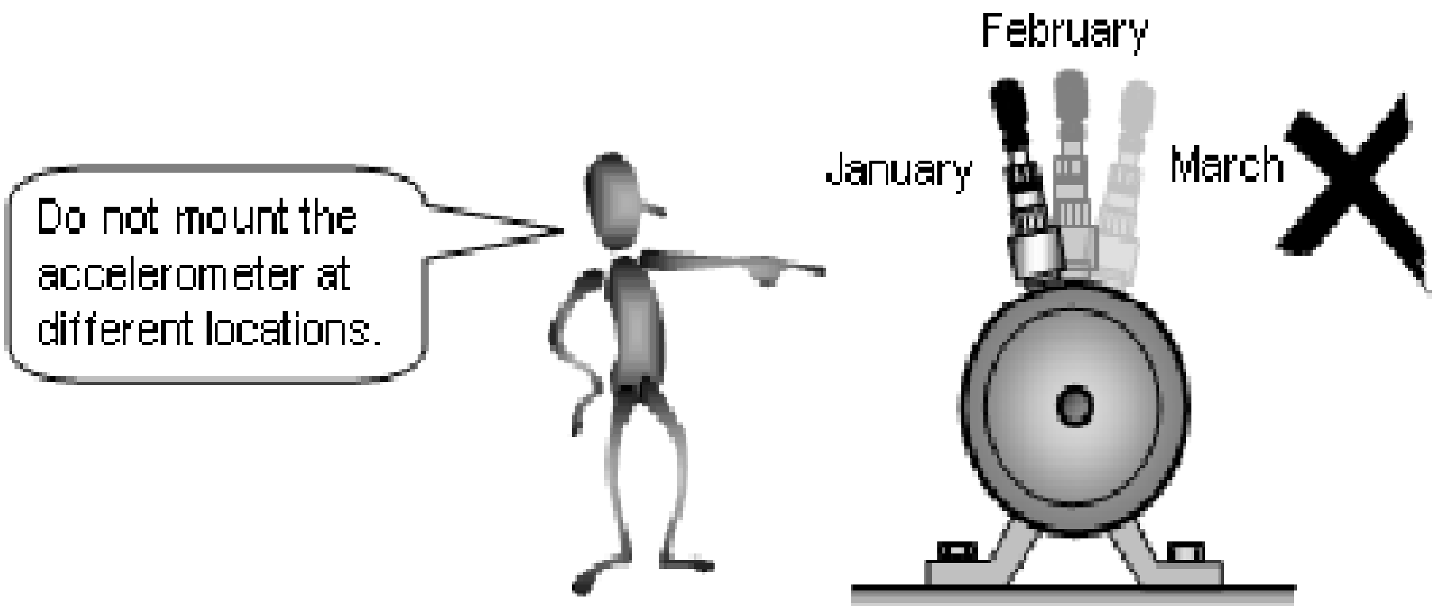




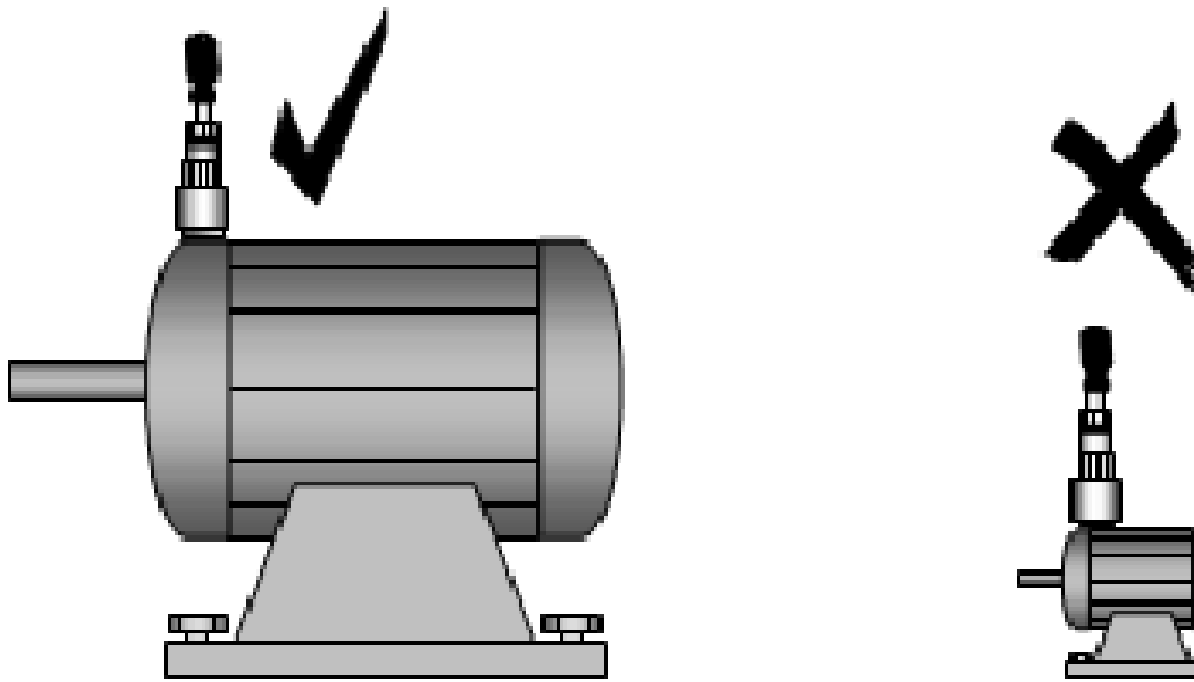
Make sure the accelerometer is oriented correctly



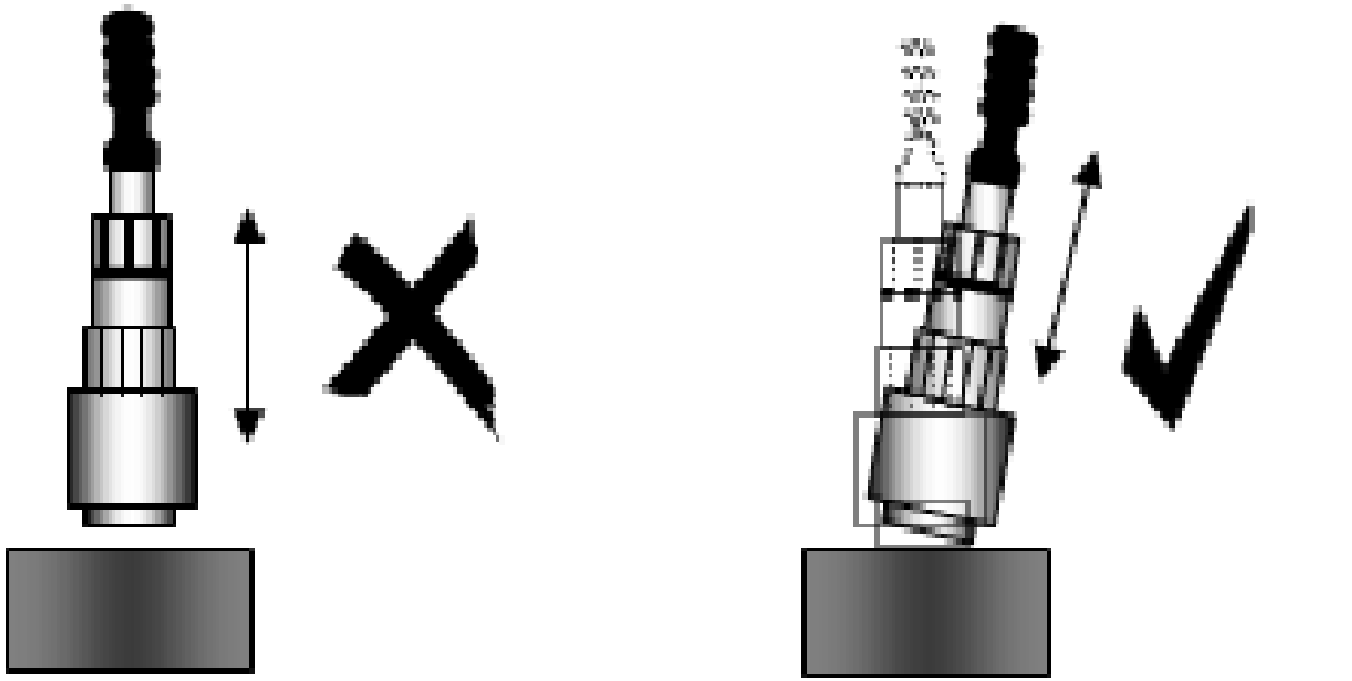
Mount the same accelerometer in same location



Mount the accelerometer on something substantial



Take care of the accelerometer




Thank you
Danke
Xie xie
Khawp khun
Yum
Mahalo
Salamat
Obrigada
Spacibo
Arigato