System Dynamics and Mechanical Vibration

If you have a smart project, you can say "I'm an engineer"

Lecture 3

Staff boarder

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System Dynamics and Mechanical Vibration

- **Lecture aims:**
  - Understand the Maintenance Management Systems
  - Identify the Fault Diagnosis using Vibration Measurement/Analysis

Machine Condition Monitoring and Condition Based Maintenance

Introduction

What is Machine Condition Monitoring and Fault Diagnostics?

- .basically it is a maintenance tool also being applied in quality control, and process control, process monitoring

Machine Condition Monitoring and Condition Based Maintenance

Introduction

ISO definition:

a field of technical activity in which selected physical parameters, associated with machinery operation, are observed for the purpose of determining machinery integrity

- not just vibration based

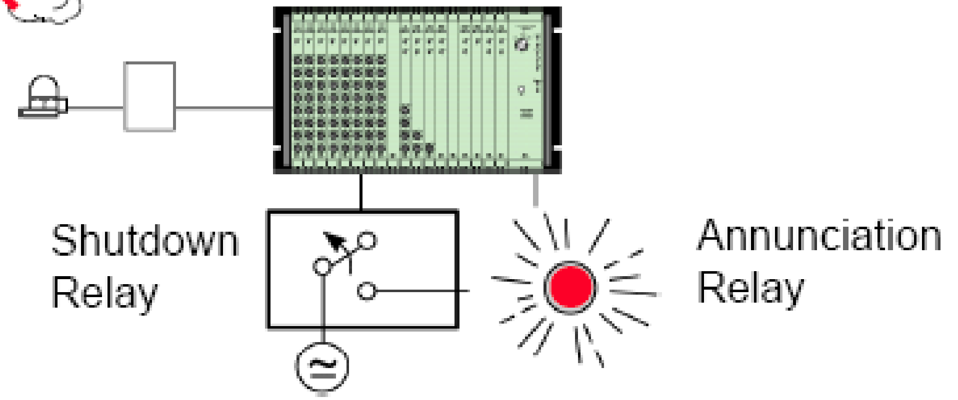
Machine Condition Monitoring and Condition Based Maintenance

Introduction

Also includes:

- oil analysis (oil quality, contamination)
- wear particle monitoring and analysis
- force
- sound pressure (intensity)
- temperature
- output (machine performance)
- product quality
- visual inspection and others

- For avoiding sudden catastrophic breakdown
- Continuous measurements
- Simple measurements
- Relays for automatically tripping.



Basic Maintenance Strategies

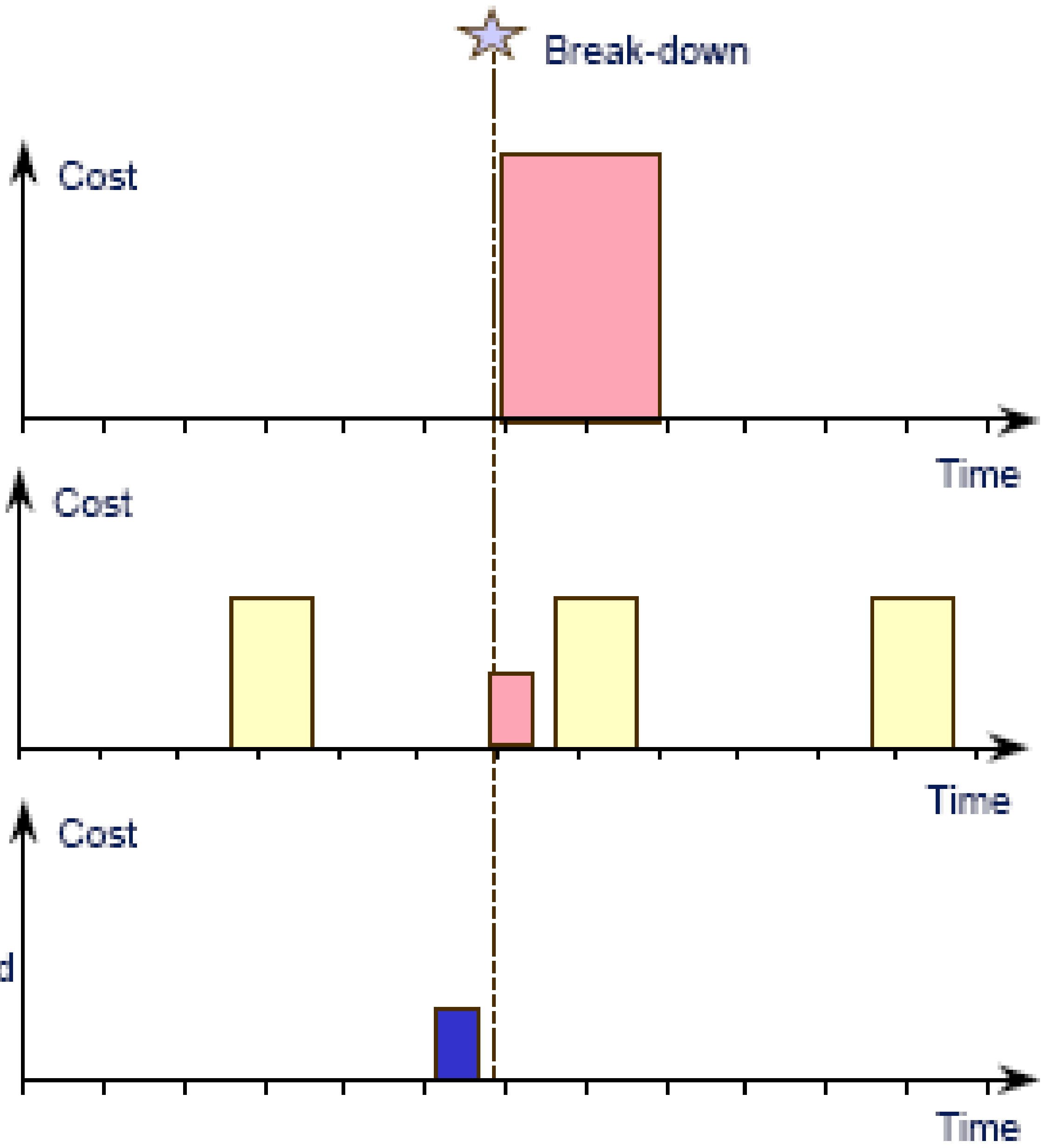
- **Breakdown or run to failure maintenance**
- **Preventive or time-based maintenance**
- **Predictive or condition-based maintenance**
- **Proactive or prevention maintenance.**

Corrective Maintenance
(Run-to-breakdown)

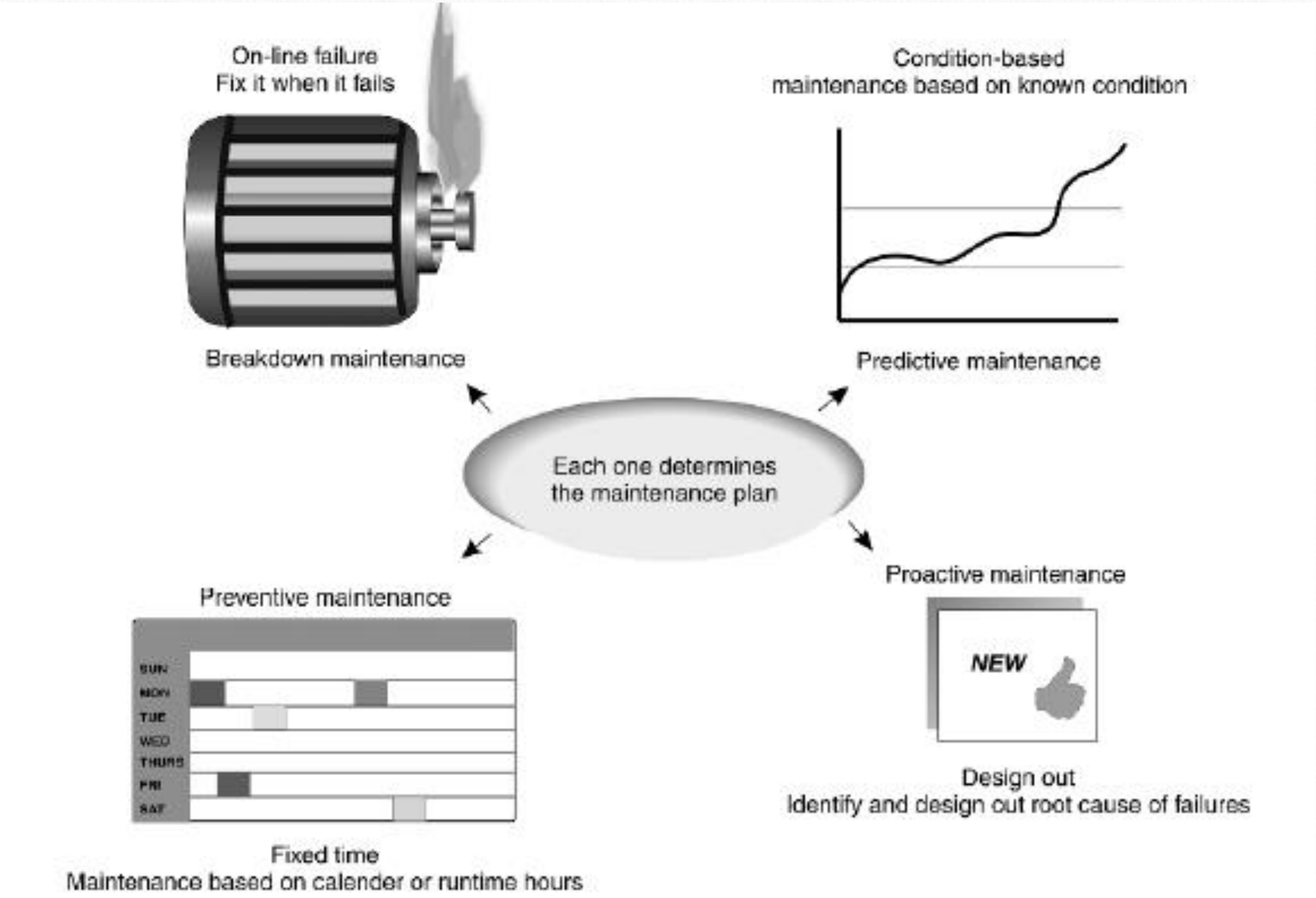
Repair it when it fails

Preventive Maintenance
(Time Based Maintenance)
Maintenance at regular intervals

Predictive Maintenance
(On Condition Maintenance)
Problem detected before predicted failure.
Maintenance planned ahead



Basic Maintenance Strategies



Basic Maintenance Strategies

Condition Based (on-condition, predictive, pro-active, reliability centered) Maintenance

- actual condition of the machinery is assessed
- data used to optimally schedule maintenance
- maximum production and avoidance of catastrophic failures is achieved

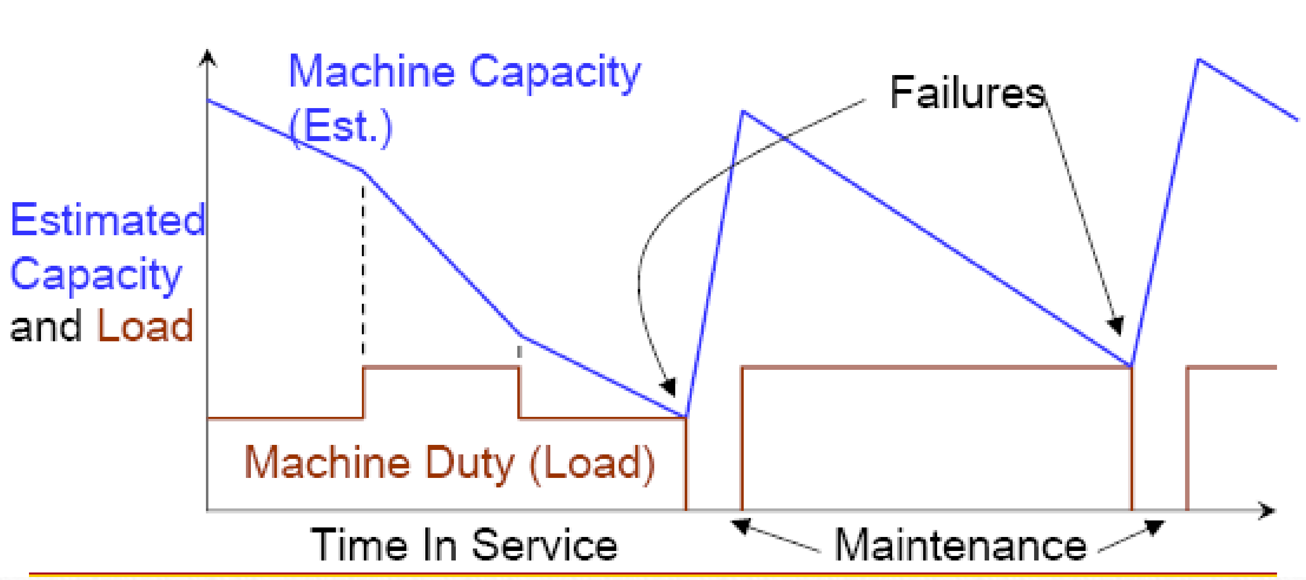
Example: Tire changes on your car.

Basic Maintenance Strategies

Run to failure (Breakdown) Maintenance

- **maintenance performed only when machinery has failed.**

Example: **Burnt out light bulb.**



Basic Maintenance Strategies

Scheduled (Preventative) Maintenance

- specific maintenance tasks performed at set time intervals (or duty cycles)
- significant margin between machine capacity and actual duty maintained.

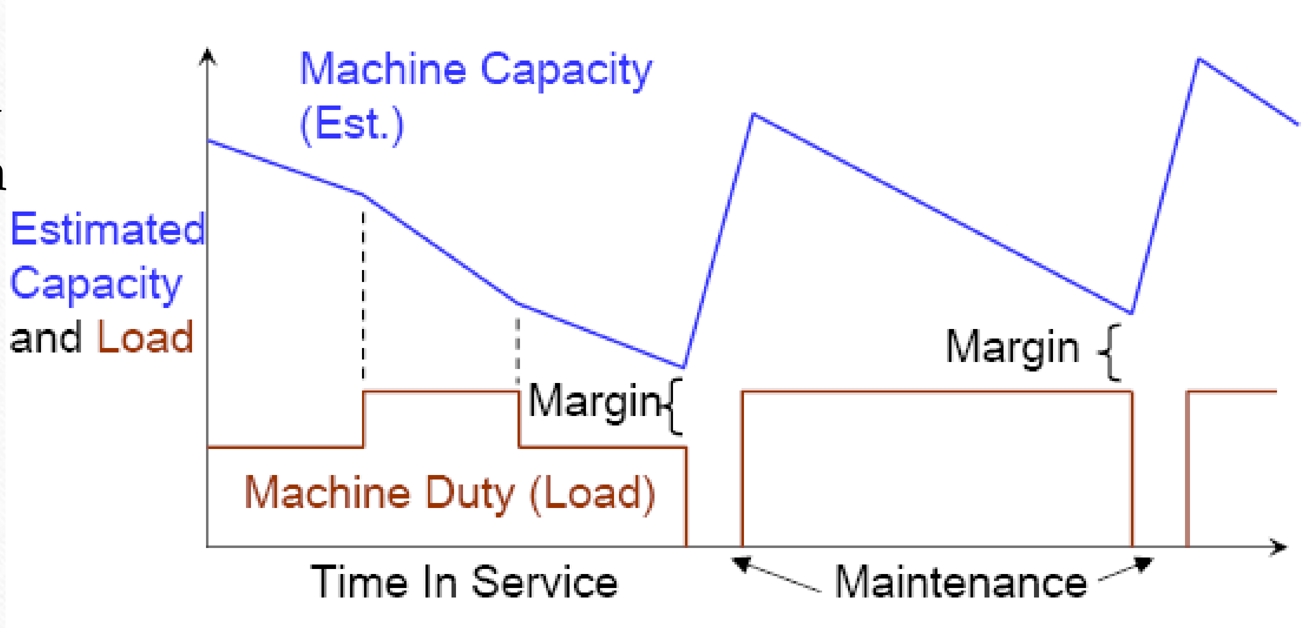
Example: Oil changes on your car, light bulbs above shop floor.

Basic Maintenance Strategies

Scheduled Maintenance

Condition Based Maintenance

- Note: margin between duty and capacity is never allowed to reach zero – breakdown avoidance.
- Results: longer time between maintenance tasks than for scheduled maintenance.



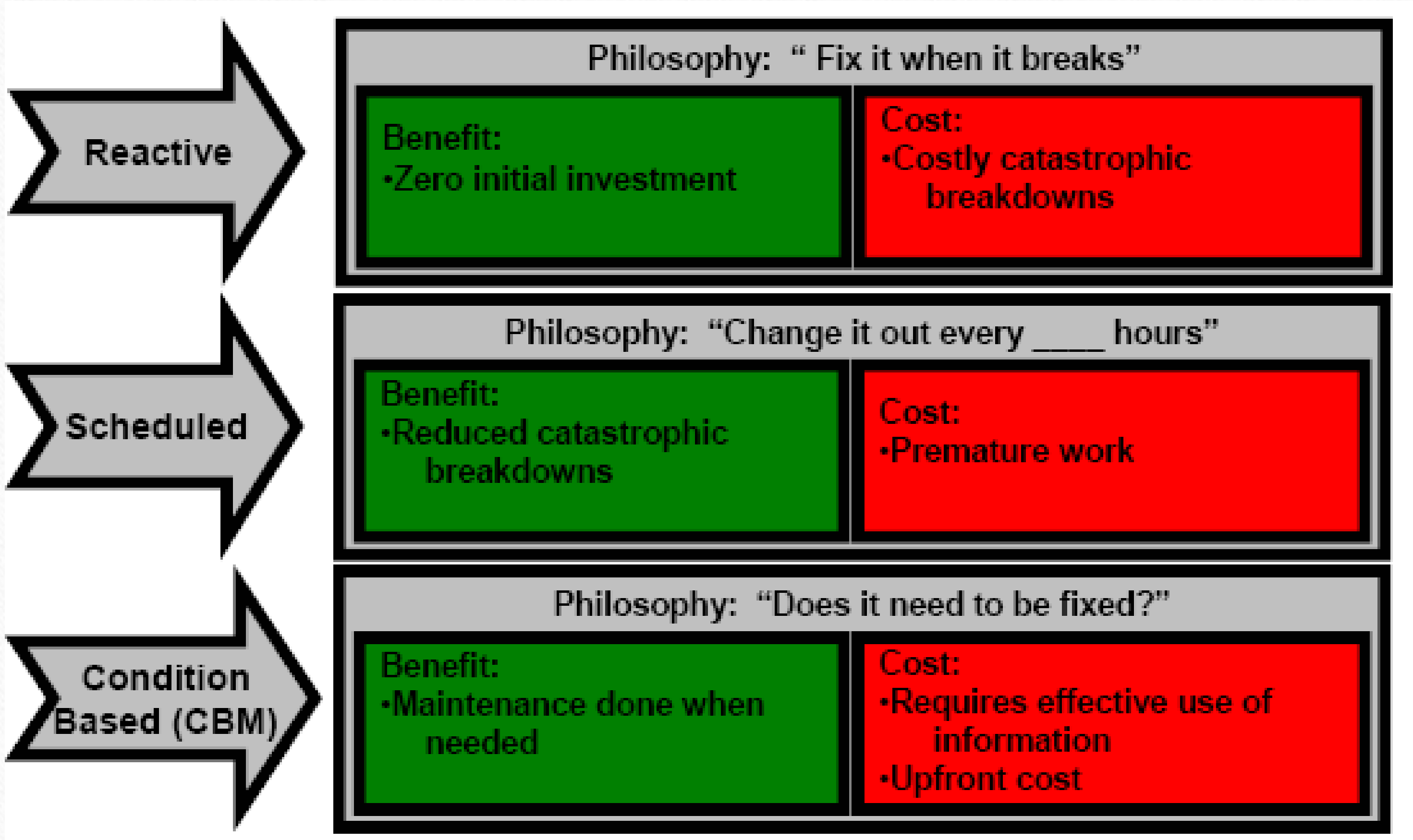
Basic Maintenance Strategies

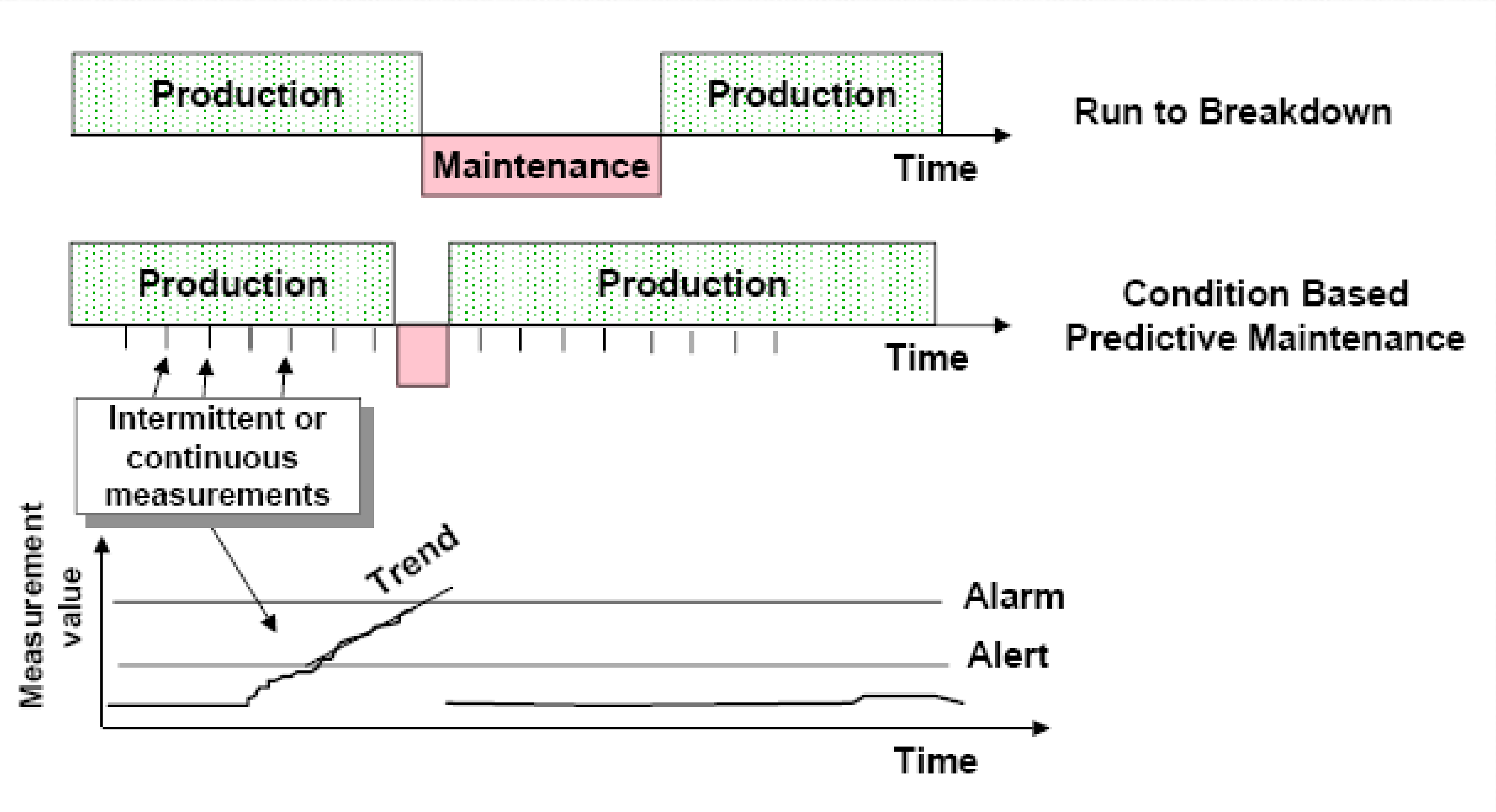
Proactive or prevention maintenance

This philosophy lays primary emphasis on tracing all failures to their root cause. Each failure is analyzed and proactive measures are taken to ensure that they are not repeated.

It utilizes all of the predictive/preventive maintenance techniques discussed above in conjunction with root cause failure analysis (RCFA). RCFA detects and pinpoints the problems that cause defects. It ensures that appropriate installation and repair techniques are adopted and implemented. It may also highlight the need for redesign or modification of equipment to avoid recurrence of such problems.

Basic Maintenance Strategies





Production
Production
Maintenance
Time
Run to Breakdown
Production
Production
Time
Condition Based
Predictive Maintenance
Intermittent or
continuous
measurements
Measurement
value
Trend
Alarm
Alert
Time

Basic Maintenance Strategies

Advantages and disadvantages do exist.

- Situations exist where one or the other would be appropriate.
- The maintenance engineer must decide and justify action.
- Combinations of strategies may also be required.

Examples:

- increased frequency of monitoring as the age of a machine increases
- maximum time between overhauls with monitoring looking for random failures

Basic Maintenance Strategies

Factors which Influence Maintenance Strategy

- classification of machine
- critical to production?
- high cost of replacement?
- long lead time for replacement?
- manufacturers recommendations
- failure data (history) & failure modes
- redundancy
- safety (plant personnel, community, environment)
- parts cost/availability
- costs (personnel, administrative, equipment)
- running costs

Machine Condition Monitoring and Fault Diagnostics

Potential advantages

- increased machine availability and reliability
- improved operating efficiency
- improved risk management (less down time)
- reduced maintenance costs (better planning)
- reduced spare parts inventories
- improved safety
- improved knowledge of machine condition

(safe overloading of machine possible)

Machine Condition Monitoring and Fault Diagnostics

Potential disadvantages

- monitoring equipment costs (high)
- operational costs (running the program)
- skilled personnel needed
- needs strong management commitment
- long run-in time to collect machine histories and set trends
- reduced costs are harder to sell as direct
benefits to management than increased profits

Plant machinery classification and recommendations

Usually the criticality analysis categorizes the equipment as:

- Critical
- Essential
- General purpose.

The ***critical*** equipment are broadly selected on the following basis:

- If their failure can affect plant safety.
- Machines that are essential for plant operation and where a shutdown will curtail the production process.
- Critical machines include unspared machinery trains and large horsepower trains.
- These machines have high capital cost, they are very expensive to repair (e.g., high-speed turbomachinery) or take a long time to repair.
- Perennial 'bad actors' or machines that wreck on the slightest provocation of an off-duty operation.
- Finally, machinery trains where better operation could save energy or improve production.

Plant machinery classification and recommendations

The *essential* equipment are broadly selected on the following basis:

- Failure can affect plant safety.
- Machines that are essential for plant operation and where a shutdown will curtail a unit operation or a part of the process.
- They may or may not have an installed spare available.
- Start-up is possible but may affect production process.
- High horsepower or high speed but might not be running continuously.
- Some machines that demand time-based maintenance, like reciprocating compressors.
- These machines require moderate expenditure, expertise and time to repair.
- Perennial ‘bad actors’ or machines that wreck at a historically arrived time schedule. For example, centrifugal fans in corrosive service.

Plant machinery classification and recommendations

The *general purpose* equipment are broadly selected on the following basis:

- Failure does not affect plant safety.
- Not critical to plant production.
- Machine has an installed spare or can operate on demand.
- These machines require low to moderate expenditure, expertise and time to repair.
- Secondary damage does not occur or is minimal.

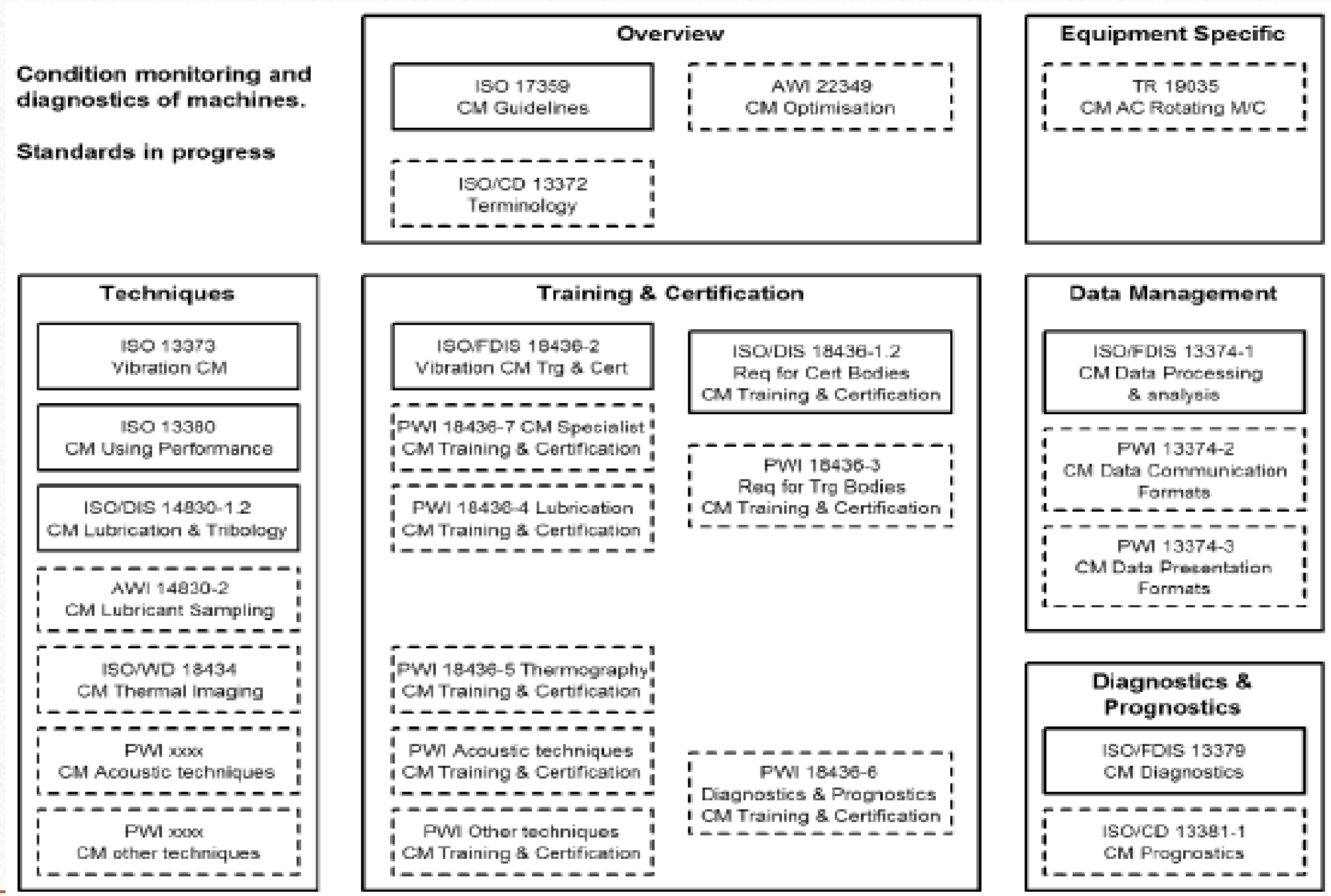
Standards Based on Machinery Type

ISO TC 108 – Mechanical Vibration and Shock

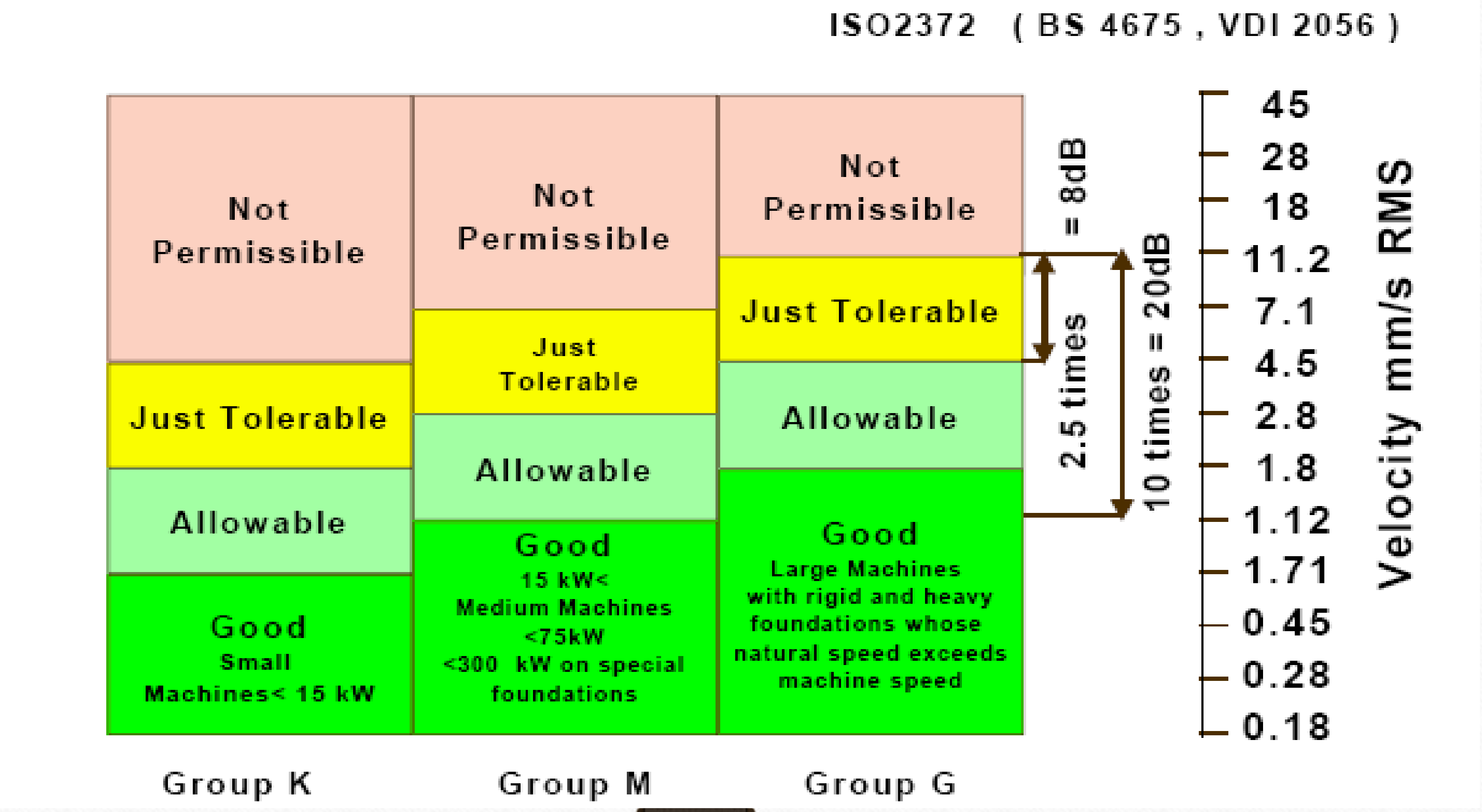
Scope (general): Standardization in the field of mechanical vibration and shock, and condition monitoring and diagnostics of machines.

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

Standards Based on Machinery Type



Standards Based on Machinery Type



Standards Based on Machinery Type

ISO 2372 – ISO Guideline for Machinery Vibration Severity					
Ranges of Vibration severity		Examples of quality judgment for separate classes of machines			
Velocity – in/s – Peak	Velocity – mm/s – rms	Class I	Class II	Class III	Class IV
0.015	0.28				
0.025	0.45				
0.039	0.71				
0.062	1.12				
0.099	1.8				
0.154	2.8				
0.248	4.5				
0.392	7.1				
0.617	11.2				
0.993	18				
1.54	28				
2.48	45				
3.94	71				

A – Good
B – Acceptable
C – Still acceptable
D – Not acceptable

Vibration Transducers

Definition:

a transducer is device which senses a physical quantity (vibration, temperature, pressure, etc.) and converts it into an electrical signal.

- output is proportional to the measured variable
- vital link in the measurement chain
- missed or distorted information cannot be recovered later
- usually require amplification and conversion electronics

Transducers must be

- correct for the task
- properly mounted
- in good working order (properly calibrated)
- fully understood (characteristics)

Standards Based on Machinery Type

Three main classes:

- Displacement transducers (contact and noncontact)
- Velocity transducer (electro mechanical, piezoelectric)
- Accelerometers (piezoelectric)

Force and frequency considerations usually dictate the type of measurements and applications that are best suited for each transducer

Frequency Ranges of Application

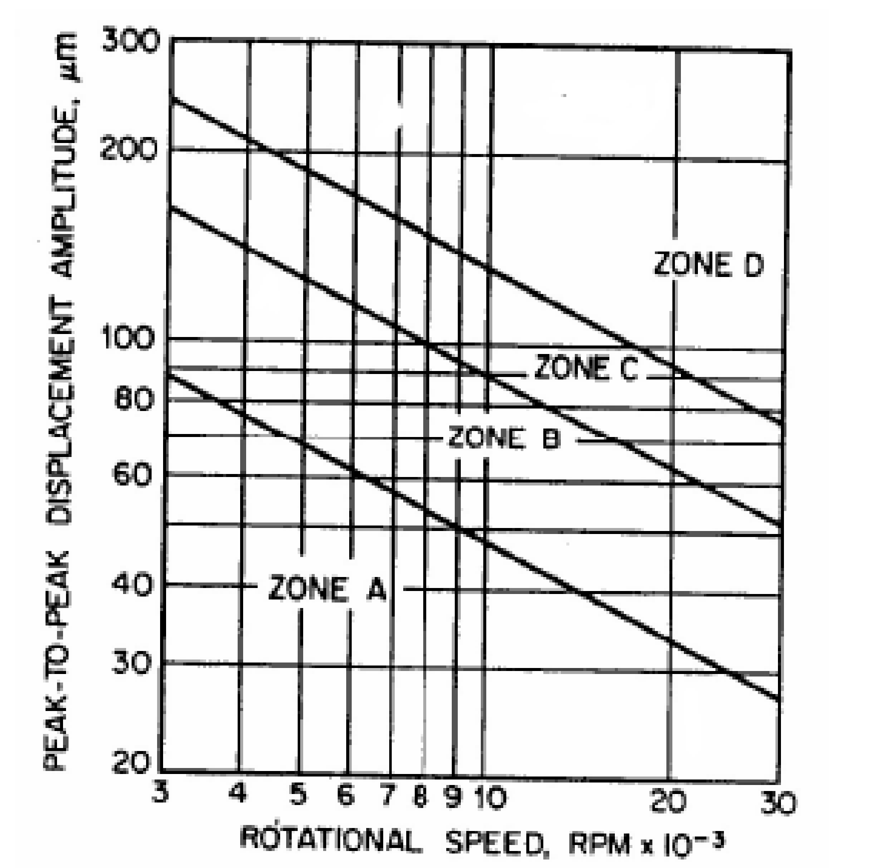
General guidelines for transducer selection.

• displacement	< 1000 Hz (1500 Hz)
• velocity	
(electromechanical)	10 - 1000 Hz
(piezolectric)	10 - 2000 Hz
• accelerometer	> 1.0 Hz

Standards Based on Machinery Type

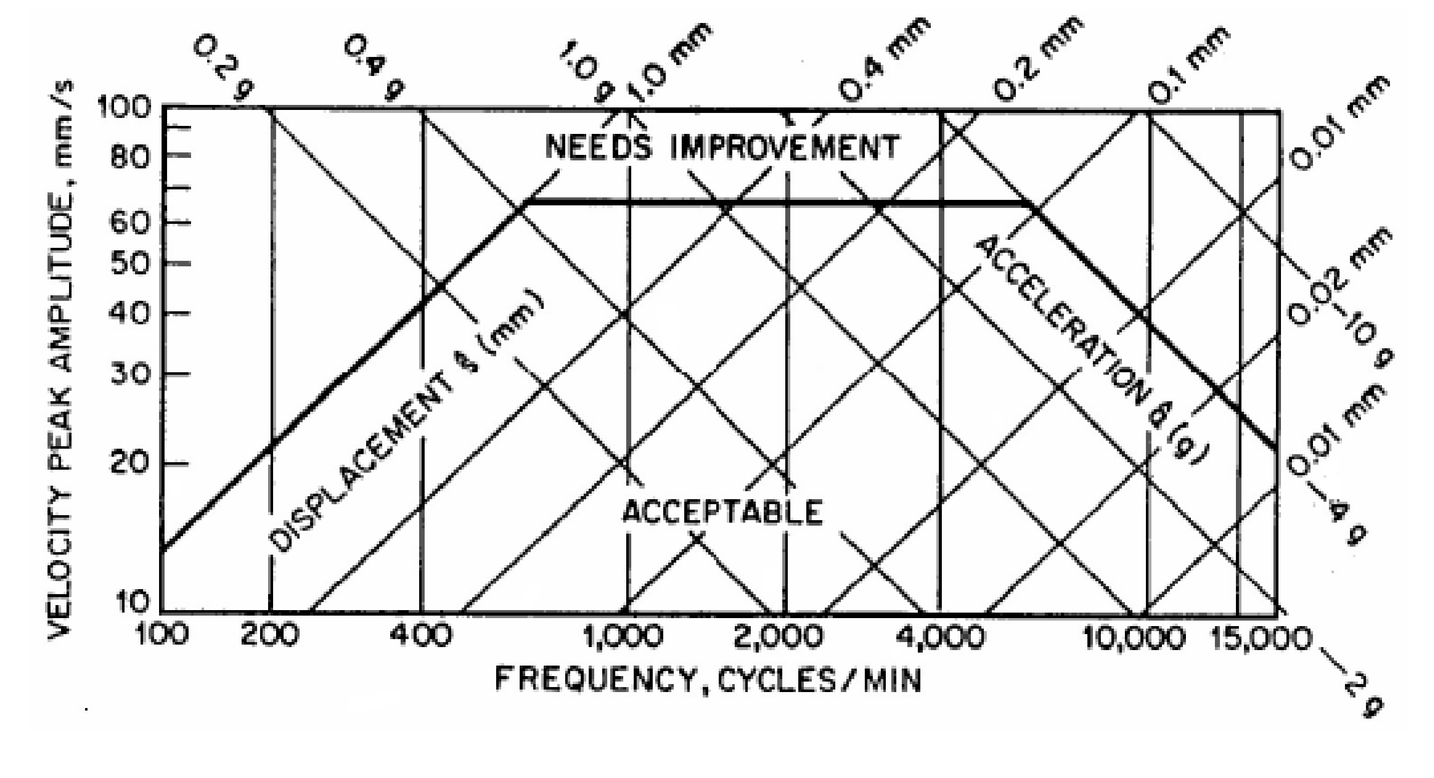
RMS velocity vibration severity		Support classification	
mm/s	in./sec	Rigid supports	Flexible supports
0.46	0.018		
0.71	0.028	Good	
1.12	0.044		Good
1.8	0.071		
2.8	0.11	Satisfactory	
4.6	0.18		Satisfactory
7.1	0.28	Unsatisfactory	
11.2	0.44		Unsatisfactory
18.0	0.71		
28.0	1.10	Unacceptable	
46.0	1.80		
71.0	2.80		Unacceptable

Standards Based on Machinery Type



A – good
B – Acceptable
C – Monitor closely
D - Unacceptable

Standards Based on Machinery Type



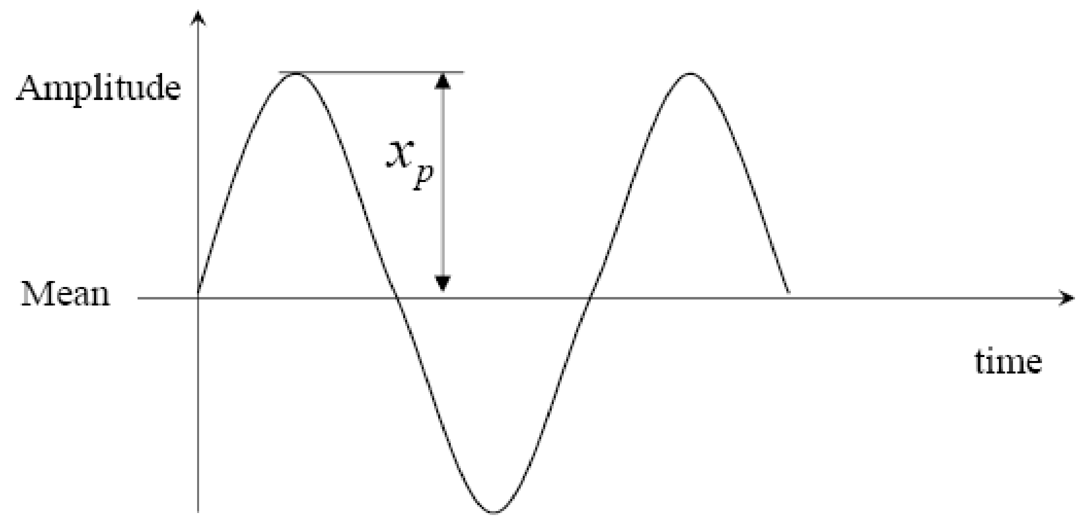
Vibration Descriptors

Peak Value (zero-to-peak)

Indicates peak vibration level of the signal.

Definition:

$$x_p = \max\left[x(t) - \bar{x}\right]$$



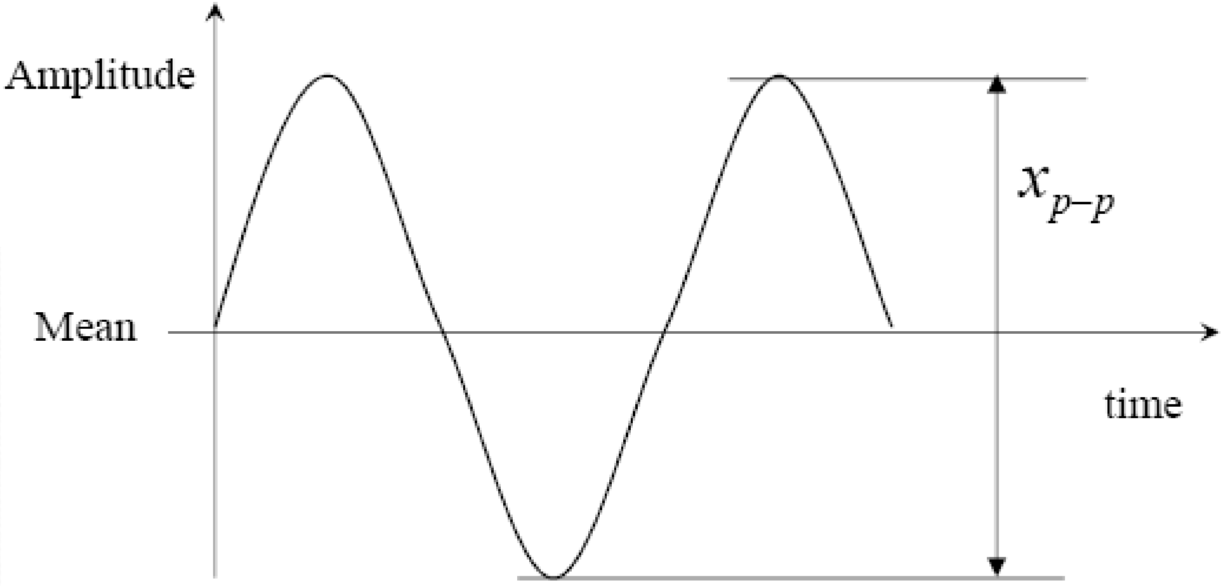
Vibration Descriptors

Peak-to-Peak

Indicates total fluctuation in the vibration signal.

Definition:

$$x_{p-p} = \max[x(t)] - \min[x(t)]$$



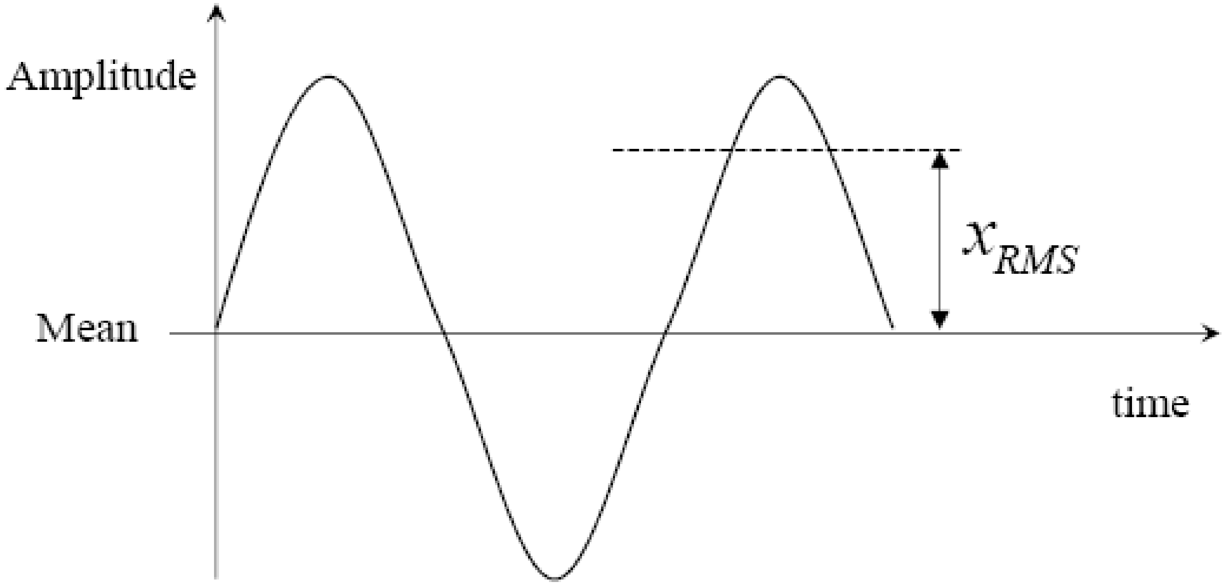
Vibration Descriptors

RMS (root mean square)

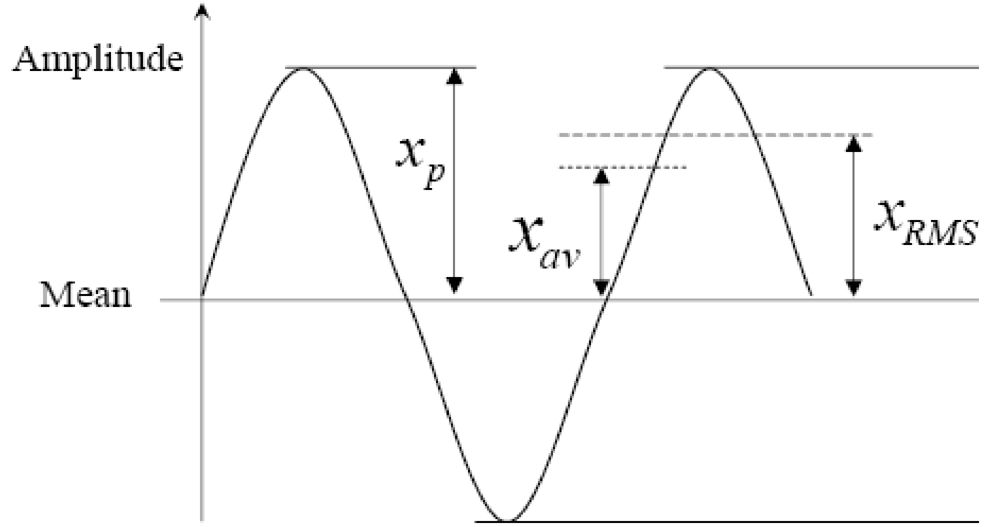
Value proportional to the energy in the vibration signal.

Definition:

$$x_{RMS} = \sqrt{\frac{1}{T}\int [x(t)]^2\, dt}$$



Vibration Descriptors



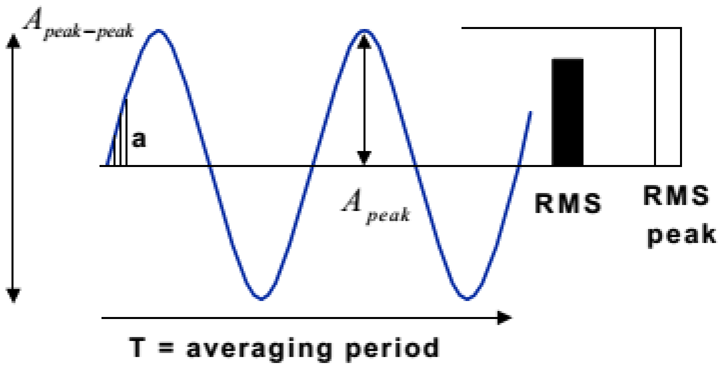
$$x(t) = A\sin(\omega t + \theta)$$

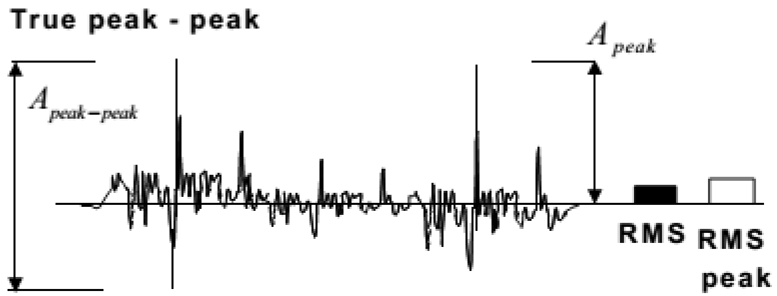
$$x_{RMS} = 0.707A$$

$$x_p = A$$

$$x_{p-p} = 2A$$

$$x_{av} = 0.637A$$





$$A_{RMS} = \sqrt{\frac{1}{T}\int_0^T a^2(t)\,dt}$$

For Sine waves only:

$$A_{peak} = \sqrt{2} * A_{RMS}$$

Crest factor = $\frac{A_{peak}}{A_{RMS}}$

K factor = $A_{RMS} * A_{peak}$

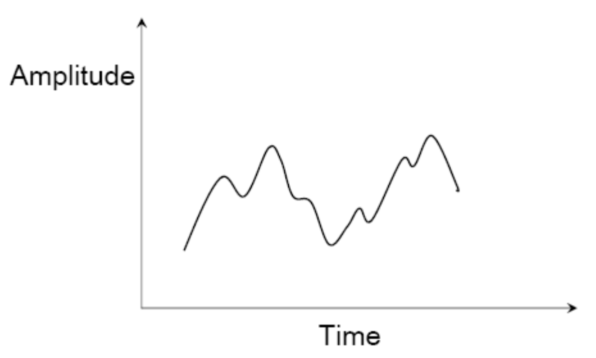
Vibration Descriptors

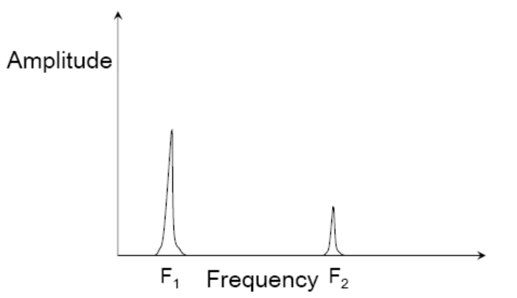
Note that equations on the last slide are true for simple harmonic motion only. If the vibration signal has a different character the simplification below does not hold.

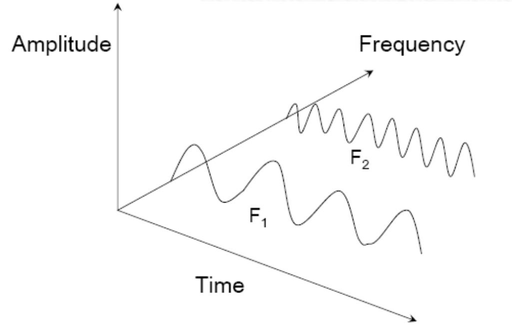
$$x_{RMS} \neq 0.707A$$

But rather, the RMS value must be calculated from...

$$x_{RMS} = \sqrt{\frac{1}{T}\int [x(t)]^2 dt}$$

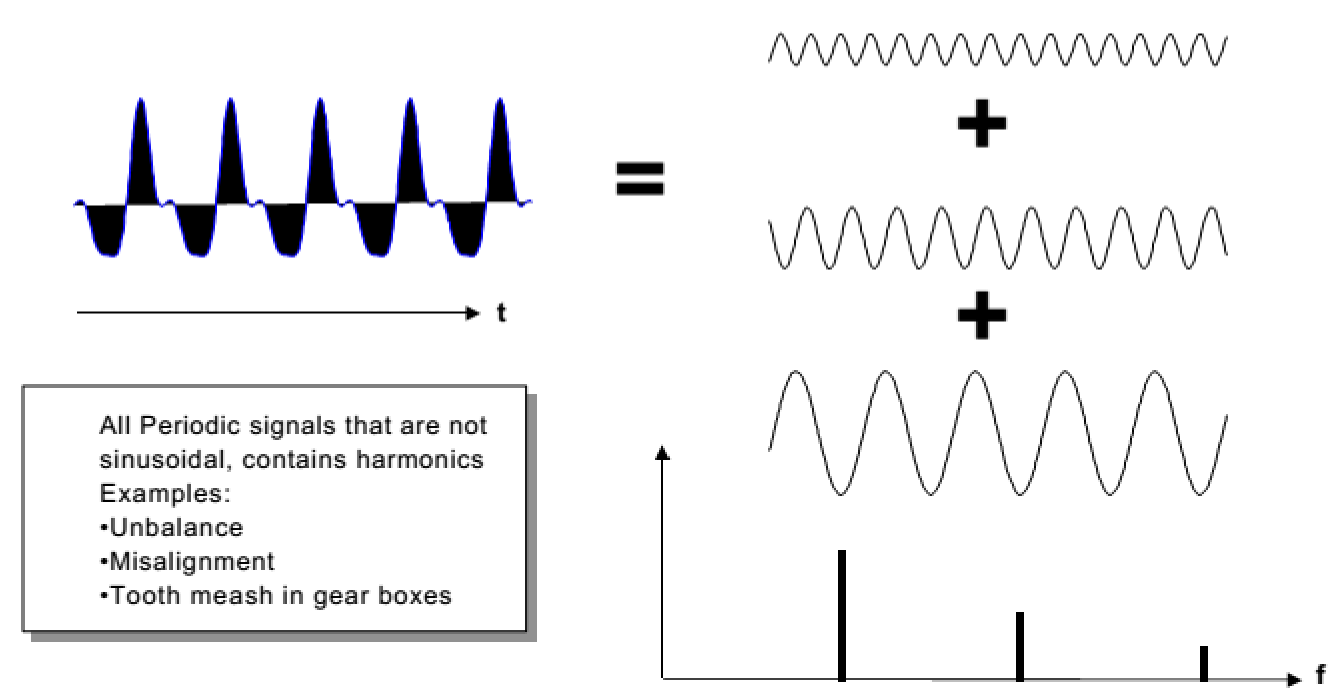






Vibration Descriptors

According to Fouriers theorem, all periodic signals can be produced from sinusoidals. Often machine signals are not purely sinusoidal, therefore we most of the see harmonics in the machine signal spectrum.



Decibel (dB) units

A measure of vibration amplitude

- Logarithmic scale
- With respect to a reference value
- Effective in displaying small values together with very large values.

$$dB = 20 \log_{10} \left[\frac{A_{rms}}{A_{ref}} \right]$$

dB increase	Linear Multiplication
6	x 2
10	x 3
20	x 10
30	x 30
40	x 100
50	x 300
60	x 1000
70	x 3000

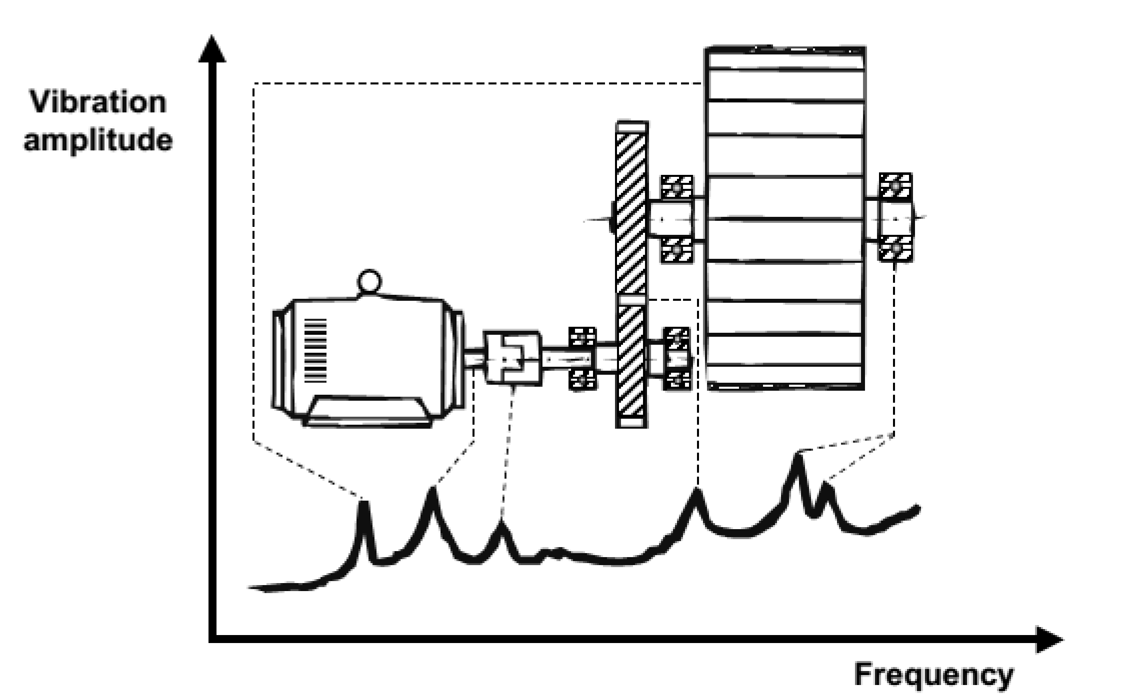
Fault analysis

- Unbalance
- Misalignment
- Eccentricity
- Bent Shaft
- Shaft Crack
- Mechanical Looseness
- Journal Bearing Faults
- Rolling Element Bearing Faults
- Rotor Rub
- Cavitation
- Electrical Motor Problems
- Gear Faults

Fault Detection

The vibration that is measured on this machine is analyzed in a frequency spectrum. Each frequency peak corresponds to a cyclic event in the machine.

The leftmost peak in the spectrum corresponds to the rotation speed of the fan. The second peak to the motor rotation frequency. Coupling misalignments are often coming up at two times this frequency. At the frequency of tooth mesh (and its harmonics), you may see gear problems. In the high frequency you may see problems in rotating element bearings.

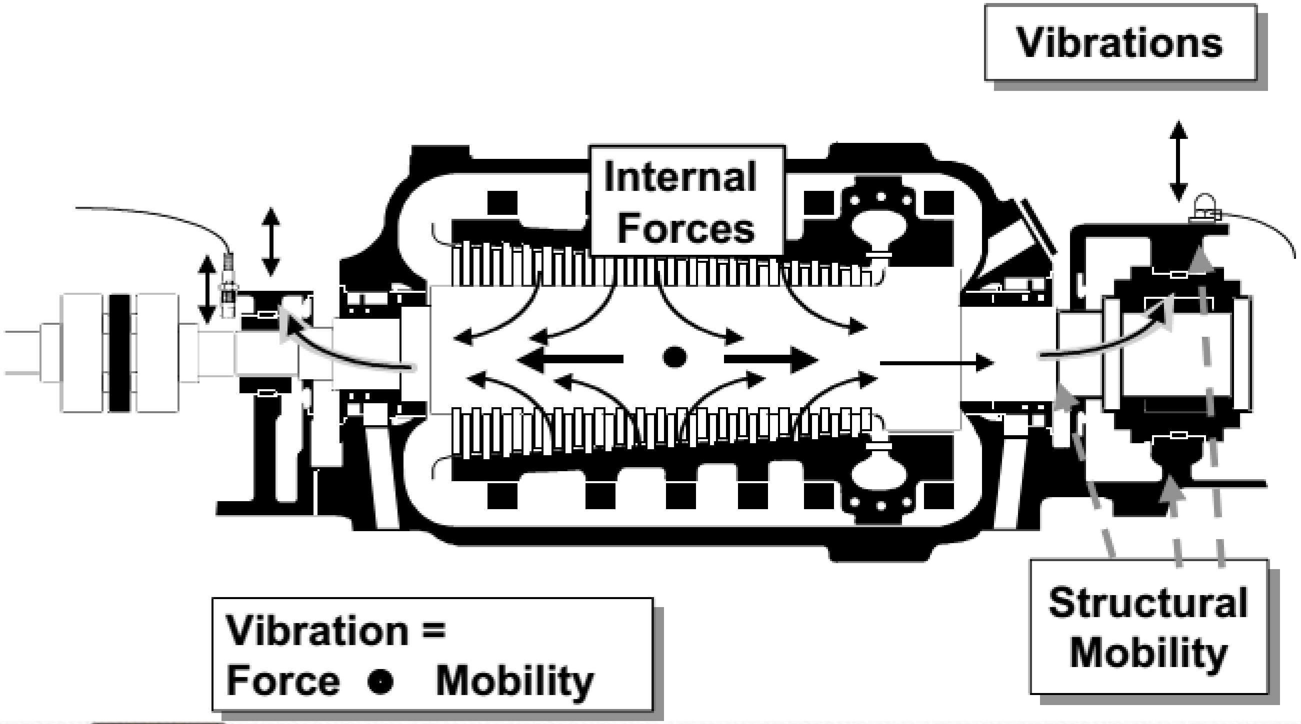


Fault Detection

Changes in forces can be caused by direct changes in the work process or by changes in the properties of the machine elements.

The amount of vibration generated by the forces passing through a machine structure at any point is given by Force * Mobility = Vibration

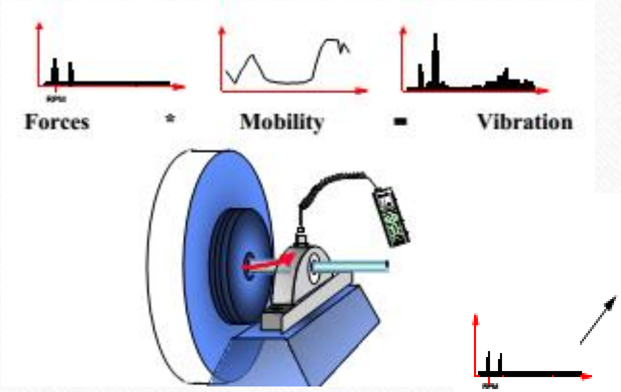
The vibrations can either be measured as relative movement of the shaft with respect to the bearing housing using a displacement probe (left bearing on the drawing) or as absolute movement of the bearing housing using an accelerometer.



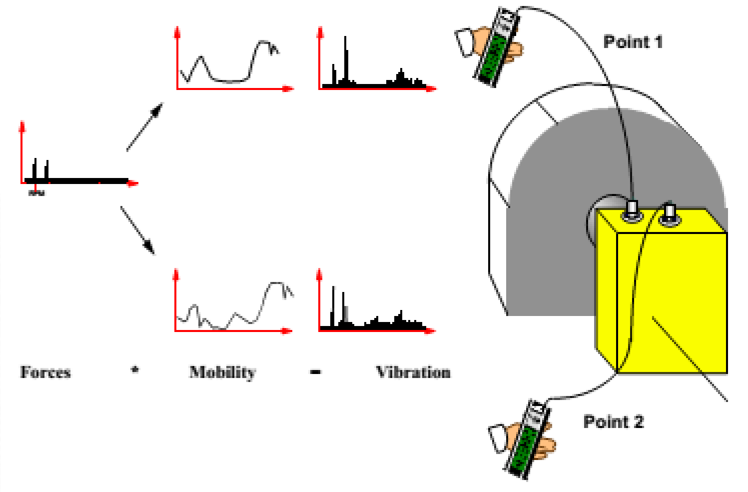
Fault Detection

The mobility may be different at different frequencies. This means that the highest peak in the vibration spectrum does not necessarily correspond to the highest force component in the machine.

The mobility is also very dependent upon where on the machine you make the measurement



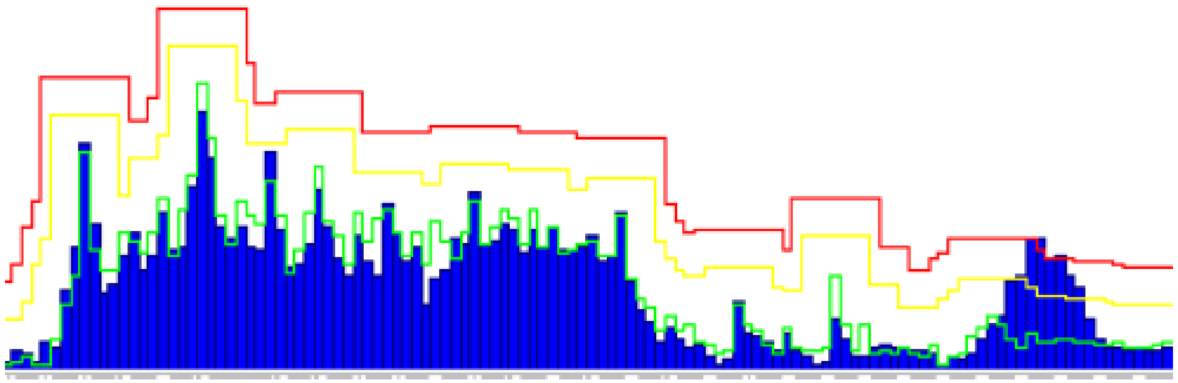
The mobility of a structure can be measured by exiting it with a force (measured with a force transducer), from a hammer or a shaker and measure the produced vibration.



Therefore the vibration measured may vary very strongly from point to point.

Fault Detection

The CBP spectra with its *wide frequency range* and *adequate resolution in any frequency range,* has proven to be the best tool there is for fault detection.



- Constant Percentage Bandwidth Spectra
- Most efficient tool for Fault Detection

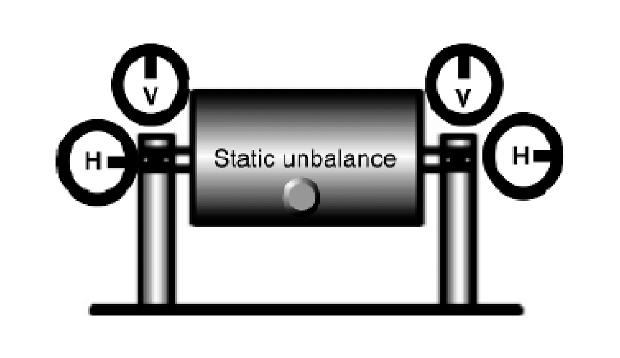
Fault Detection

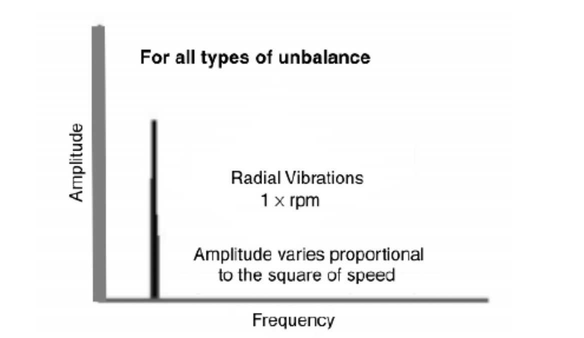
Unbalance

Static unbalance

That condition, which exists in a rotor when vibratory, force
its bearings as a result of centrifugal forces.

The *rotating centerline* is defined as the axis about which the rotor would rotate if not constrained by its bearings (also called the principle inertia axis or PIA). The *geometric centerline* (GCL) is the physical centerline of the rotor.





Static unbalance (PIA and GCL are parallel)

The amplitude at the 1× varies proportional to the square of speed.

in-phase and steady

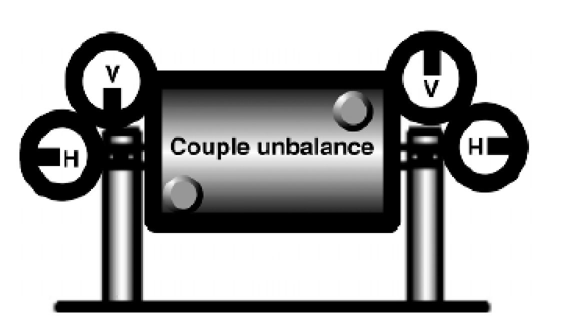
Fault Detection

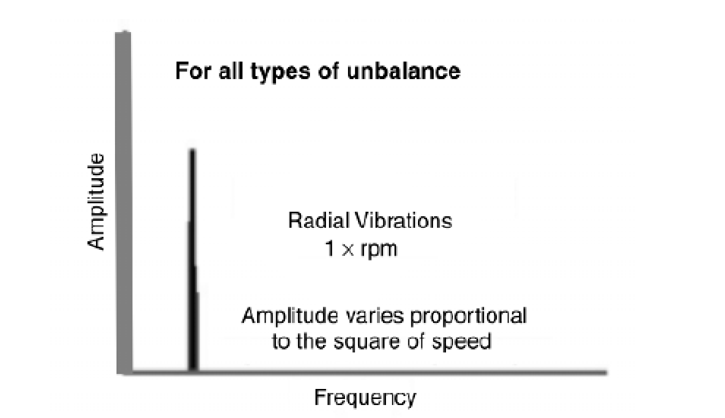
Couple unbalance

The amplitude at the 1× varies proportional to the square of speed.

Dynamic unbalance (PIA and GCL do not touch or coincide).

Couple unbalance tends to be 180° out of phase on the same shaft.



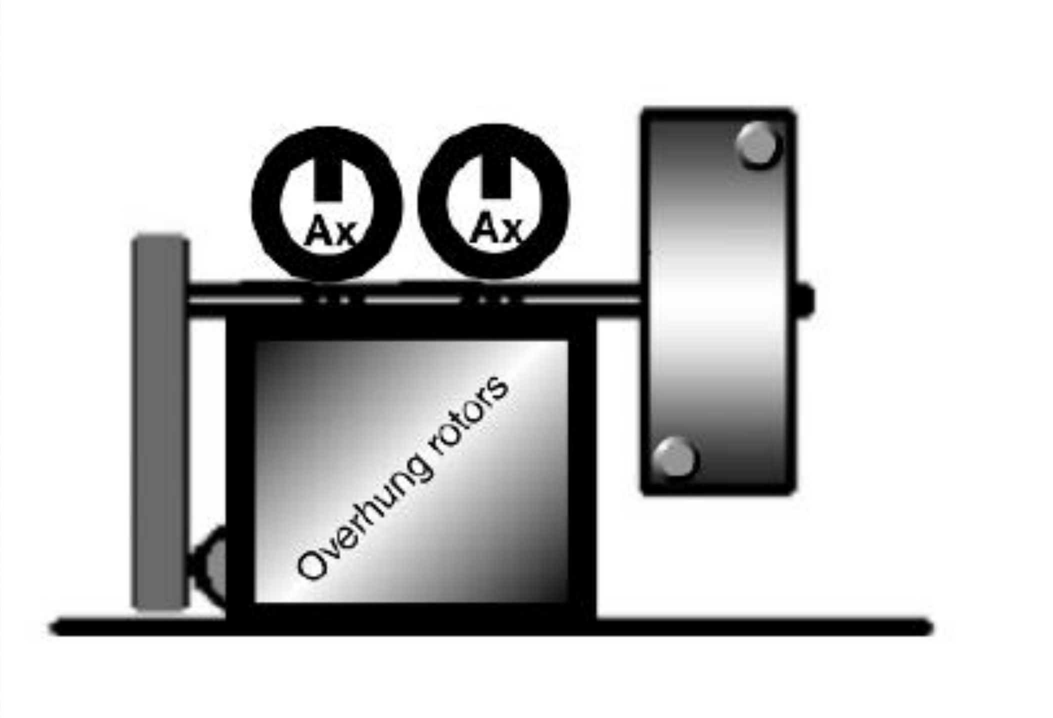


Fault Detection

Unbalance – overhung rotors

The amplitude at the 1× varies proportional to the square of speed.

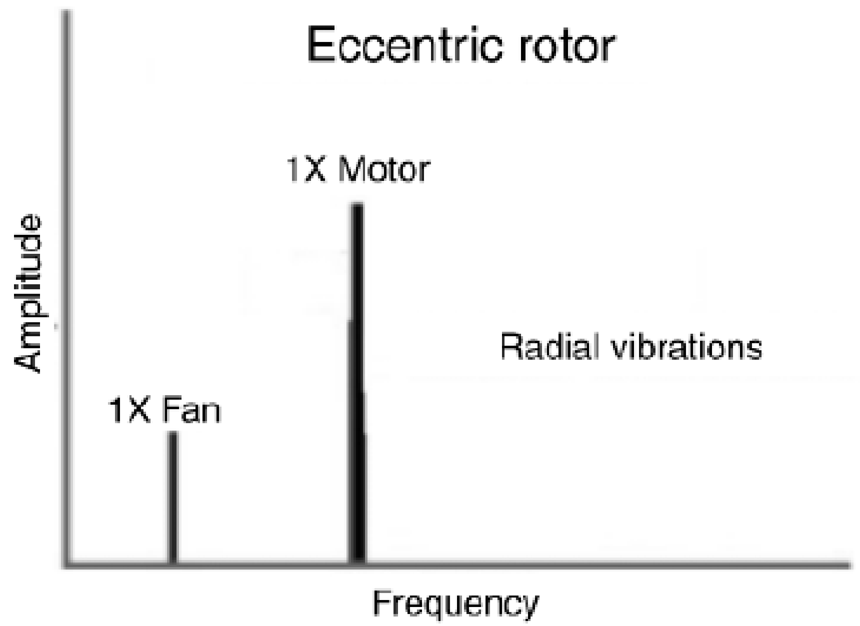
The axial phase on the two bearings will seem to be in phase where as the radial phase tends to be unsteady.



Fault Detection

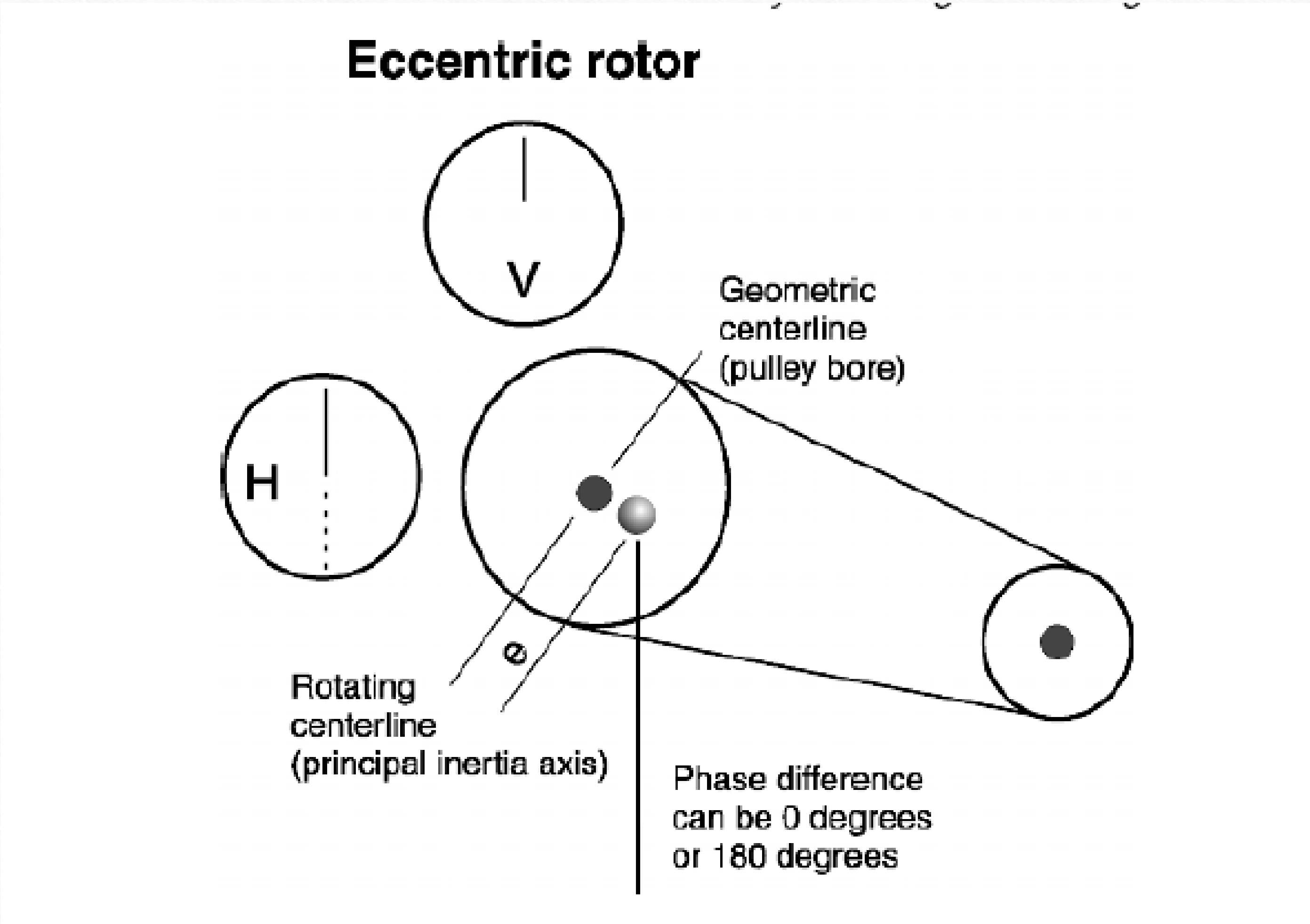
Eccentric rotor

Eccentricity occurs when the center of rotation is at an offset from the geometric centerline of a sheave, gear, bearing, motor armature or any other rotor.



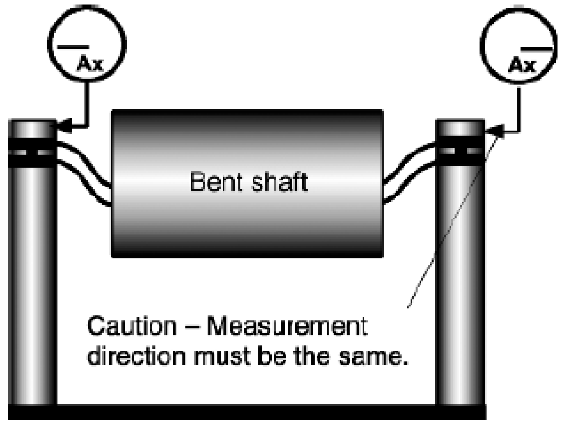
Here the amplitude varies with the load even at constant speeds

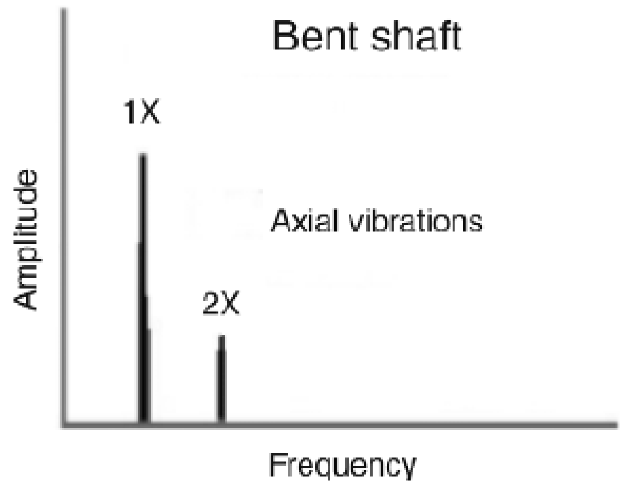
Fault Detection



Fault Detection

Bent shaft

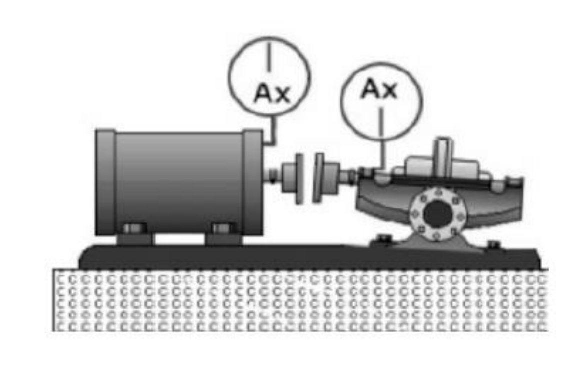


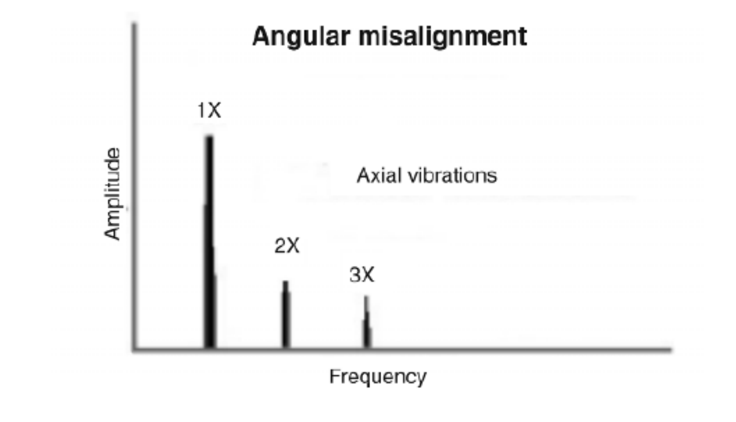


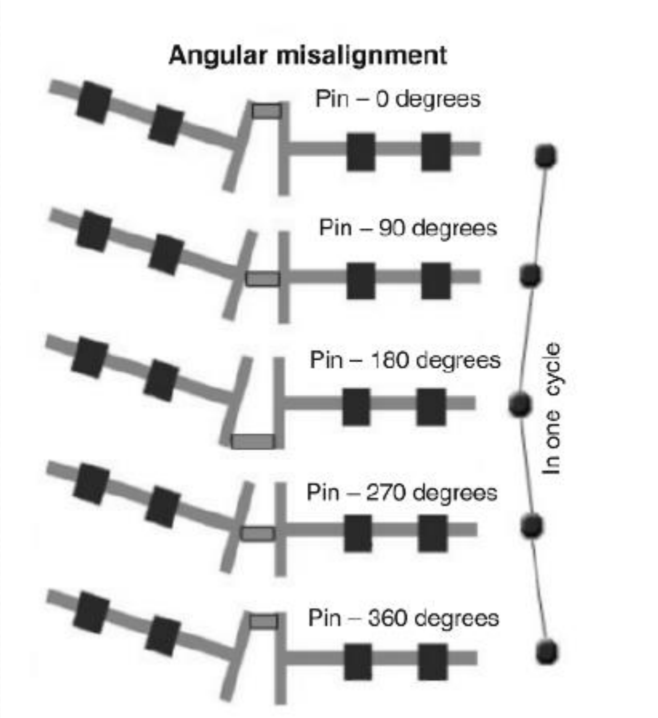
Fault Detection

Misalignment

Angular misalignment

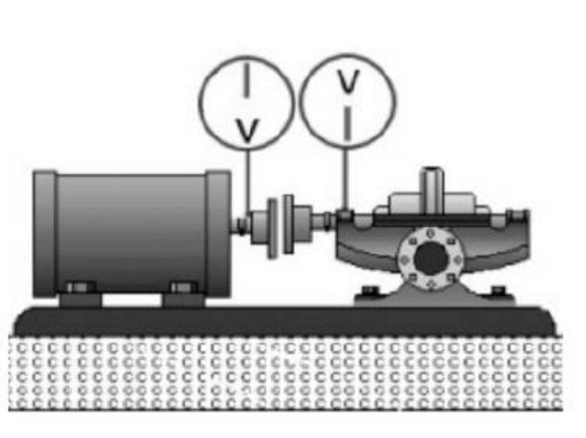


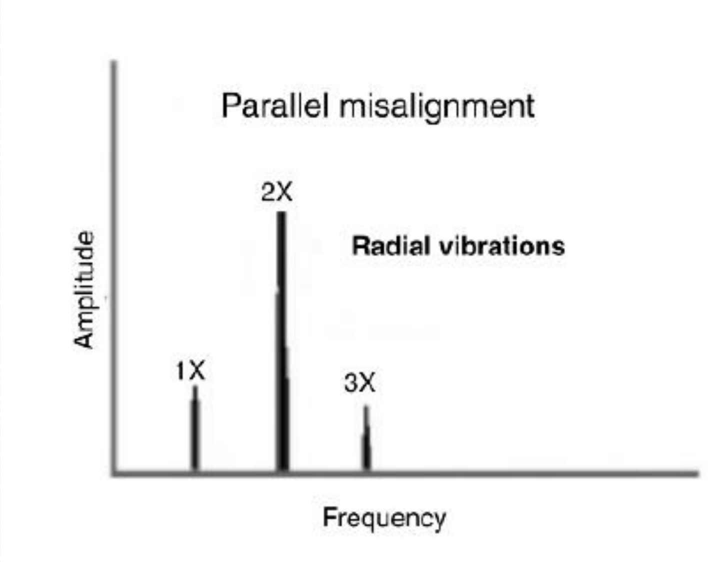


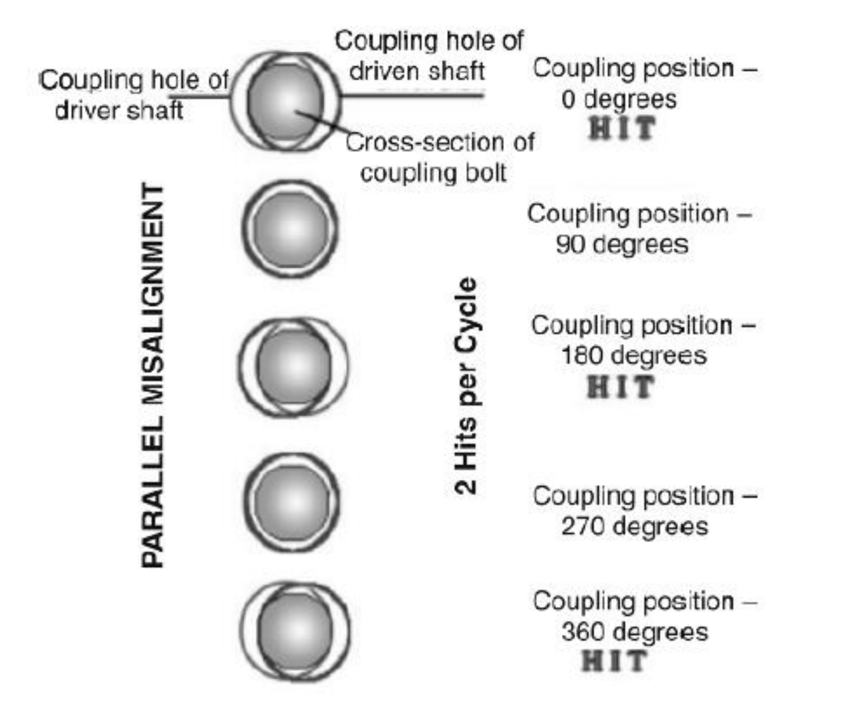


Fault Detection

Parallel misalignment

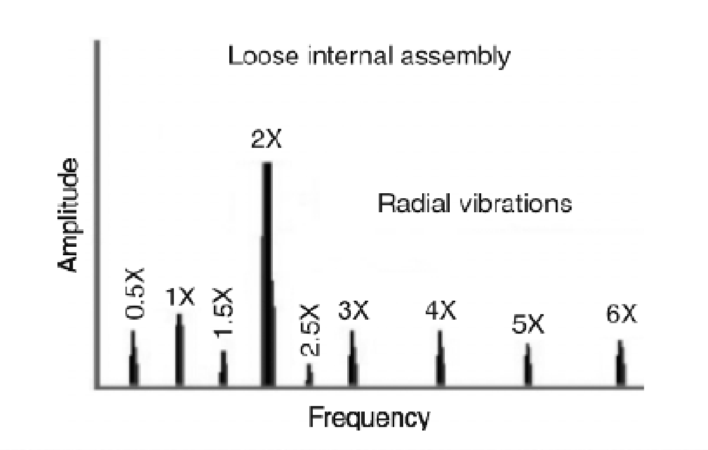




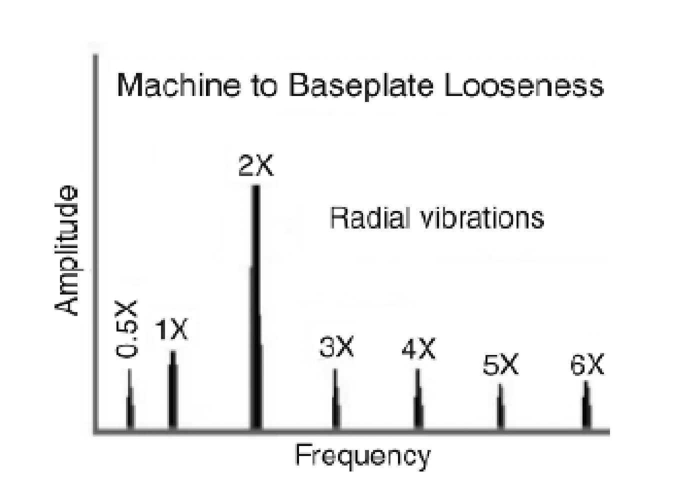


Fault Detection

Mechanical looseness

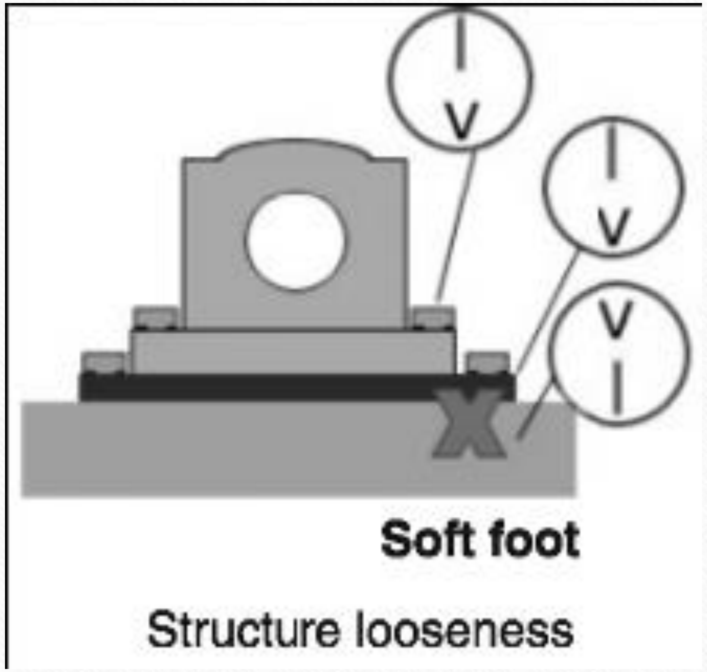


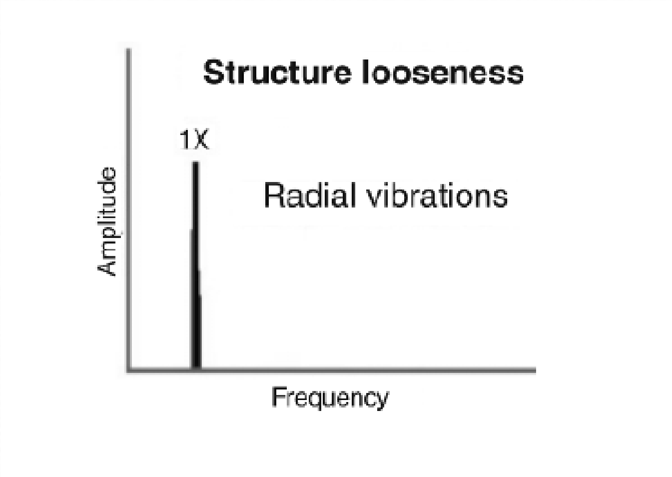
Looseness between machine to base plate



Fault Detection

Structure looseness

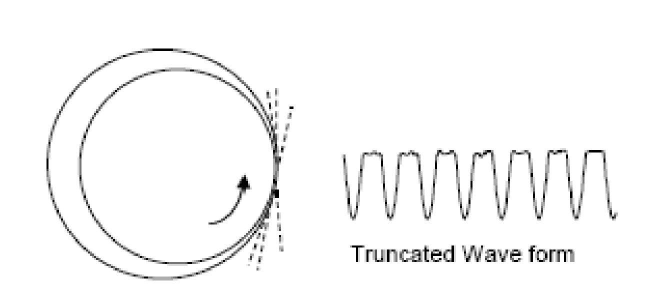


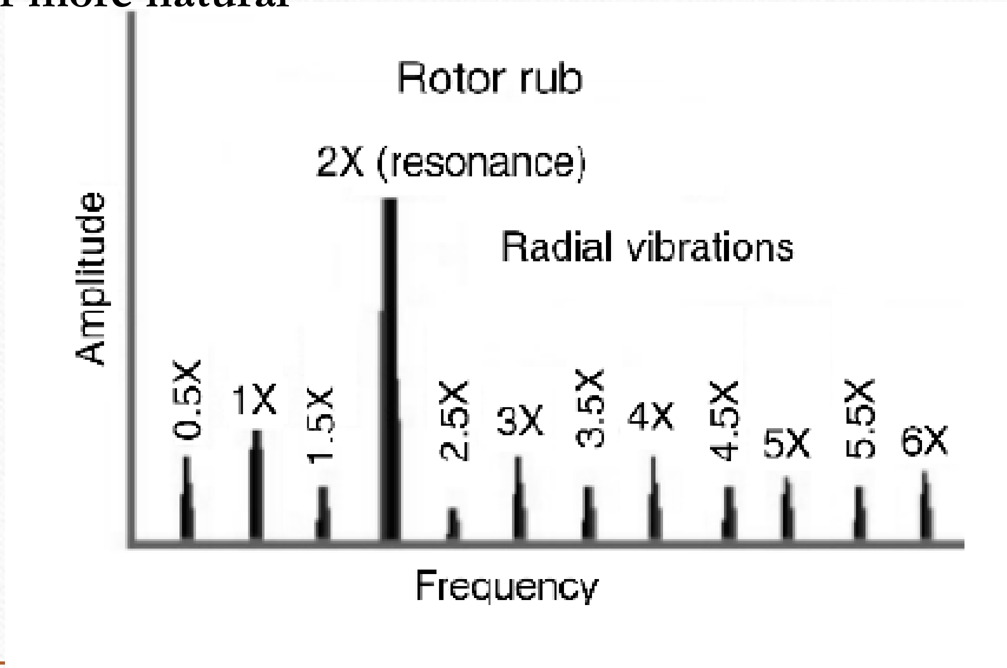


Fault Detection

Rotor rubs

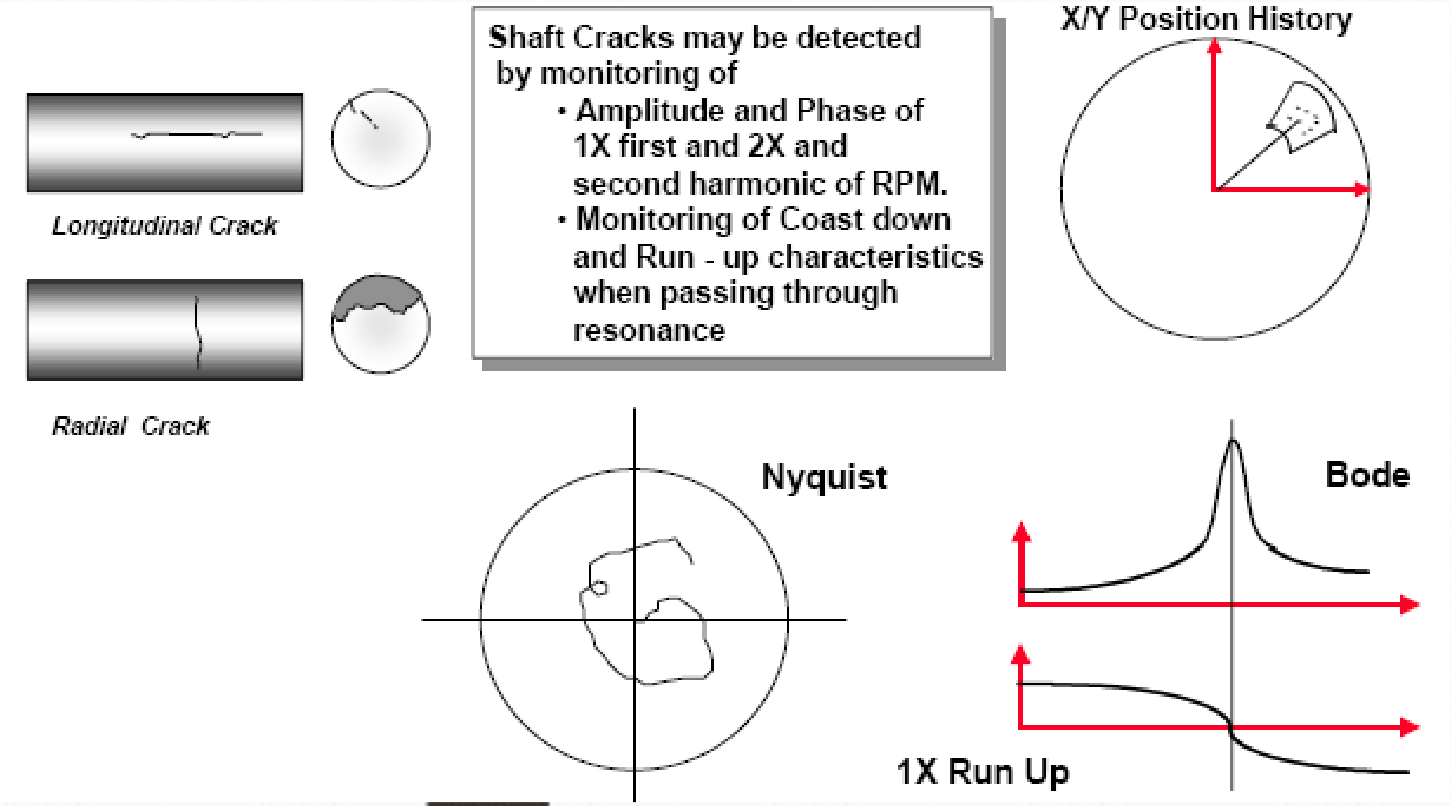
Rotor rubs produce a spectrum that is similar to mechanical looseness. A rub may be either partial or throughout the whole cycle. These generally generate a series of frequencies, and tend to excite one or more natural frequencies.





Fault Detection

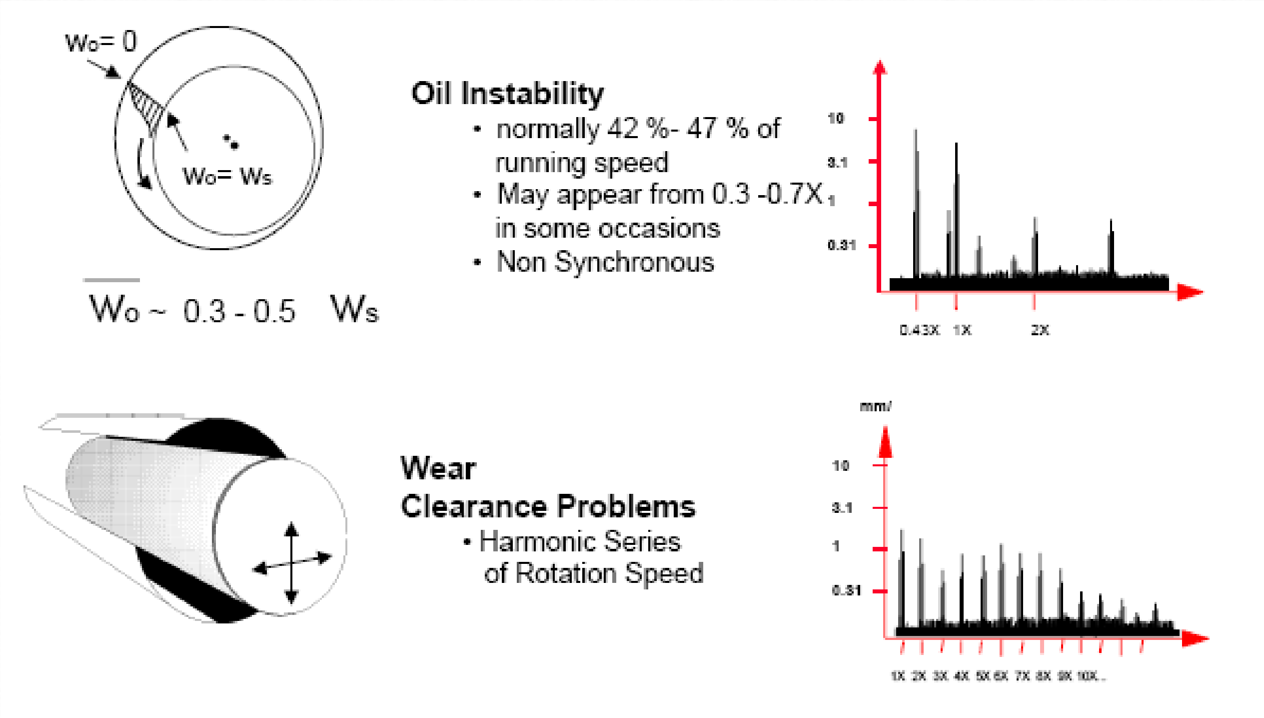
Shaft Crack

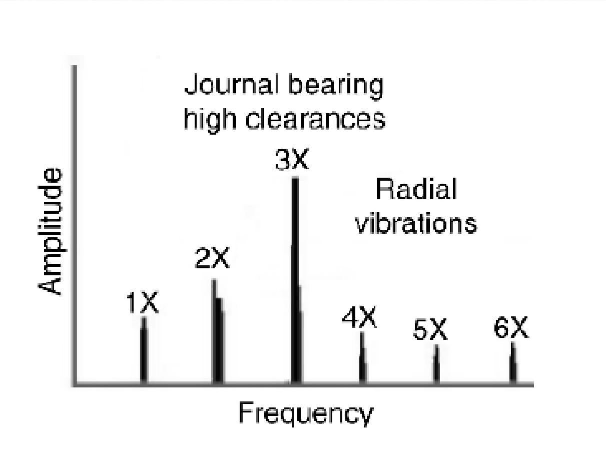


Fault Detection

Journal bearings

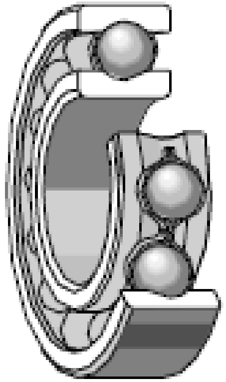
High clearance in journal bearings



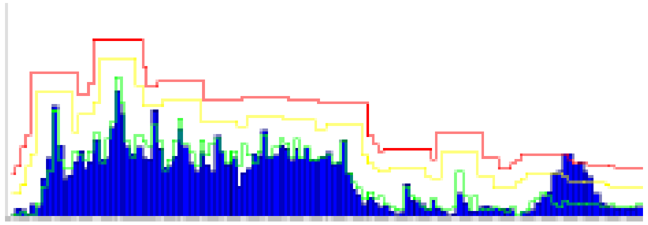


Fault Detection

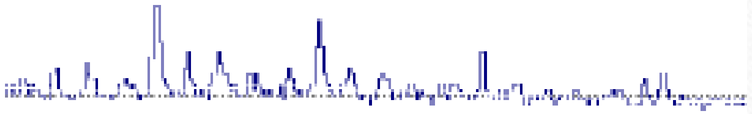
Rolling Element Bearings



Faults in Rolling Element Bearings are Detected with CPB in the High frequency range



Envelope Spectra can be used both for Detection and Diagnosis of Rolling Element Bearing Faults



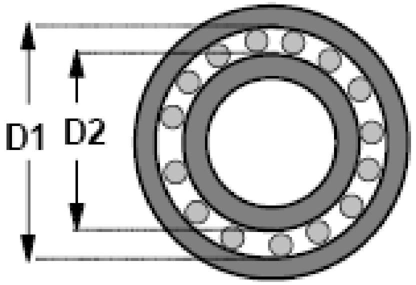
No Defects on Rolling Element Bearing

↓

"Flat" Envelope Spectrum.

Rolling Element Bearing Frequencies

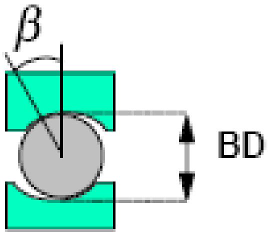
Fault Detection



$$PD = \frac{D1 + D2}{2}$$

n = *number of balls*

f_r = *rotation frequency*



BPFO = $$f_{outer}\,(Hz) = \frac{n}{2} f_r \left(1 - \frac{BD}{PD}\cos\beta\right)$$

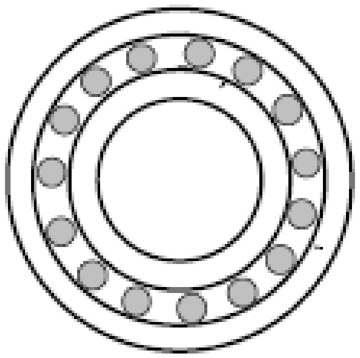
BPFI = $$f_{inner}\,(Hz) = \frac{n}{2} f_r \left(1 + \frac{BD}{PD}\cos\beta\right)$$

BSF = $$f_{ball}\,(Hz) = f_r \frac{PD}{BD}\left[1 - \left(\frac{BD}{PD}\cos\beta\right)^2\right]$$

$$f_{cage}\,(Hz) = \frac{1}{2} f_r \left(1 - \frac{BD}{PD}\cos\beta\right)$$

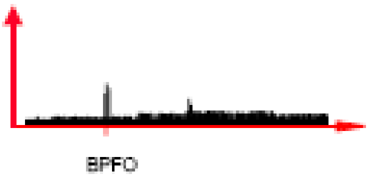
Typical Bearing Defects Development: Envelope Analysis

Fault Detection



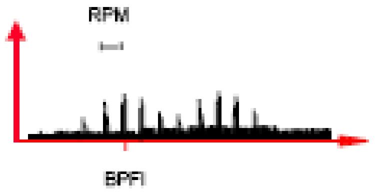
1. Outer Race Faults

- Lead Time Month's
- Ball Pass Frequency Outer Race (BPFO) and Harmonic



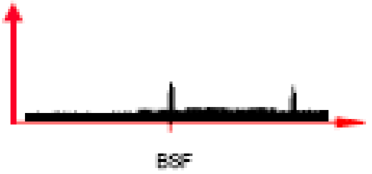
2. Inner Race Faults

- Lead Time Days - Weeks
- Ball Pass Frequency Inner Race (BPFI) With Side bands of Rotation speed



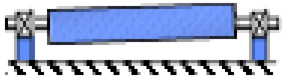
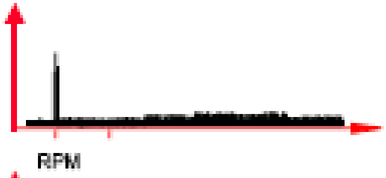
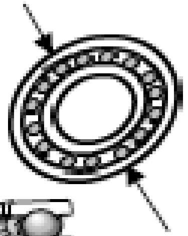
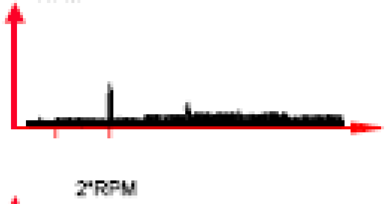
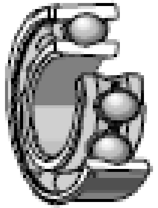
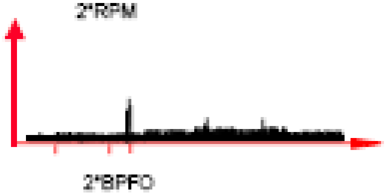
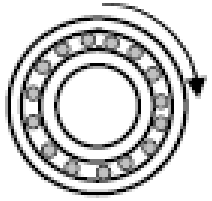
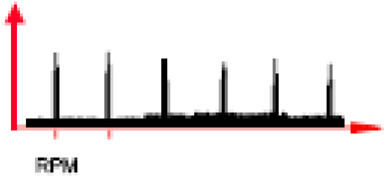
3. Ball Defects

- Requires Immediate action
- Ball Spin Frequency BSF with Harmonics.
- Often in combinations with above with various inter-harmonics.



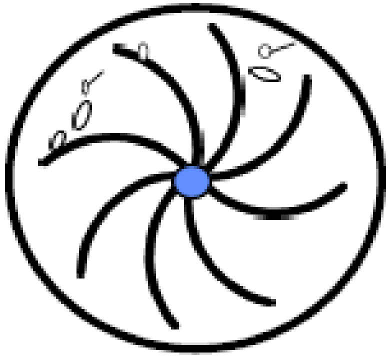
Bearing Mounting Defects
Analyzed with Envelope Analysis

Fault Detection

	*Rotor Misalignment* *Rotor Unbalance*	1*RPM	
	*Radial Tension of Bearing*	2*RPM	
	*Misalignment of outer Race*	2*BPFO	
	*Slip of Race in the Mounting Seat*	Harmonics of RPM	
	*Lubrication Defect*	Increase of Background level	

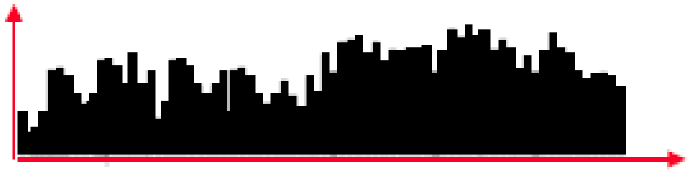
Fault Detection

Cavitation



Cavitation is caused by the collapse of small bubbles that occurs during local boiling at certain condition of the fluid (low dynamic pressure)
The Collapses are short in time and thus wide in Frequency.

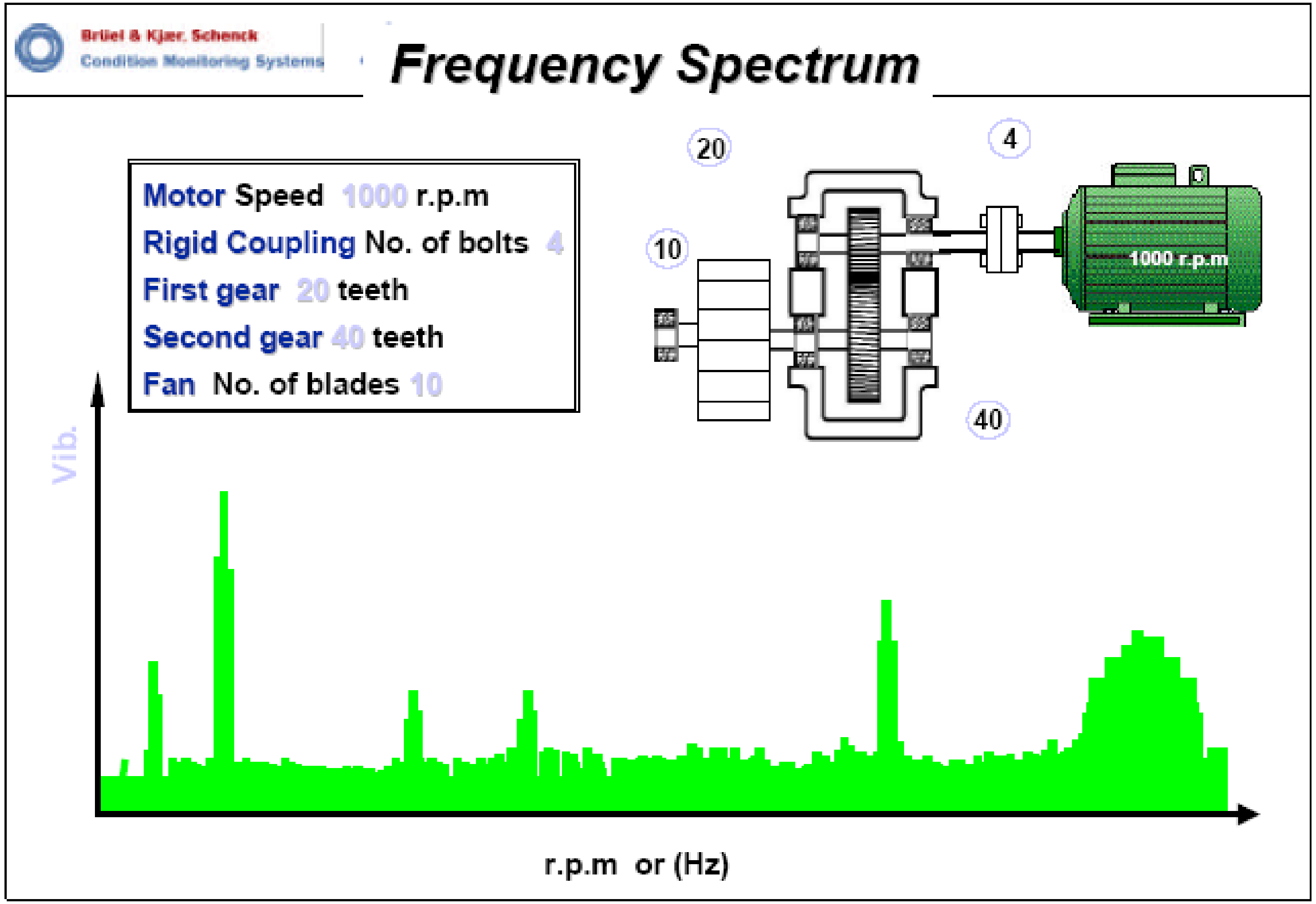
- The resonances are exited throughout the spectrum
- Specially high Frequencies are exited
- In Envelope Spectra an increase of the background level with no distinct lines are seen.



CPB Spectrum

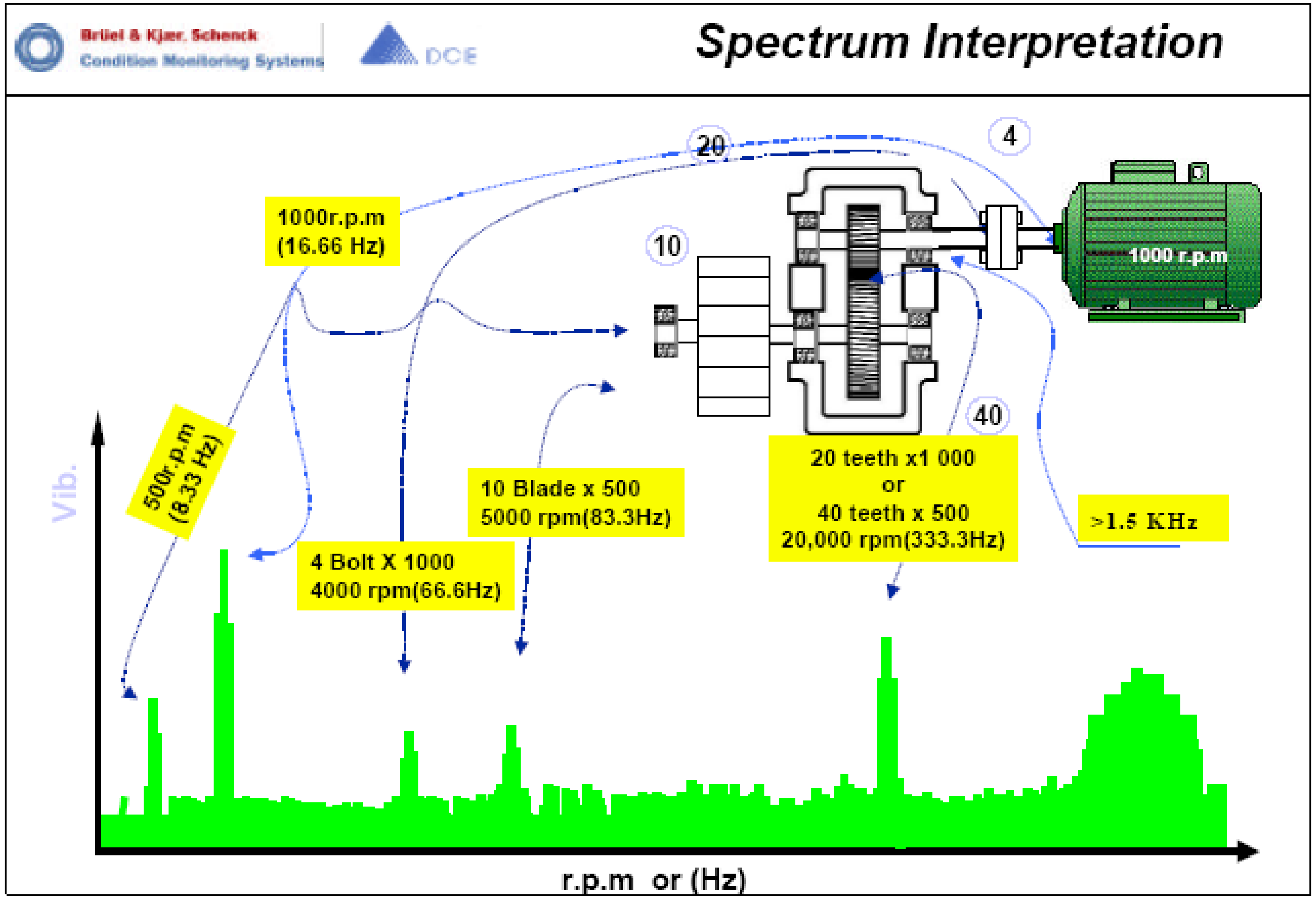
Envelope Spectrum

Case Study



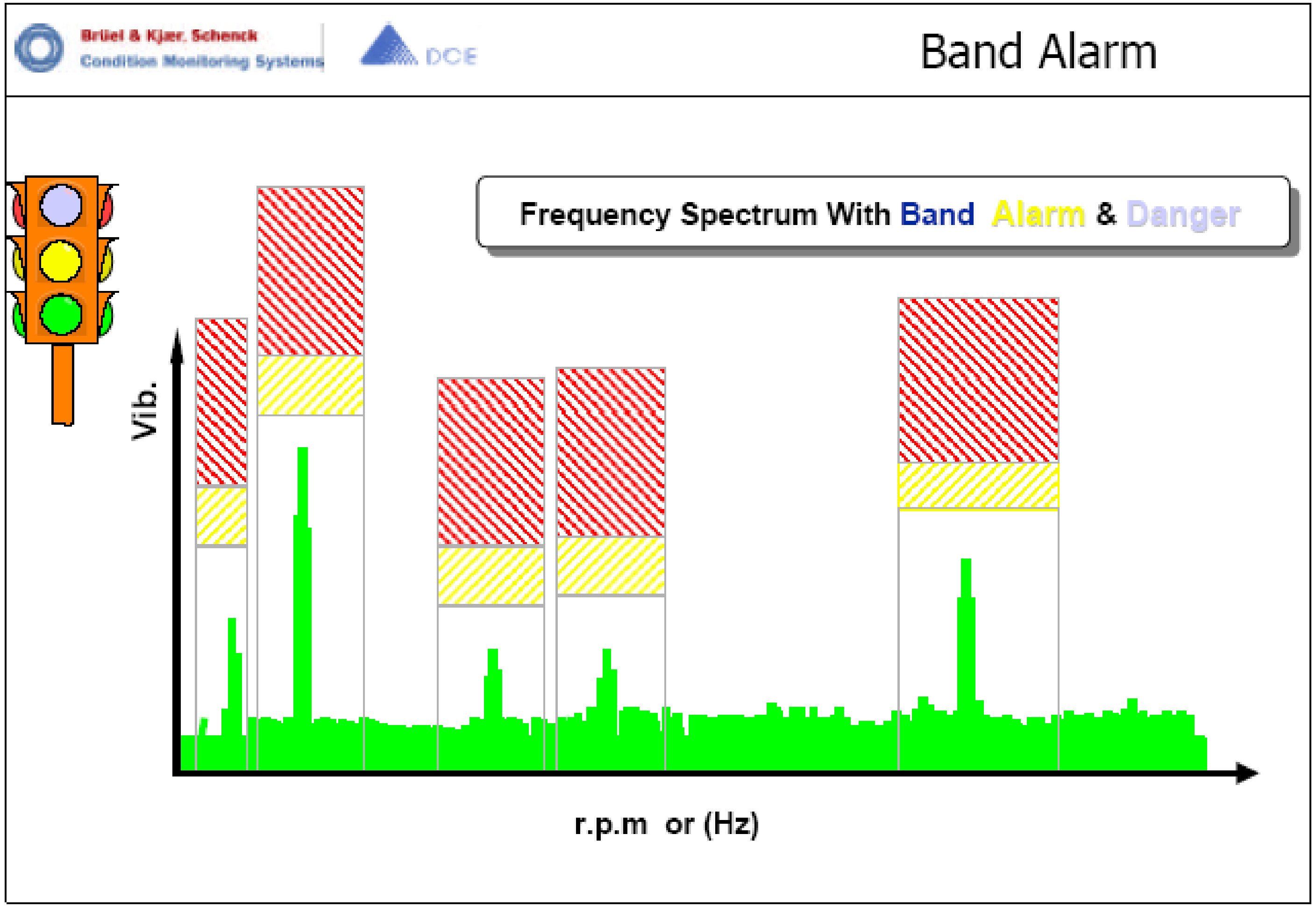
Brüel & Kjær, Schenck
Condition Monitoring Systems
Frequency Spectrum
Motor Speed 1000 r.p.m
Rigid Coupling No. of bolts 4
First gear 20 teeth
Second gear 40 teeth
Fan No. of blades 10
20
4
10
1000 r.p.m
40
Vib.
r.p.m or (Hz)

Case Study



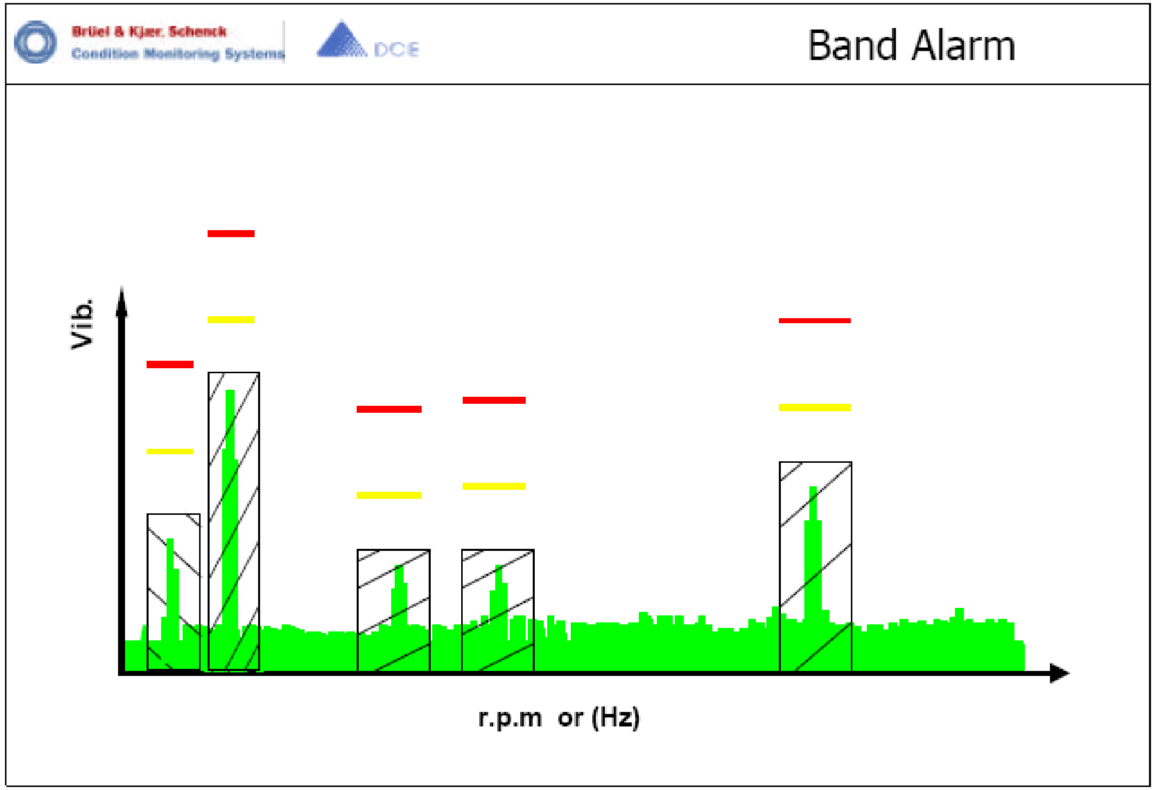
Brüel & Kjær. Schenck
Condition Monitoring Systems
DCE
Spectrum Interpretation
1000r.p.m
(16.66 Hz)
20
4
10
1000 r.p.m
500r.p.m
(8.33 Hz)
Vib.
10 Blade x 500
5000 rpm(83.3Hz)
40
20 teeth x1 000
or
40 teeth x 500
20,000 rpm(333.3Hz)
>1.5 KHz
4 Bolt X 1000
4000 rpm(66.6Hz)
r.p.m or (Hz)

Case Study

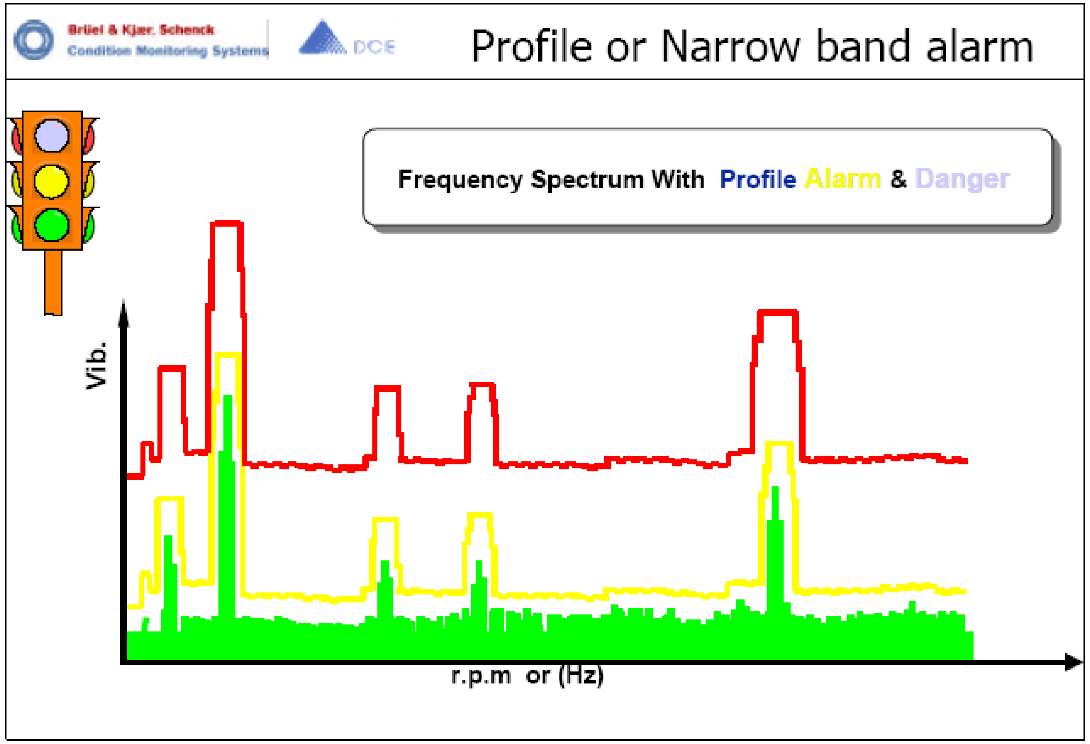


Brüel & Kjær. Schenck
Condition Monitoring Systems
DCE
Band Alarm
Frequency Spectrum With Band Alarm & Danger
Vib.
r.p.m or (Hz)

Case Study

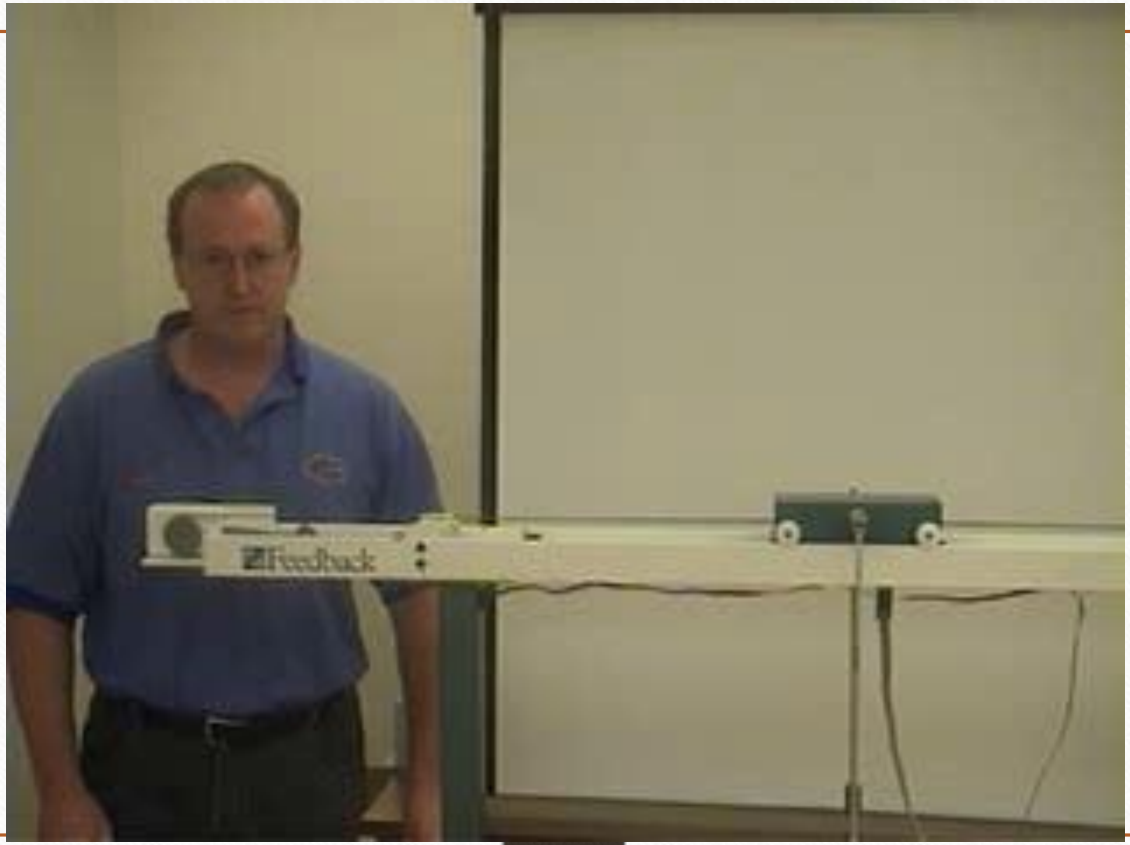


Brüel & Kjær. Schenck
Condition Monitoring Systems
DCE
Band Alarm
Vib.
r.p.m or (Hz)

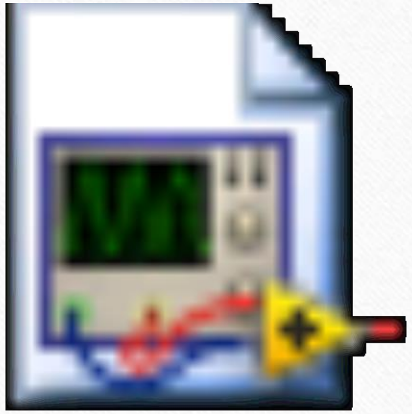


Brüel & Kjær. Schenck
Condition Monitoring Systems
DCE
Profile or Narrow band alarm
Frequency Spectrum With Profile Alarm & Danger
Vib.
r.p.m or (Hz)

Inverted Pendulum



Program



Express Vibration Lab.vi

Appendix

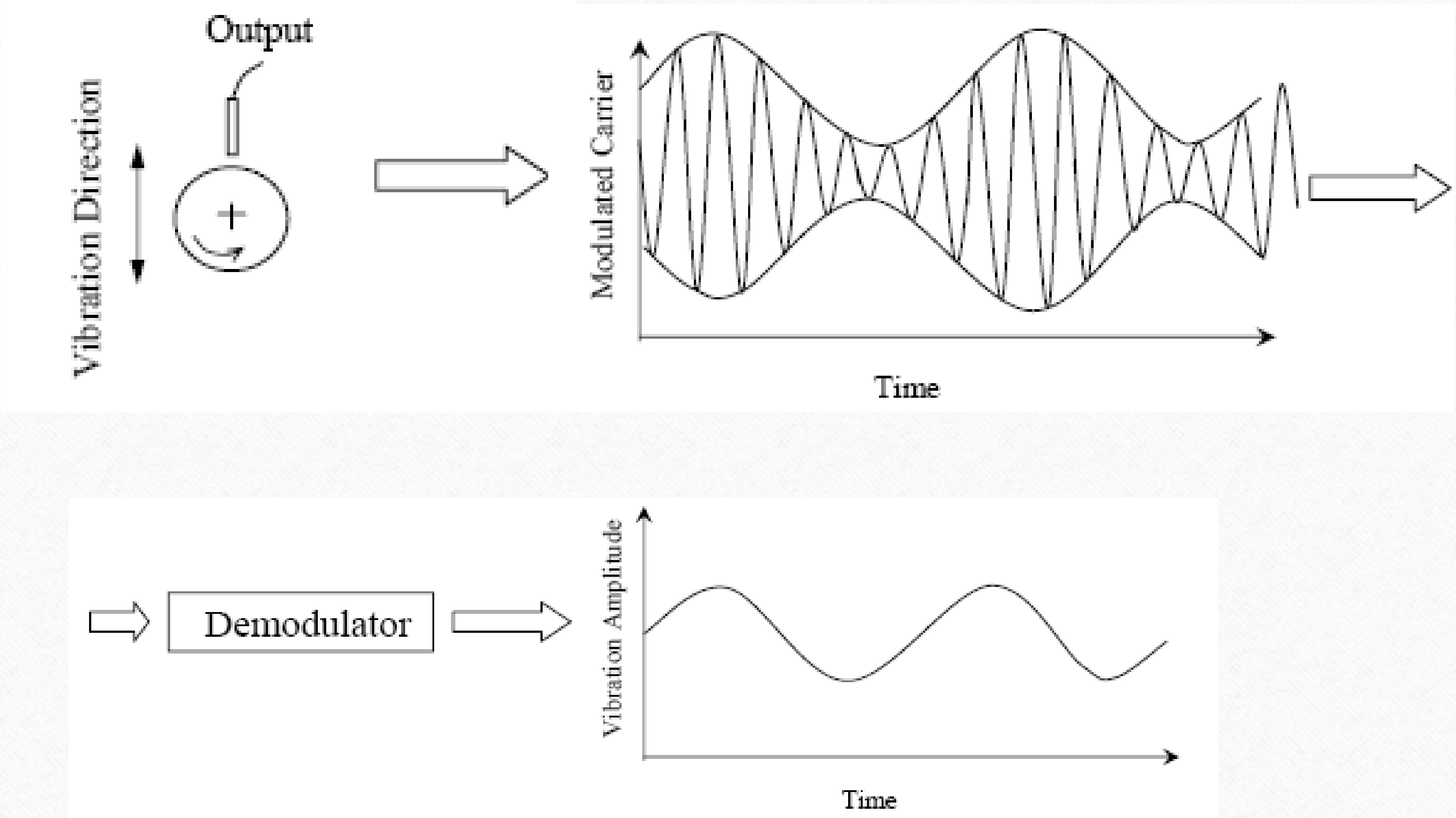
Type of motion sensed:

- **displacement transducers**
- **velocity transducers and**
- **accelerometers**

Eddy Current Based Non-Contact Displacement Transducers

- operate on eddy current principles
- usually consist of probe, cable, oscillator signal demodulator
- probe tip emits a magnetic field
- conductive material brought close
- eddy current induced at the surface of the material
- energy extracted from excitation circuitry
- excitation amplitude varies linearly over short range

Appendix

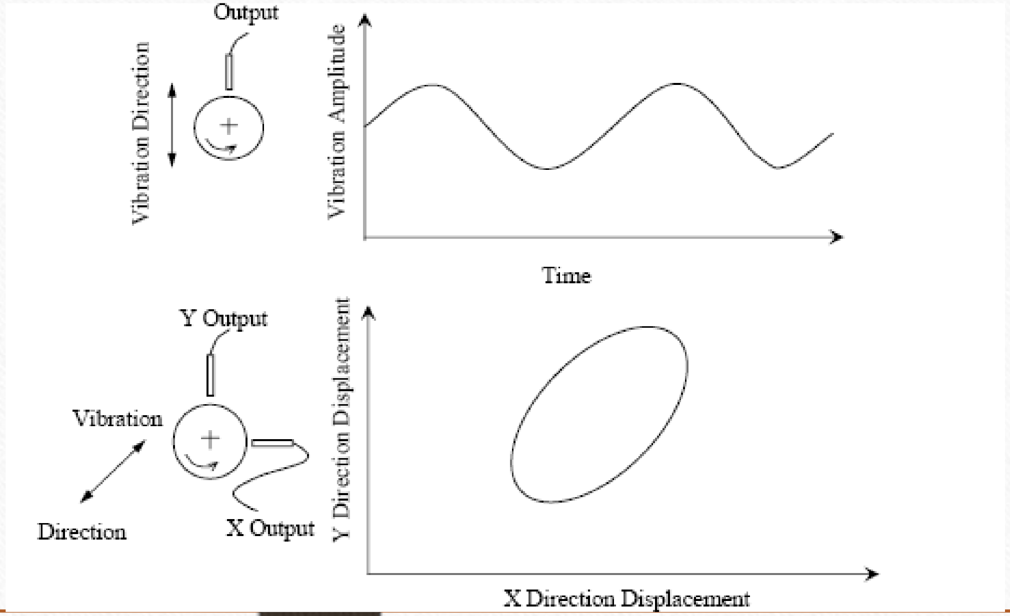


Eddy Current Probe Operation

Appendix

Applications

- fluid film radial or thrust bearings
- indicate shaft motion and position relative to the bearing.
- radial shaft displacement
- seal clearances
- used in pairs 90° apart to show shaft dynamic motion (orbit) within its bearing.



Appendix

Construction and Operation

- probe excited at a frequency of 1.5 kHz
- excitation produces magnetic field radiating from probe tip
- eddy currents are induced into conductive material close to the tip
- energy extracted from probe is proportional to the distance to the conductive material
- as the distance from tip to conductive material is varied, a proportional DC voltage is produced
- linear range is limited
- proper calibration is essential
- conductive material essential

Calibration

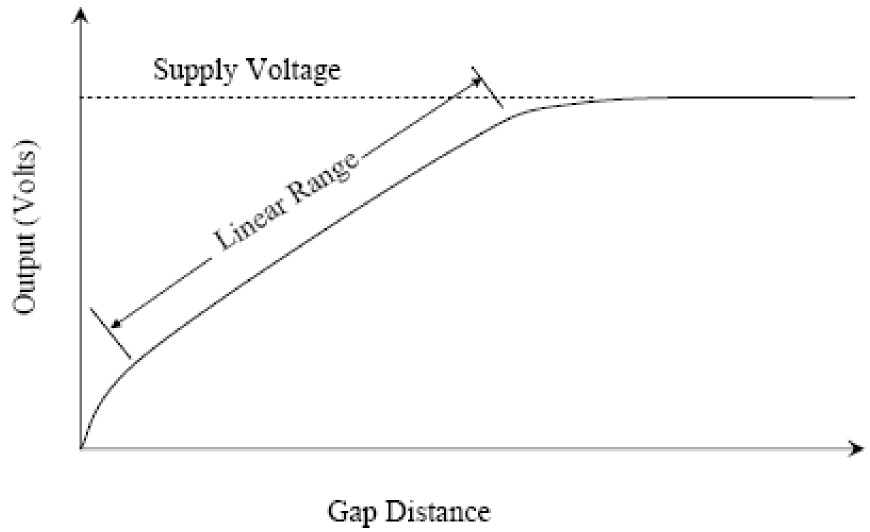
The calibration curve has three regions:
1 - probe in contact with, or very near the shaft (0 volts DC output).
2 - linear region, change in gap distance produces a proportional change in DC output.
(Typical linear gap - 0.25 mm to 2.25 mm) (industry standard - 8 volts/mm output)
3 - as supply voltage is reached the system looses constant proportionality.

Appendix

System Sensitivity = Slope of Linear Part of Curve

$$= \frac{\text{Change in Output}}{\text{Change in Gap}}$$

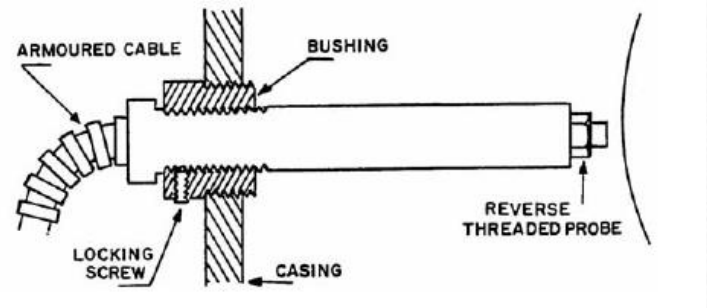
- probe linearity depends on target
  - conductivity
  - porosity.
  - surface condition (cracks, rust, pits, etc)
- temperature and pressure influences
- capable of both static and dynamic measurements

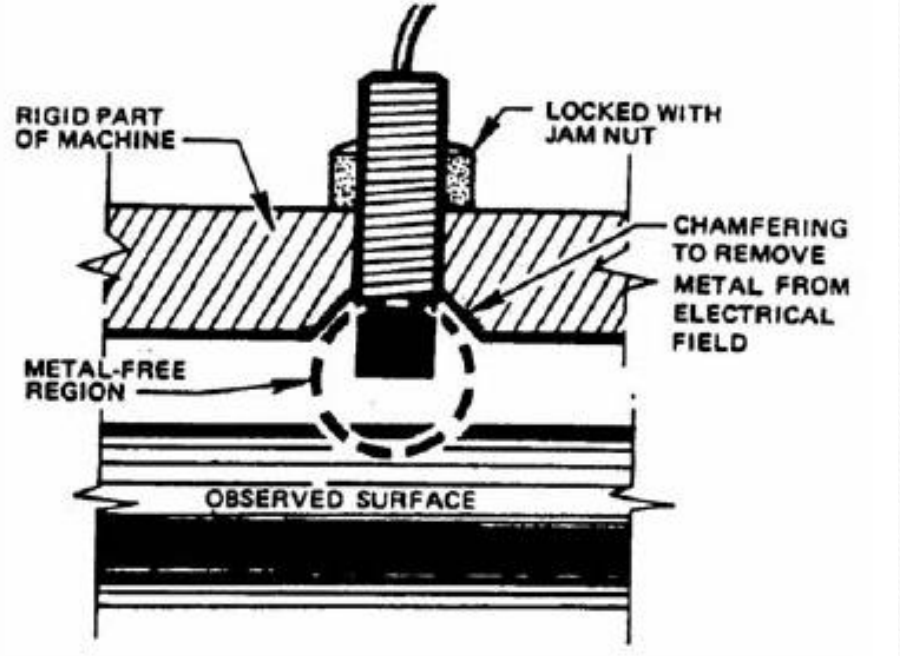


Appendix

Installation

- secure, rigid mounting essential
- adaptors useful
- minimum tip clearance of two times the diameter from any surface
- check resonant frequency of probe extensions
- do not locate probes too close together
- take care when handling cables





Installation - Clearance

Velocity Transducers

Appendix

Electromechanical:
- a permanent magnet supported by springs moves within a coil of wire
- movement is proportional to force on sensor
- voltage is proportional to force

Piezoelectric:
- acceleration sensing element is integrated to produce output proportional to velocity

Construction and Operation (Electromechanical)
- magnet, spring, damping fluid, coil
- designed to have a very low natural frequency
- good sensitivity typically above 10 Hz.
- high frequency response is limited by the inertia of the system (1,500 Hz)
- self generating device, produces a low impedance signal, no need for additional signal conditioning.

Appendix

Limitations

Temperature

- damping fluid may boil at high temperature

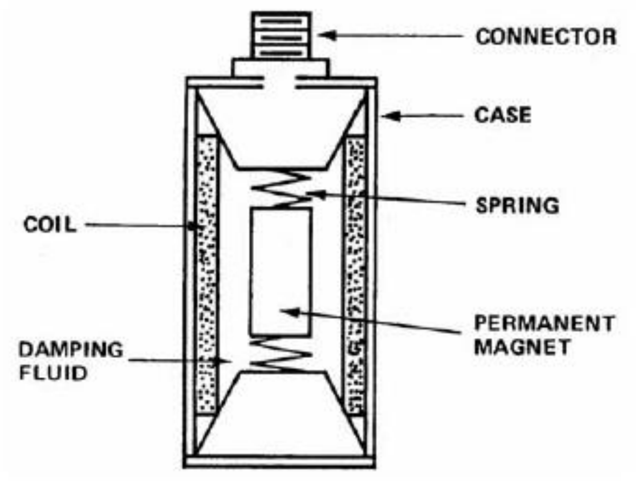
Mechanical reliability

- the moving parts become worn over time Orientation
- limited to only vertical or horizontal mounting

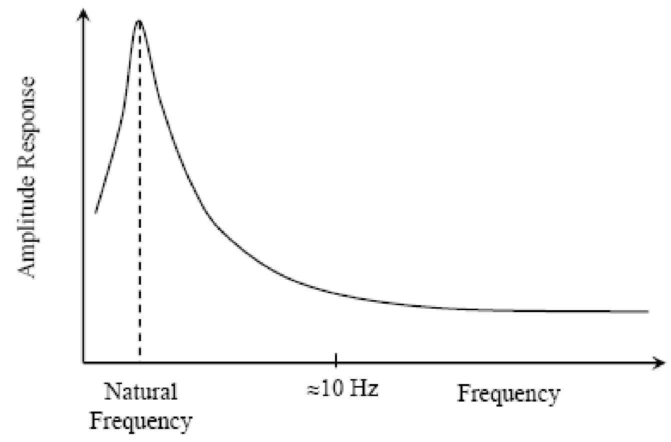
Narrow frequency range limit - 10 Hz to 1.5 kHz.

Phase shift at low frequencies

- shift in phase relationship may occur below 50 Hz. (will affect analysis work)



Electromechanical Velocity Probe

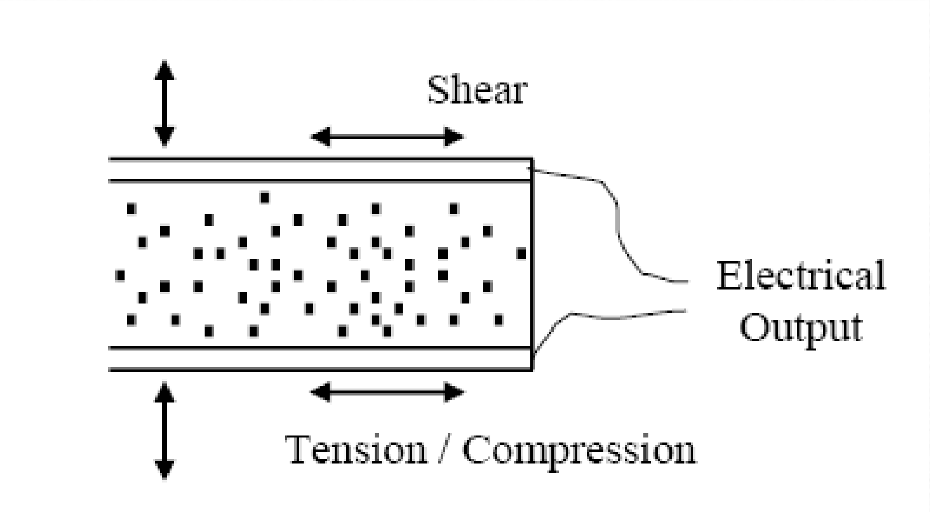


Electromechanical Velocity Probe - Sensitivity

Appendix

Accelerometers

- most commonly used acceleration transducers
- contain one or more piezoelectric crystal elements (natural quartz or man made ceramics)
- produce voltage when stressed (tension, compression or shear)
- voltage generated is proportional to the applied force.



Appendix

Application

- linear response over a wide frequency range (0.5 Hz to 20 kHz) (up to 50 kHz)
- broad dynamic amplitude range
- signal can be electronically integrated to velocity and displacement
- resistant to temperature changes
- reliable - no moving parts
- self generating output signal
- variety of sizes
- insensitive to non-axial vibration (< 3% of main axis of sensitivity)
- all orientations allowed

Note: Signals contain many frequency components.

- lots of information available but it may be difficult to extract this information.

Accelerometer Types

General Purpose:

- top or side mounted connectors
- sensitivity 1 to 10 mV/m/s2
- weight 10 to 50 grams
- frequency range 0 to 12 kHz.

Appendix

Miniature:

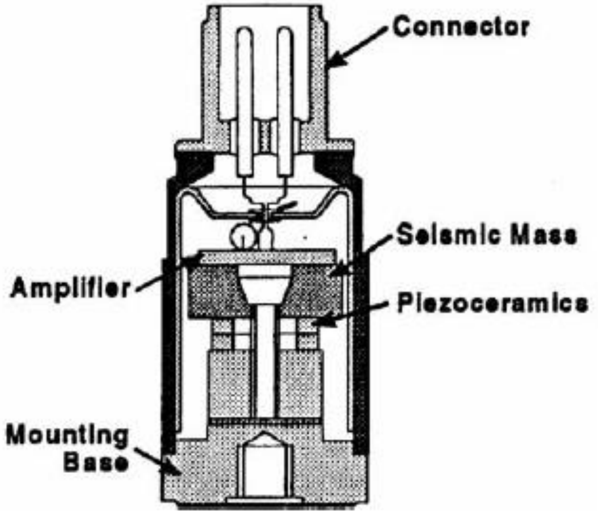
- sensitivity 0.05 to 0.3 mV/m/sec2
- weight 0.4 to 2 grams
- frequency range 1 to 25 kHz
- for use on high level or high frequency applications, on delicate structures, etc.

Other (specialty):

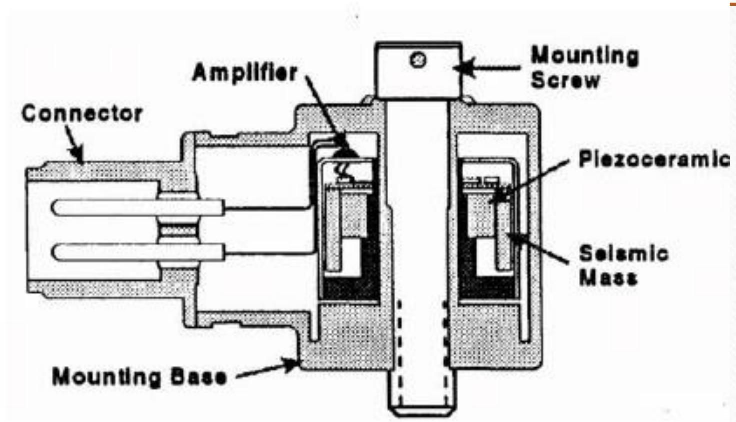
- tri-axial accelerometer
- high temperature resistance
- high sensitivity
- low frequency sensitive
- shock resistant

Operation

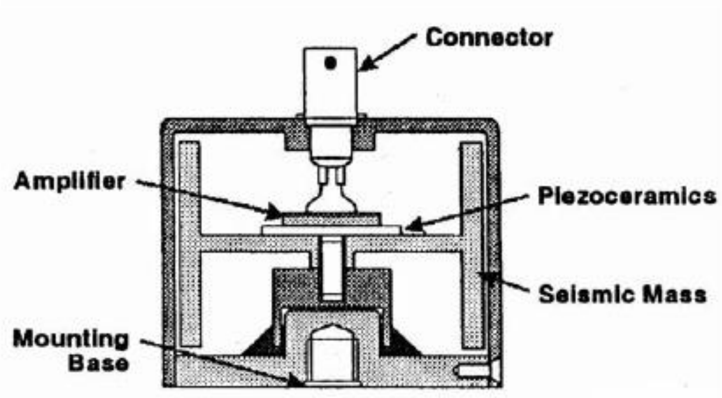
- piezoelectric crystal mechanically stressed as a result of force (acceleration) applied to sensor
- mass - crystal - sensor base - structure
- crystal produces an electrical output proportional to force (acceleration)
- absolute acceleration of sensor is output



Compression Mode Accelerometer



Shear Mode Accelerometer



Flexure Mode Accelerometer

Appendix

Performance Characteristics

Dynamic Range:

- affects low and high limits of acceleration levels measurable
- lower limit set by noise from cables, connections, amplifiers, etc. (0.01 m/sec2)
- upper limit set by accelerometers structural strength (50K to 100 K m/sec2)
- high output requires large piezoelectric assembly
- amplifiers can boost the signal
- mass will affect light or flexible structures
- accelerometer mass should be < 1/10 the mass of the vibrating part being sampled.
- accelerometers operate below their first natural Frequency
- relatively flat linear range below natural frequency
- linear to 1/5 or 1/3 of the natural frequency
- not capable of true DC measurements
- frequencies down to 0.003 Hz with special equipment
- produce a high impedance signal, need conversion electronics

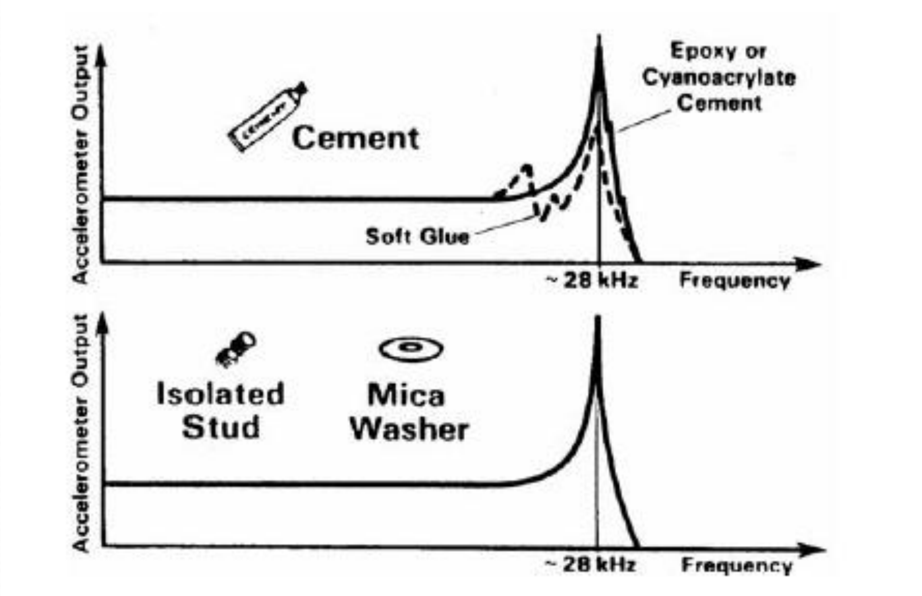
Appendix

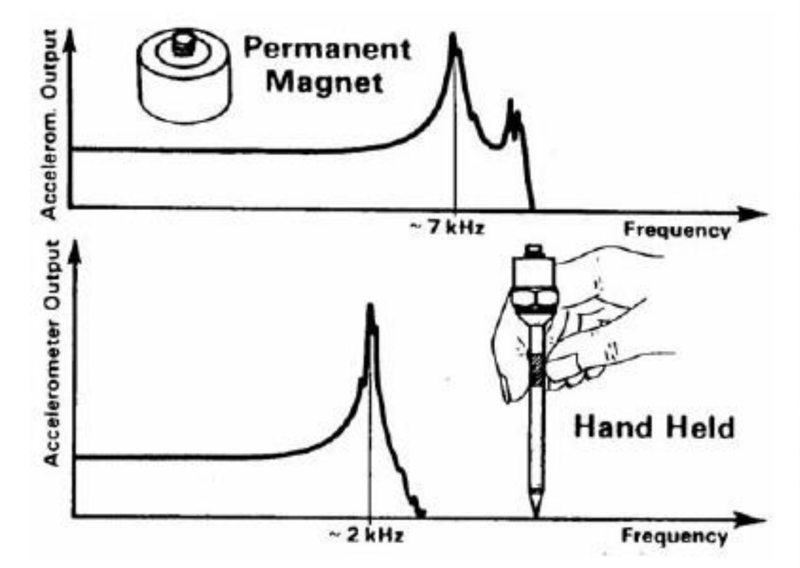
- conversion electronics may be charge or voltage type
- charge type - more complex ∴expensive

- sensitivity is independent of cable length between accel. and converter

- voltage type - relatively simple ∴less expensive

- cable length affects sensitivity





Appendix

applications:

- usually a variety of mounting methods used
- application specific
- cables and connectors important

these are common sources of noise and should be resistant to wind, corrosion, mechanical damage, EMF fields, etc.

Limitations

Temperature (Ambient and Fluctuations)

- good up to 250°C (400°C)
- piezoelectric material depolarizes
- sensitivity is permanently altered
- recalibration necessary
- temperature transients also affect output
- shear type least sensitive
- use a heat sink or mica washer

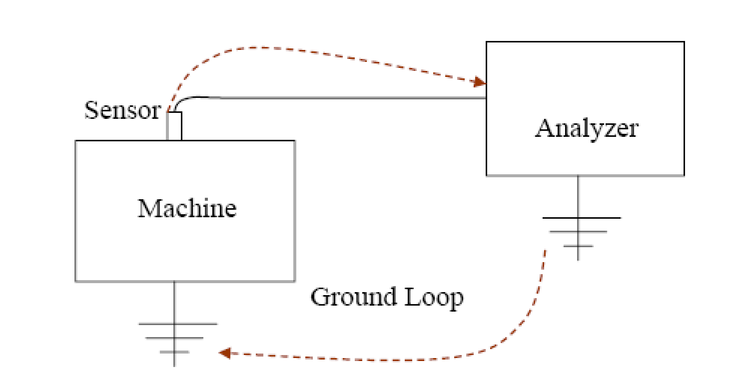
Appendix

Humidity

- sensitive to humidity but usually well sealed
- cables and connections are weak links

Cable Noise

- Ground loops - current flows in the cable shield because the accelerometer and the analyzer are grounded at different potentials
- electrically isolate sensor



Tribo-electric Noise

- induced by mechanical motion of cable
- use graphited accelerometer cable
- be sure cables are held in place

Electromagnetic Noise

- large magnetic fields can induce noise in cables
- double shielding will help

Base Strains

- if mounting surface is strained the output will be altered
- thick accelerometer bases minimize this effect
- shear type are less sensitive

Appendix

- conversion electronics may be charge or voltage type
- charge type - more complex ∴expensive

- sensitivity is independent of cable length between accelerometer and converter

- voltage type - relatively simple ∴less expensive

- cable length affects sensitivity

Recording & Analysis Instrumentation

Vibration Meters:

- give overall vibration levels
- hand held, self contained
- walk around survey use
- velocity and/or acceleration
- spike energy meter
- small, portable, inexpensive, simple to use
- no diagnostic ability (no spectrum)

Data Collectors

- micro computer based
- measures vibration, storage & transfer of data, FFT analysis
- lots more information for not much more money
- on the spot diagnostics

Appendix

Data Collectors (cont'd)

• usually used with PC to provide permanent data storage & detailed analysis software platform
• used on general purpose equipment
• multi-use - balancing capabilities
• strength of analysis capabilities depends on the supporting software

FFT Analysers:

• key instrument for diagnostics
• laboratory instrument
• data collectors & software now have same capabilities
• frequency resolution - dependent on number of lines of display and filtering (centre freq., roll off, etc.)
• aliasing - fast sampling & low pass filters
• weighting functions - elimination of leakage

Appendix

FFT Analysers (cont'd)

- averaging
- envelope detection (demodulation)
- transient capture
- memory
- order tracking
- cascade/waterfall display
- zoom
- dual channel analysis

Time Domain Instruments:

- time domain display of vibration on wave form
- some vibration characteristics and trends show better in the time domain
- FFT analysers, oscilloscopes (signal from analyser may be filtered)
- shaft displacements - orbits
- fluid film bearing analysis
- transients
- synchronous time averaging (negative averages)

Appendix

Tracking Analysers:

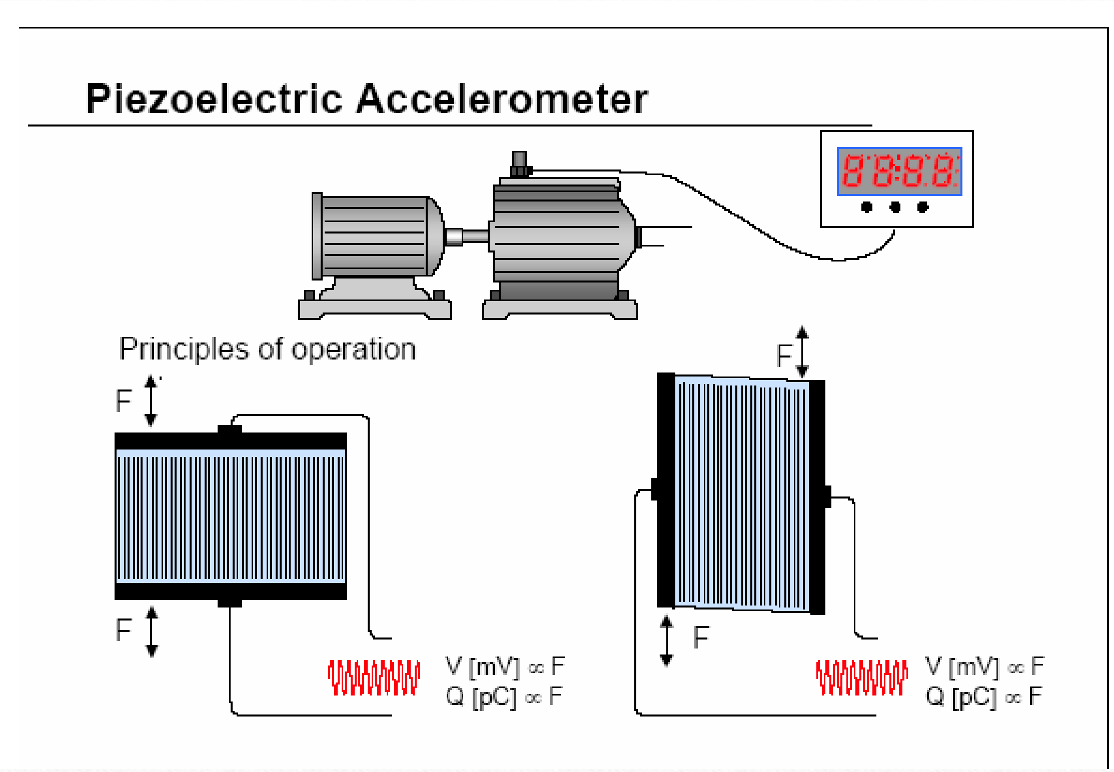
- data from changing speed machines (run up, coast down tests)
- tracking rate dependent on filter bandwidth
- need a reference signal to track speed
- variable input sensitivity
- large dynamic range

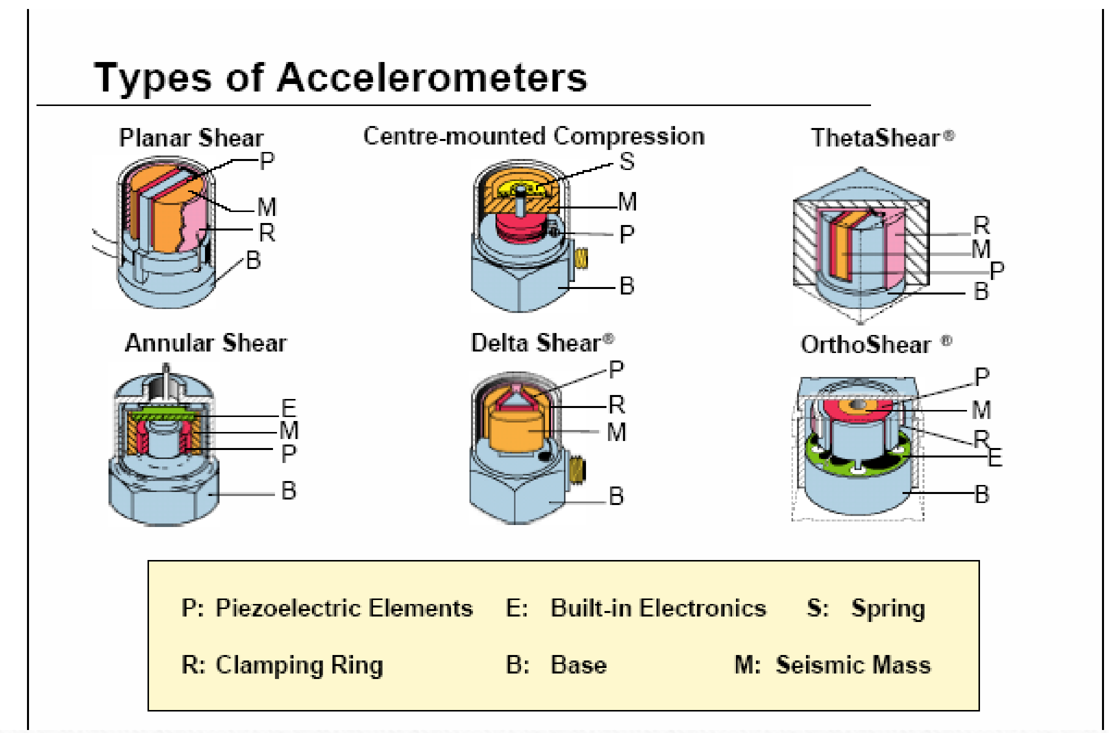
Tape Recorders (Historical Information)

Amplifiers:

- **used within vibration meters, analyzers, and tape recorders**
- **know frequency response**
- **proper use of pre-amplifiers**
- **use unit gain on tape input**

Appendix


Piezoelectric Accelerometer
Principles of operation
F
F
F
F
V [mV] ∝ F
Q [pC] ∝ F
V [mV] ∝ F
Q [pC] ∝ F


Types of Accelerometers
Planar Shear
Centre-mounted Compression
ThetaShear®
Annular Shear
Delta Shear®
OrthoShear®
P
M
R
B
S
E
P: Piezoelectric Elements
E: Built-in Electronics
S: Spring
R: Clamping Ring
B: Base
M: Seismic Mass

Appendix

Accelerometer Mounting — Fixed