



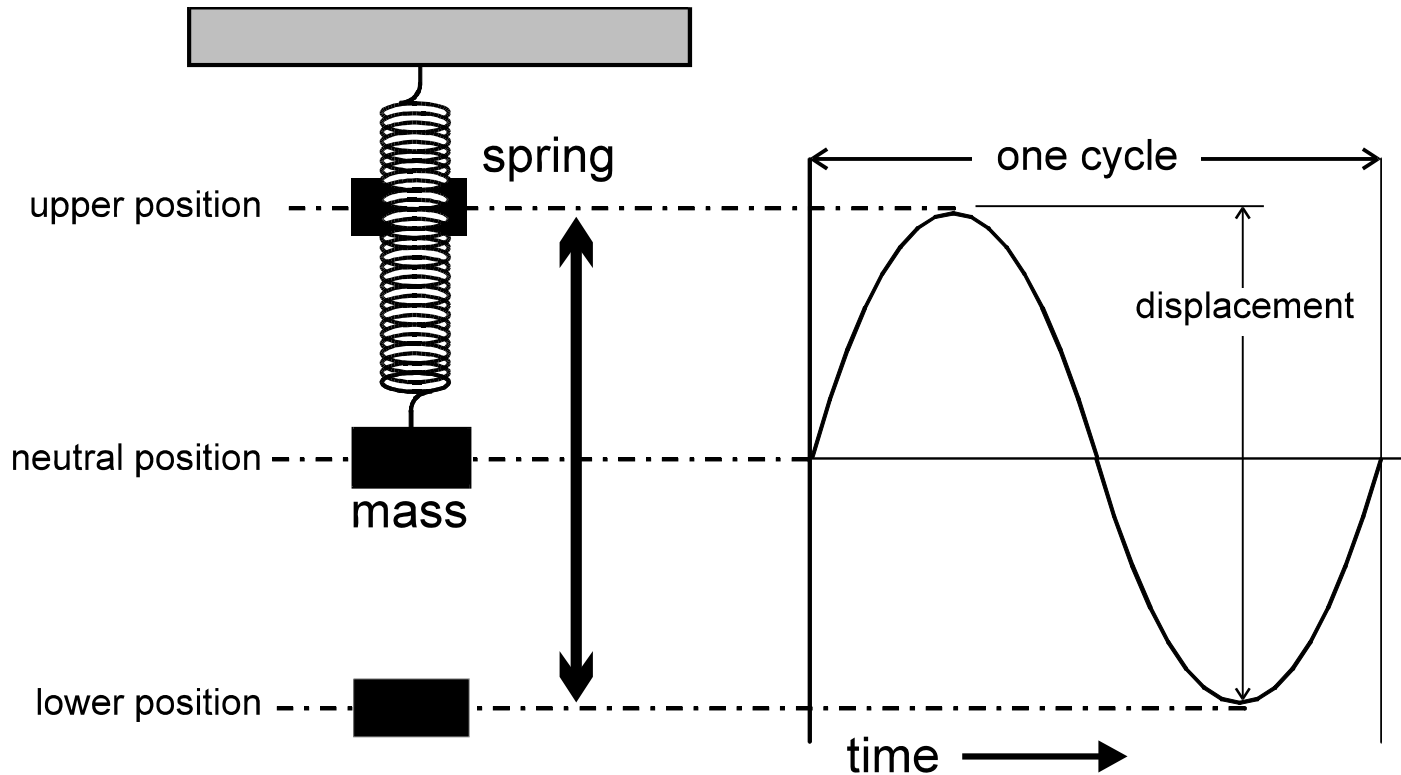
Refrigeration Division

FES Systems Inc.

Vibration Analysis Services

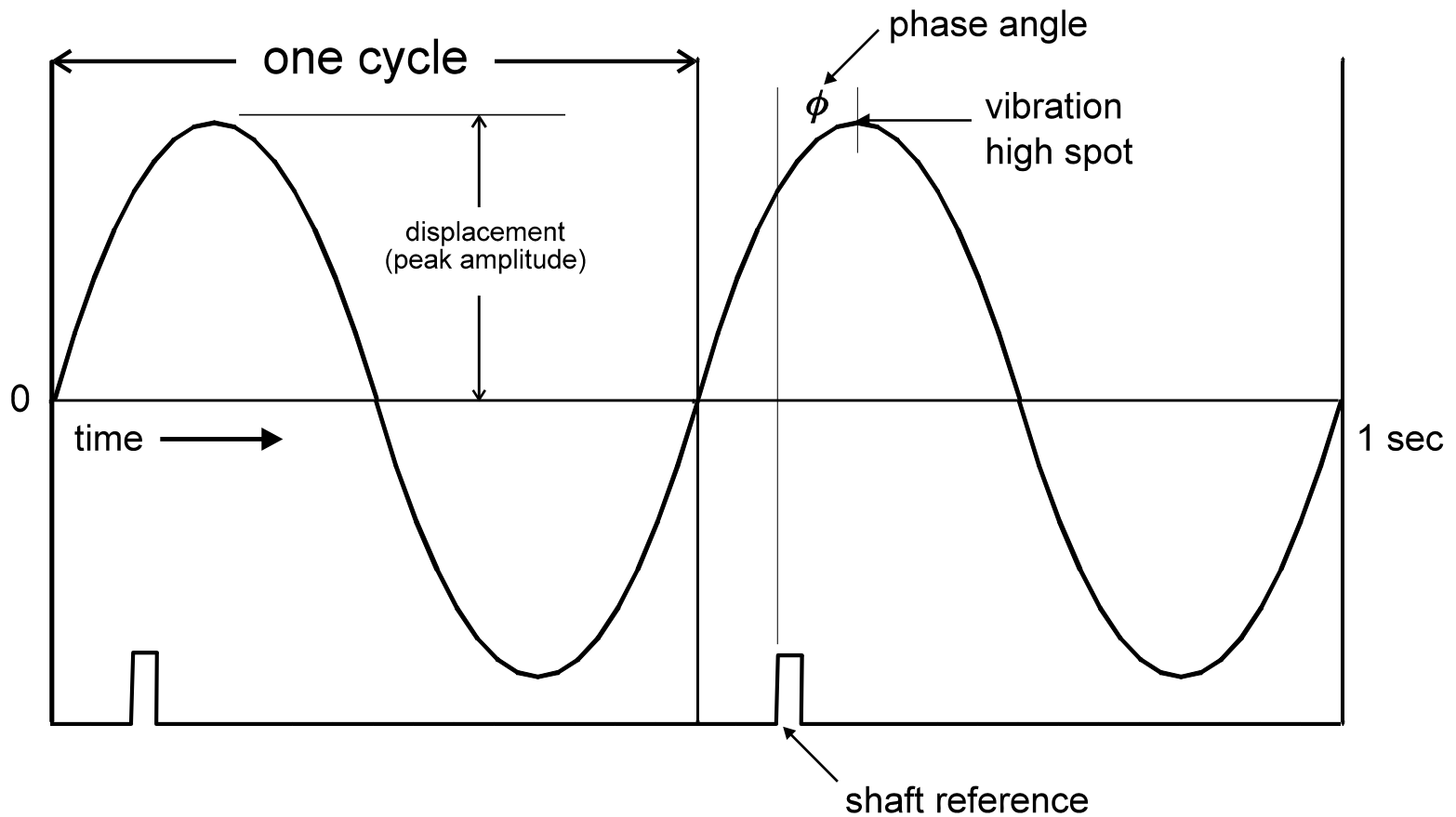
Basics of Vibration

What is Vibration?

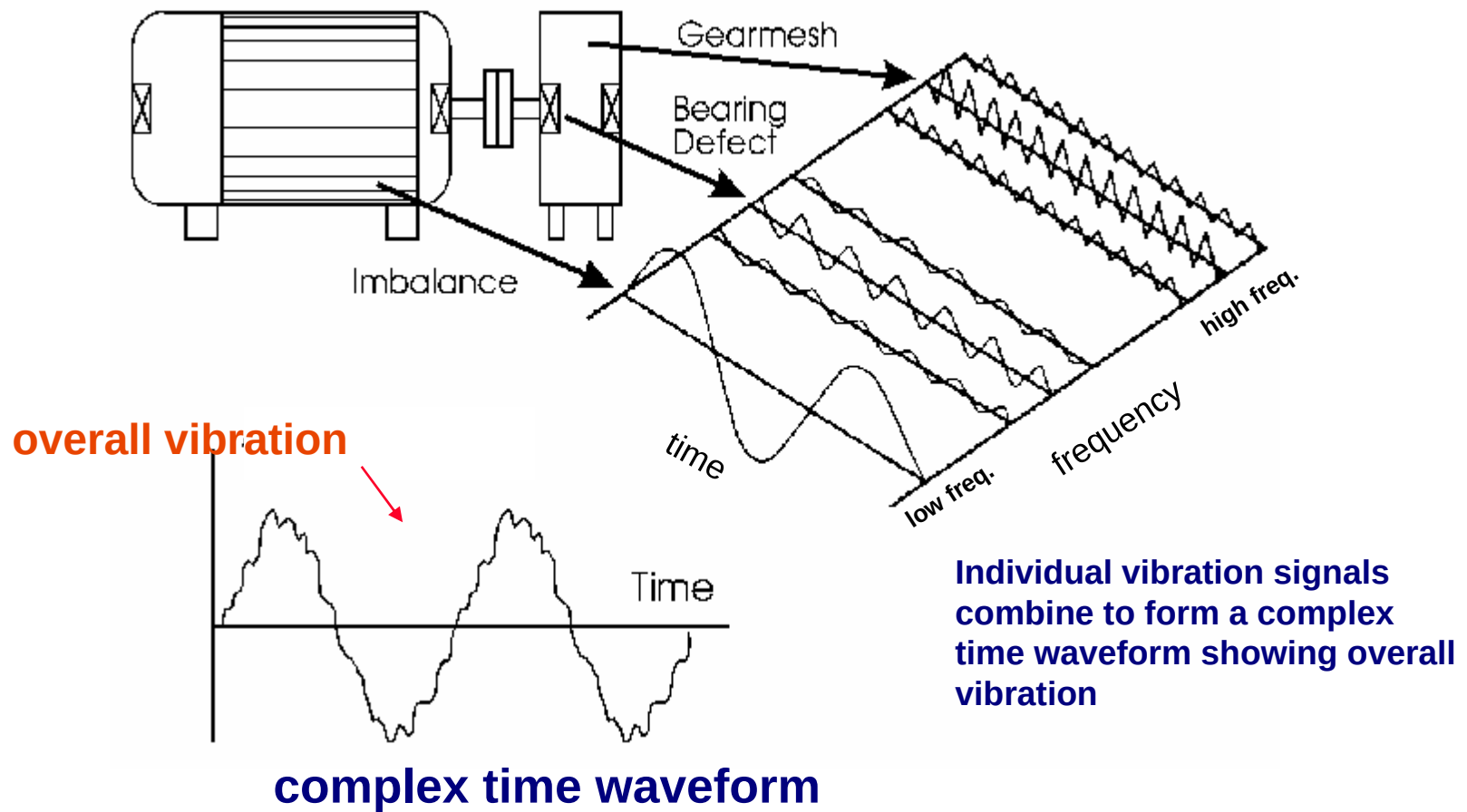


**Vibration is the movement of a body about its reference position.
Vibration occurs because of an excitation force that causes motion.**

Vibration Terms



Time Waveform Analysis

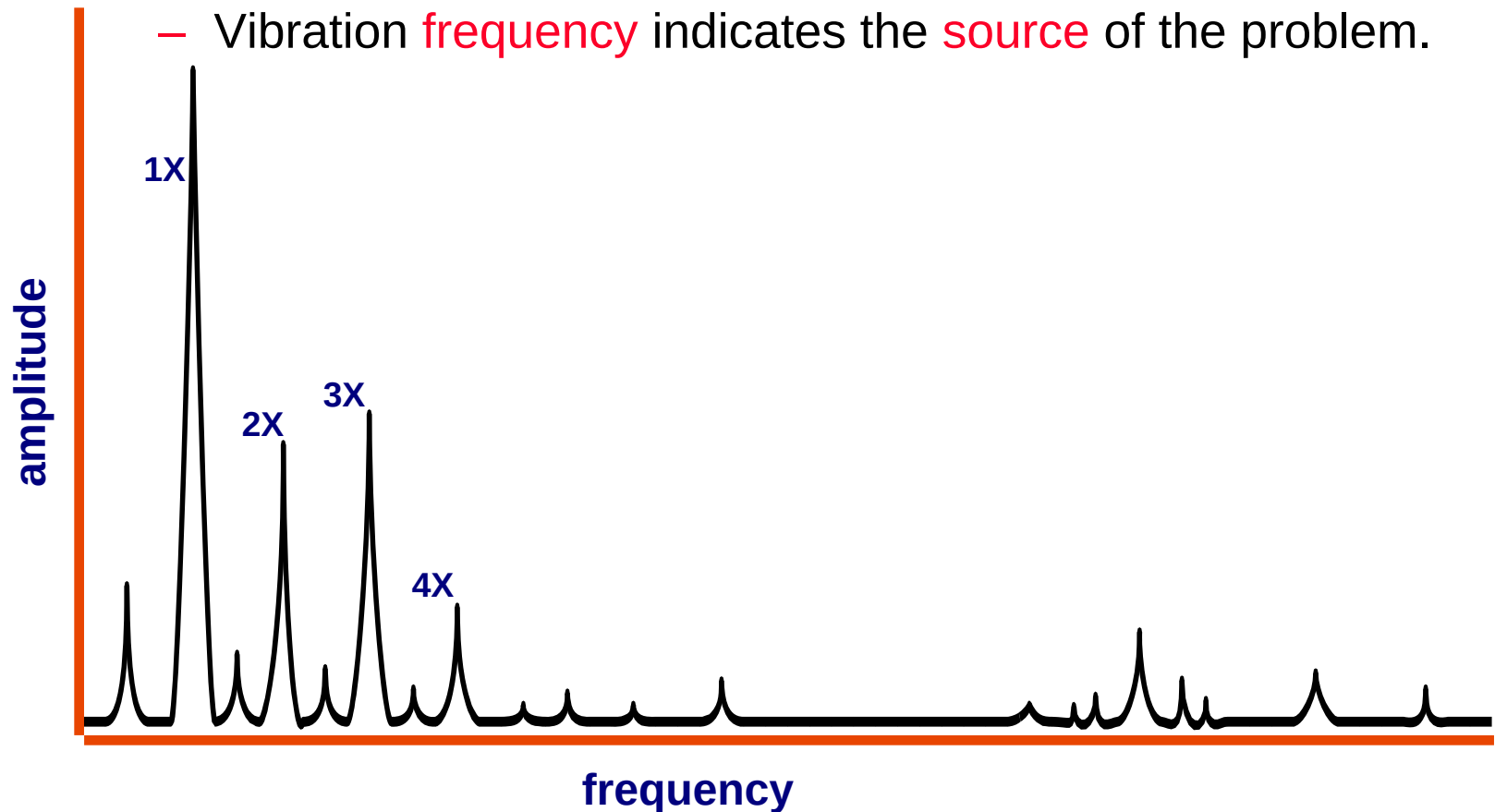


Overall Vibration

- The total vibration energy measured within a specific frequency range.
 - includes a combination of all vibration signals within measured frequency range
 - does not include vibration signals outside measured frequency range
 - produces a numerical value

Amplitude vs. Frequency

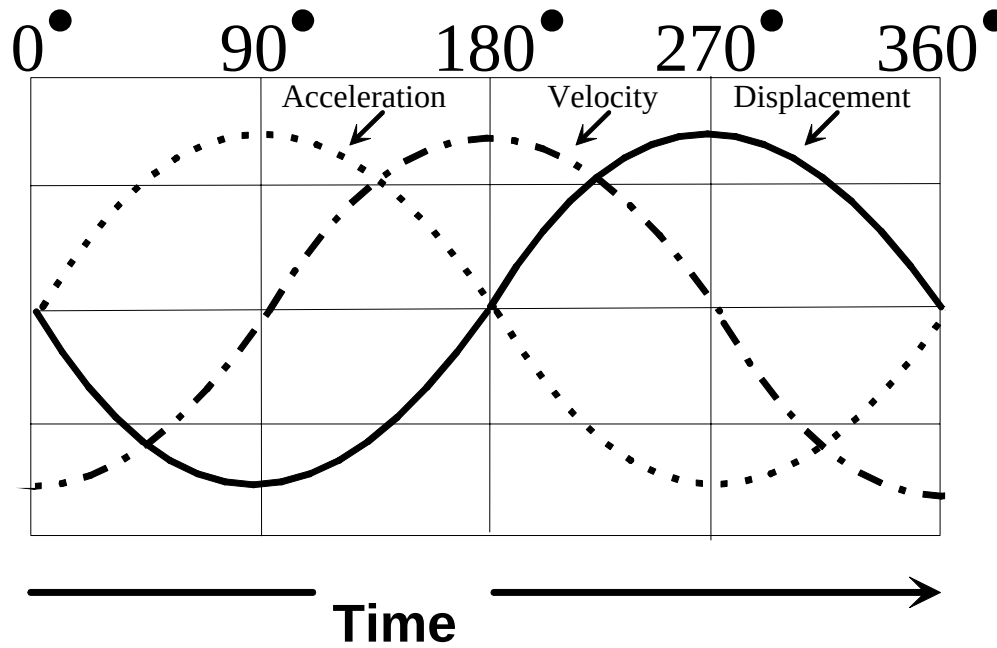
- Vibration **amplitude** indicates the **severity** of the problem.
- Vibration **frequency** indicates the **source** of the problem.



Vibration- Measurable Characteristics

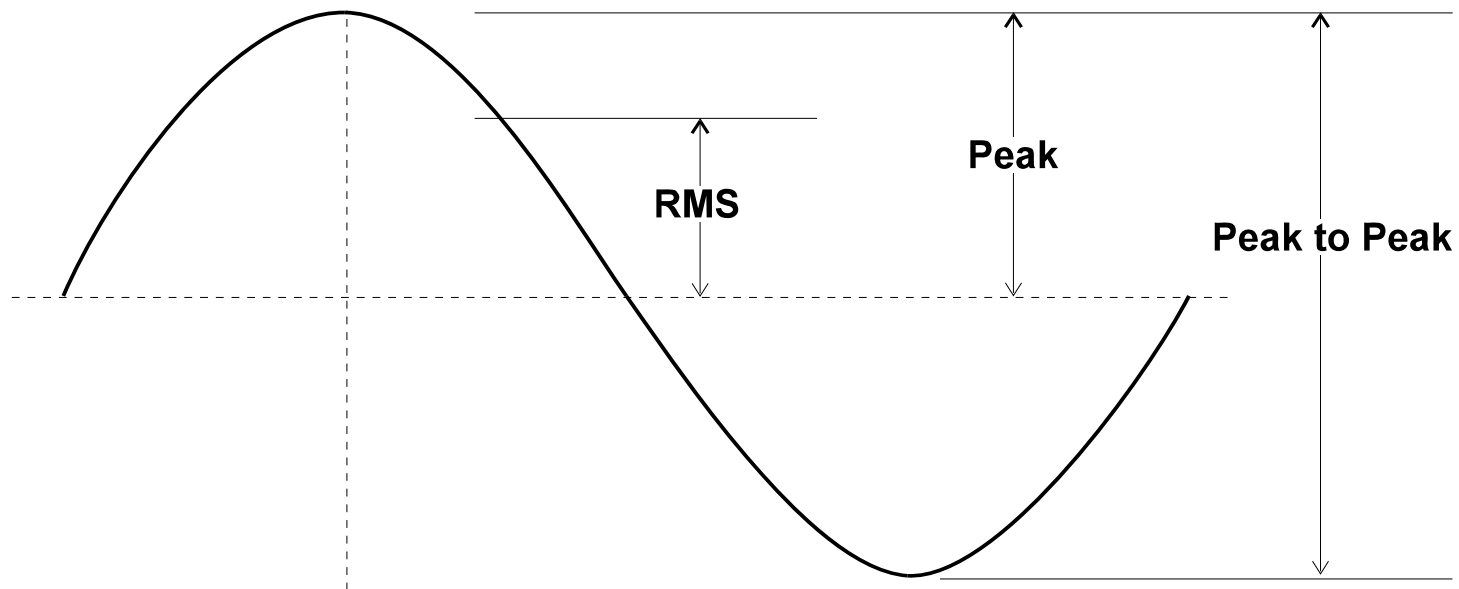
Velocity is the first derivative of displacement as a function of time, it is the rate of change in displacement (the speed of the vibration).

Acceleration is the second derivative of displacement, it is the rate of change of velocity (the change in speed of the vibration).



Scale Factors

- When comparing overall vibration signals, it is imperative that both signals be measured on the same frequency range and with the same **scale factors**. **NOTE: RMS is .707 of peak.**



Measurements & Units

Displacement (**Distance**)

mils or micrometer, mm

Velocity (**Speed** - Rate of change of displcmt)

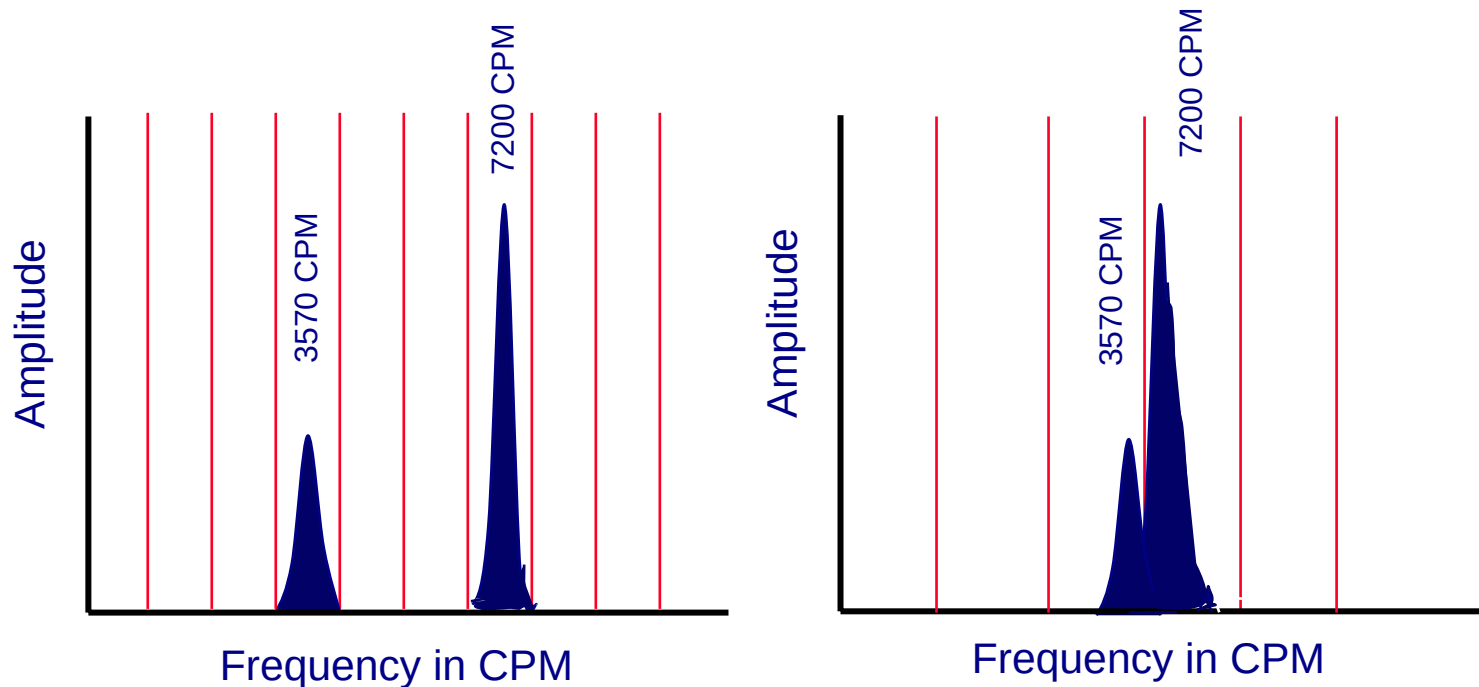
in/sec or mm/sec

Acceleration (Rate of change of velocity)

G's or in/sec² or mm/sec²

Lines of Resolution

Individual Vertical Lines or Bins Located Adjacent to One Another Along the Frequency Axis. Each Bin is used to Store Individual Amplitude at a Specific Frequency Location.



Accelerometers



- Rugged Devices
- Operate in Wide Frequency Range (Near 0 to above 40 kHz)
- Good High Frequency Response
- Some Models Suitable For High Temperature
- Require Additional Electronics (may be built into the sensor housing)

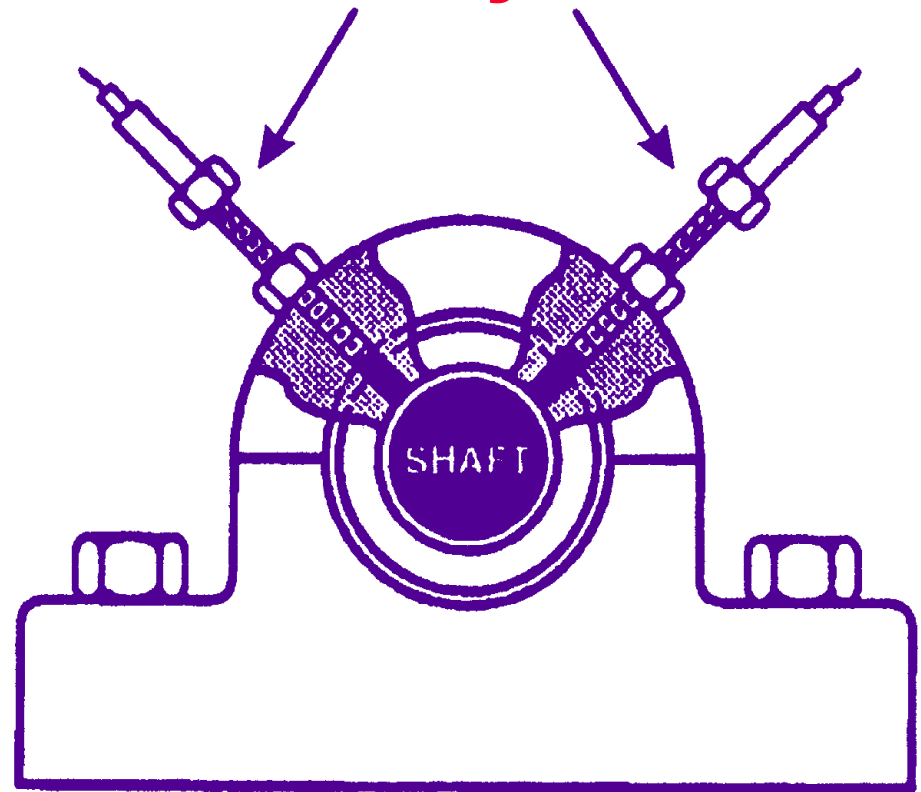
Velocity Sensors



- Often Measure Bearing Housings or Machinery Casing Vibration
- Effective in Low to Mid Frequency Range (10 Hz to around 1,500 Hz)
- Self Generating Devices

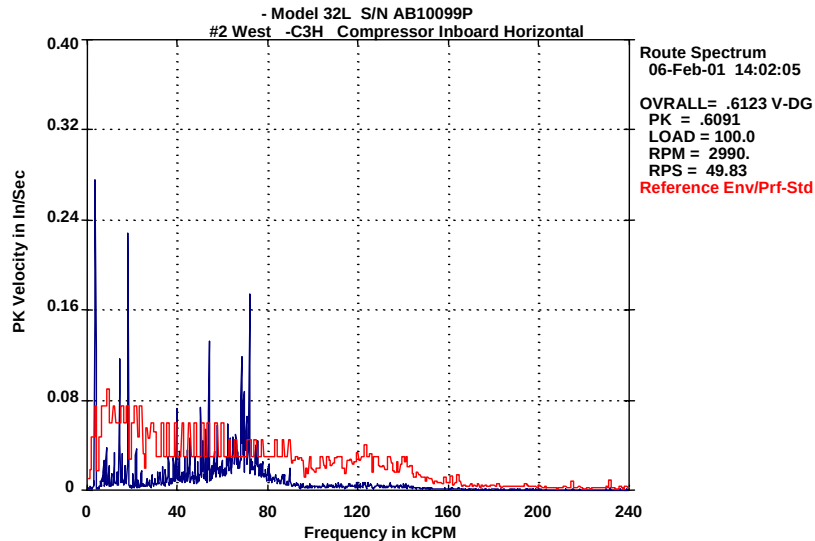
Displacement Probe/Eddy Probe

- Measure **Relative** Distance Between Two (2) Surfaces
- Accurate Low Frequency Response

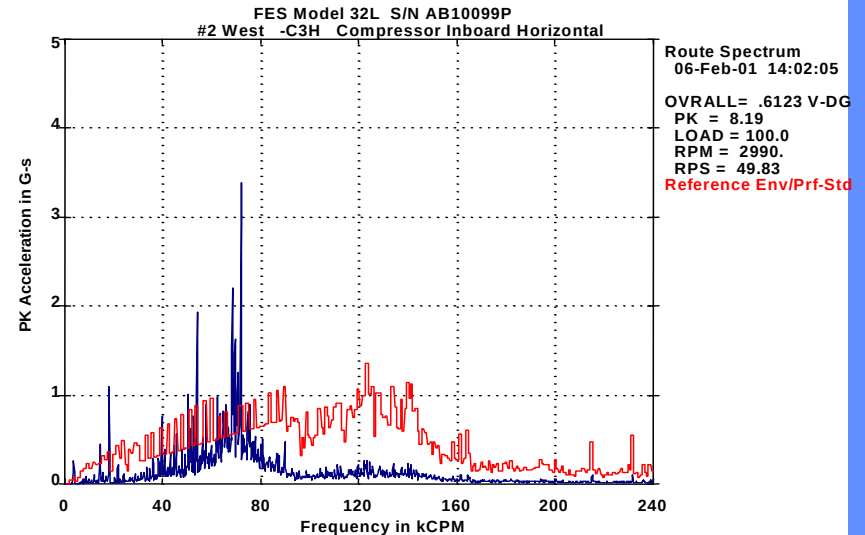


Multi-Parameter Monitoring

Same Data in Velocity and Acceleration



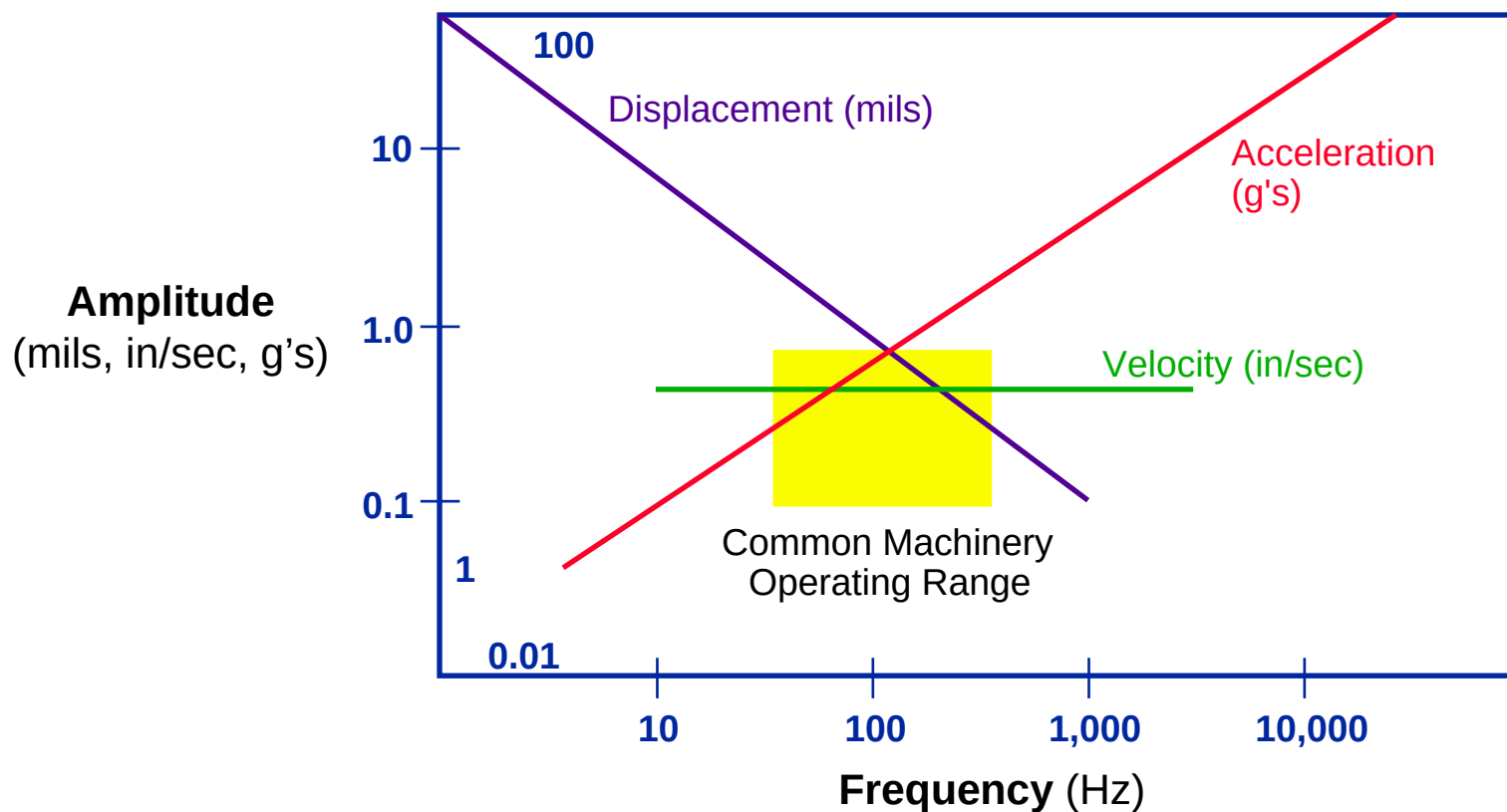
Velocity
Spectrum



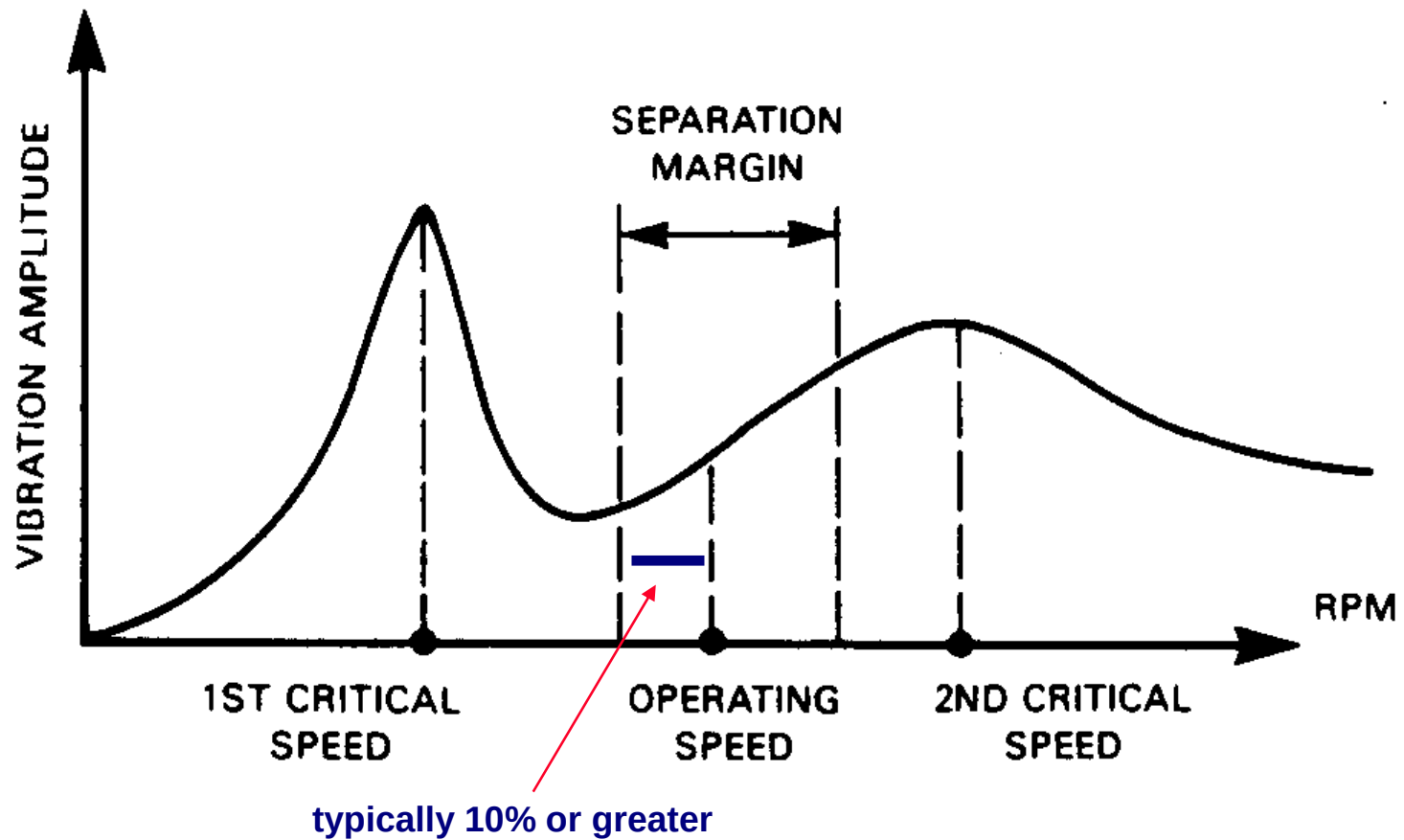
Acceleration
Spectrum

On the same bearing, low freq. events (imbalance, misalignment, etc.) show best in the velocity spectrum; while high freq. events (bearing faults, gearmesh) show best in the acceleration spectrum

Sensor Relationships



Resonance



Detection vs. Analysis

- Detection

Alarm limits are established for each measurement. When the measurement's value exceeds its programmed alarm limits, the predictive maintenance software or data collector notifies the analyst of a problem.

- Analysis

Once detected, analyzing exceptional measurements provides insight to the problem itself, and to its root cause.

Important Frequency Peaks

Rotational Speed or Even Multiples

Always present but excessive amplitude or multiple harmonics can indicate a problem.

Electric motors always have frequency peaks at shaft rotational speed and at line frequency i.e. 60 Hz.

Two pole motors will always display a 2X line frequency peak.

Important Frequency Peaks

Gas Pulsation Frequencies

Screw compressors - gas pulsation frequency(cpm) occurs at
[No. of lobes on male rotor] X [rotational speed (RPM)]

Pumps or fans - fluid pulsation frequency(cpm) occurs at
[No. of vanes, lobes or blades] X [rotational speed (RPM)]

Recip. Compressors - gas pulsation frequency (cpm) occurs
at [No. of pistons] x [rotational speed (RPM)]

Harmonics or even multiples (2X and 3X) of gas pulsation
frequencies always present and are most noticeable on oil
separator vessels.

Setting Up The Measurement

Setting Up the Measurement

- Physical Considerations

- Selecting the Machinery
- Selecting Measurement Planes
- Selecting Sensor Locations
- Surface Preparation
- Sensor Mounting Techniques

- Database Considerations

- Parameters (multi-parameters)
- Alarm Limits
- Setting F_{max}
- Scale Factors

Selecting the Machinery

Critical - If a failure or shutdown occurs, production is stopped, or machine performance creates an unsafe environment

Essential Spared - If a failure or shutdown occurs, production is disrupted

Non Essential Spared - If a failure or shutdown occurs, production loss is inconvenienced, however, a spare unit can be brought on-line, or a repair can bring the production unit back on-line without significant loss of production

Thinking Ahead

- Walk Through
- Machinery Data Sheets

Machinery Data Sheet

Machine Identification <u>1070 1070000 pump & MOTOR</u>			
Machine Description <u>CONDENSING TURBINE DRIVE PUMP</u>			

Drive Units: ☒ Electric Motor ☐ Turbine ☐ Engine ☐ Other _____			
Manufacturer <u>U.S. PUMP & MOTOR</u>	HP/kW <u>1380</u>	Phase <u>3-PT</u>	
Model:	HP: <u>75</u>	Type	
Model Number: <u>9914/3030230000R-5</u>	Order (BDO) Number:		
Unmounted End Bearing <u>SKF 7314</u>	Mounted End Bearing <u>SKF 6213</u>		
<u>3ø 460mm 60Hz</u>			

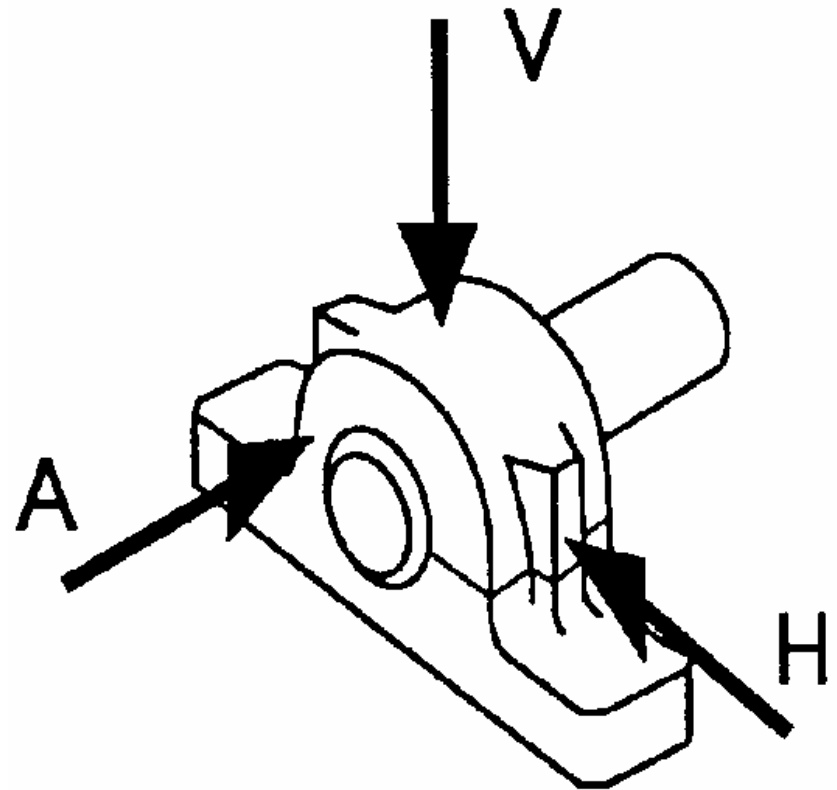
Gearbox: ☒ No Gearbox ☐ Speed Reducer ☐ Coupled Reducer			
Manufacturer	Ratio	Type	
Rated RPM Input	Rated Output RPM		
Pinion Input Gear Teeth	Gear Output Gear Teeth		
Shaft Input Gear Teeth	Shaft Gear Teeth		
BE SURE TO NOTE GEARBOX BEARING IDENTIFICATION ON SKETCH			

Driven Units: ☒ Pump ☐ Fan ☐ Compressor ☐ Other _____			
Manufacturer: <u>TIGERSON PUMP</u>	HP/kW: <u>1800</u>	Capacity: <u>3530GPM</u>	
Model:	HP:	Type: <u>6-11-50</u>	
Serial Number: <u>1185-9008</u>	Order (BDO) Number:		
Range: <u>1</u>	Impeller Version: <u>7</u>		
Unmounted End Bearing: <u>UNKN</u>	Mounted End Bearing: <u>N/A</u>		

ADDITIONAL NOTES ON REVERSE SHEET ☐ YES ☒ NO

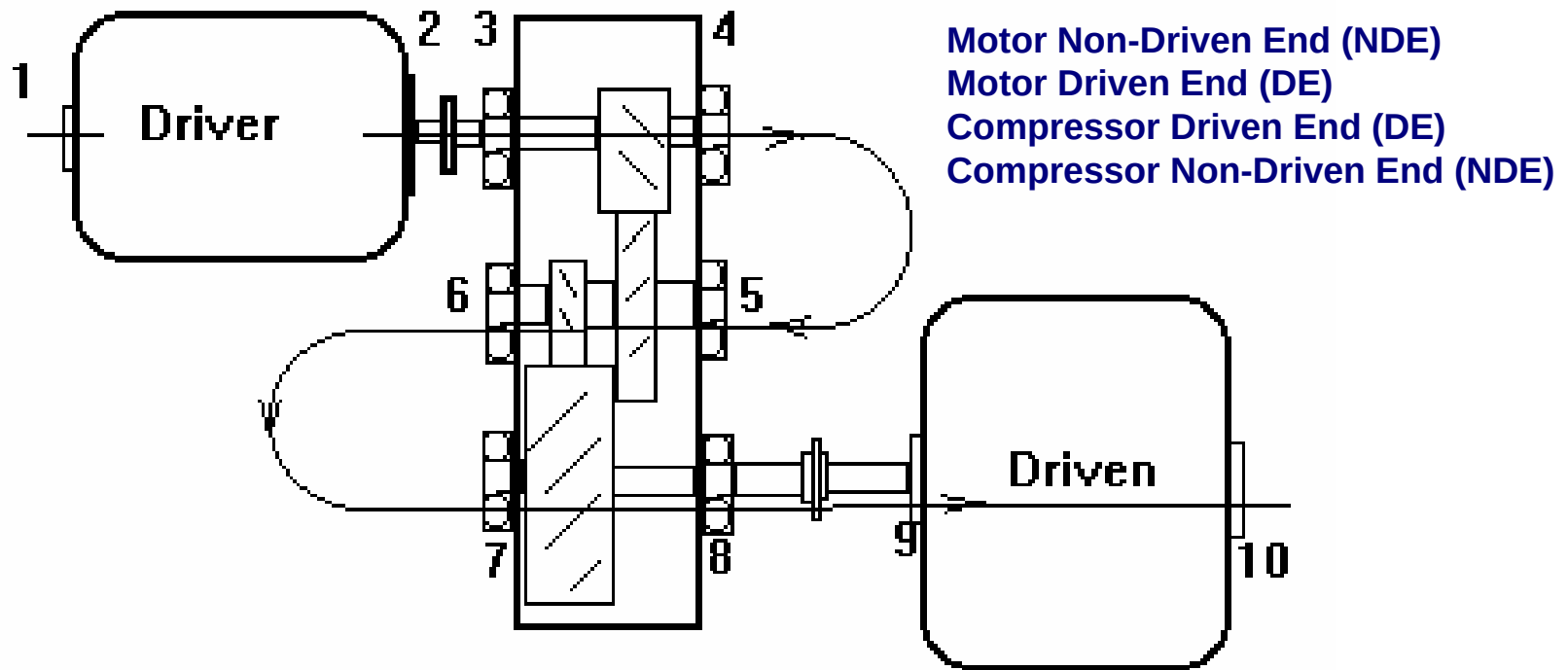
Measurement Planes

- radial
 - vertical
 - horizontal
- axial

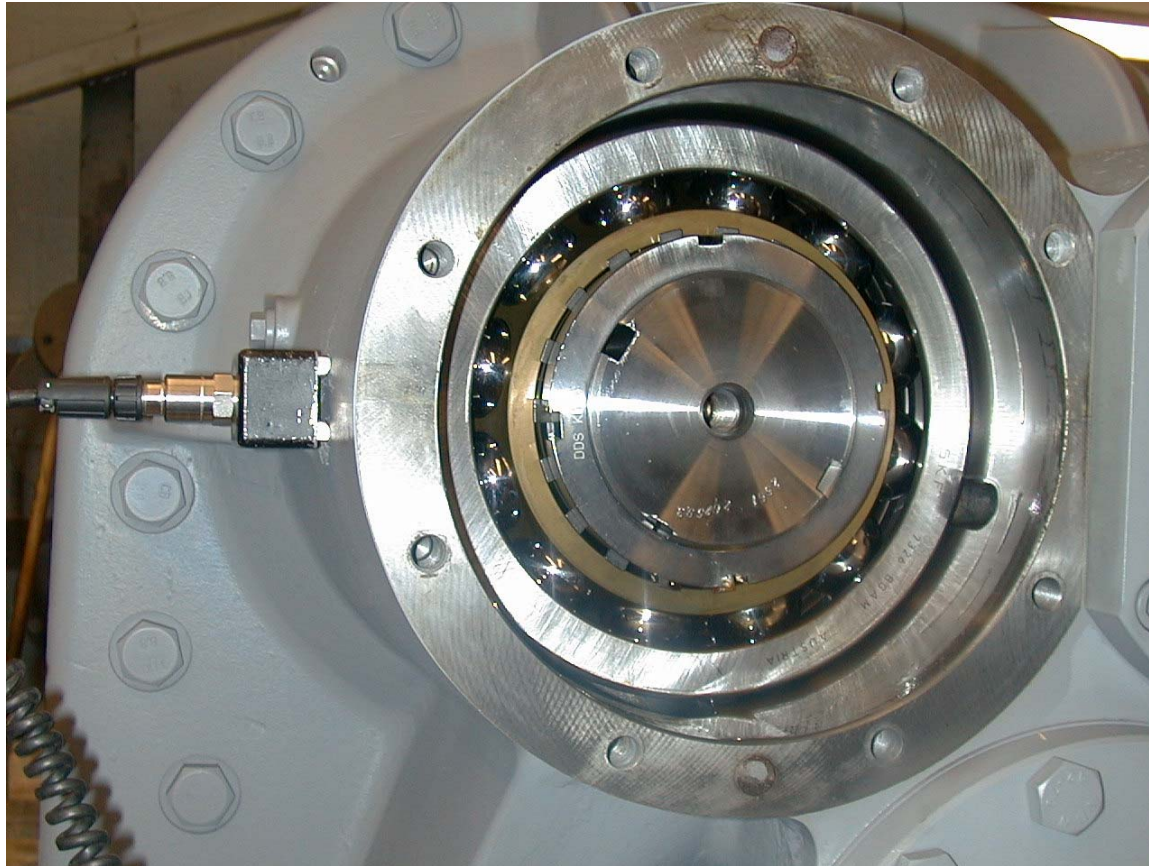


Sensor Location (qualifying and identifying)

Measurement POINT numbering
follows flow of power:



Sensor Location

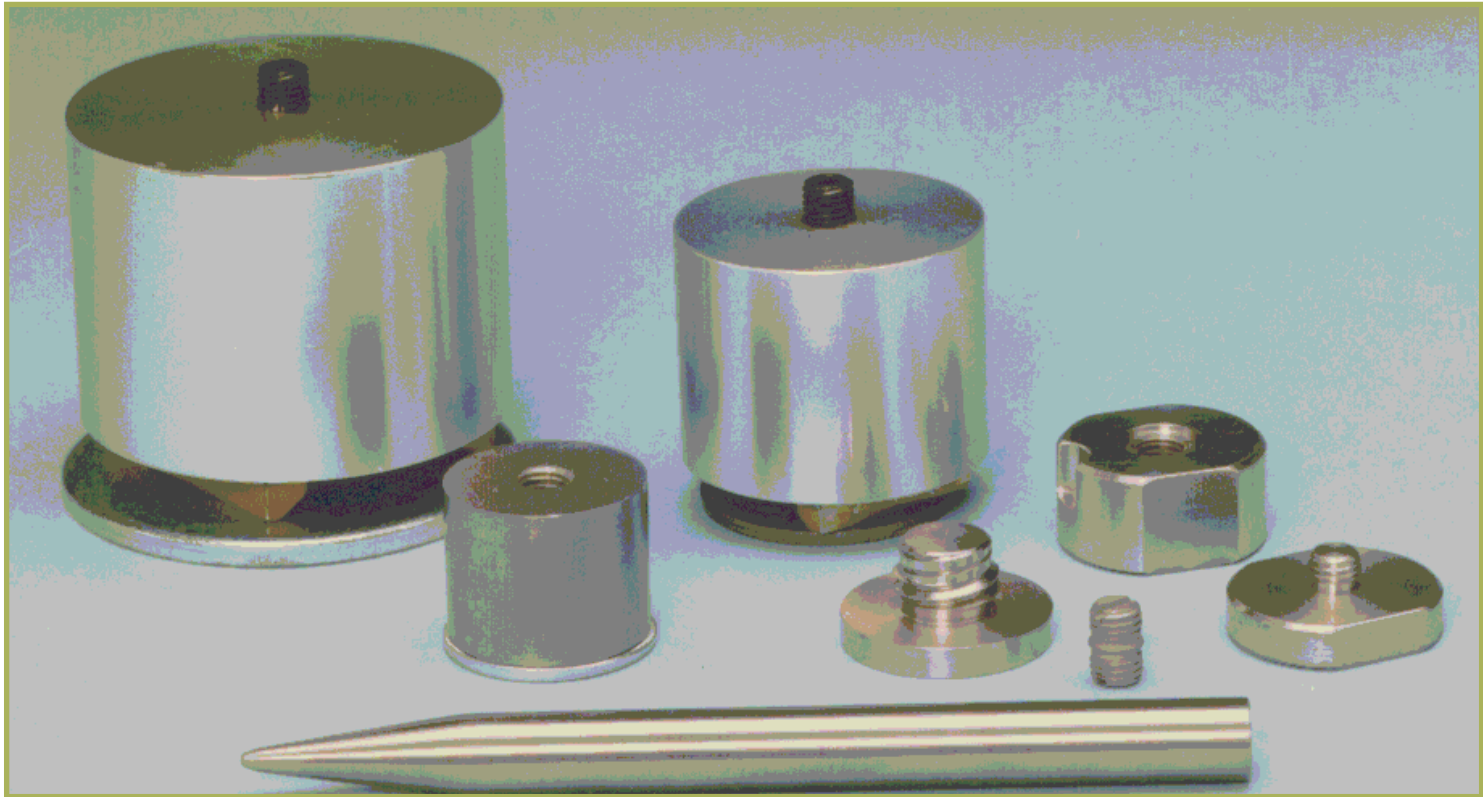


The accelerometer must be located over the bearing of interest. Avoid air gaps in housings whenever possible. Air gaps will skew vibration readings.

Sensor Location



Mounting Methods

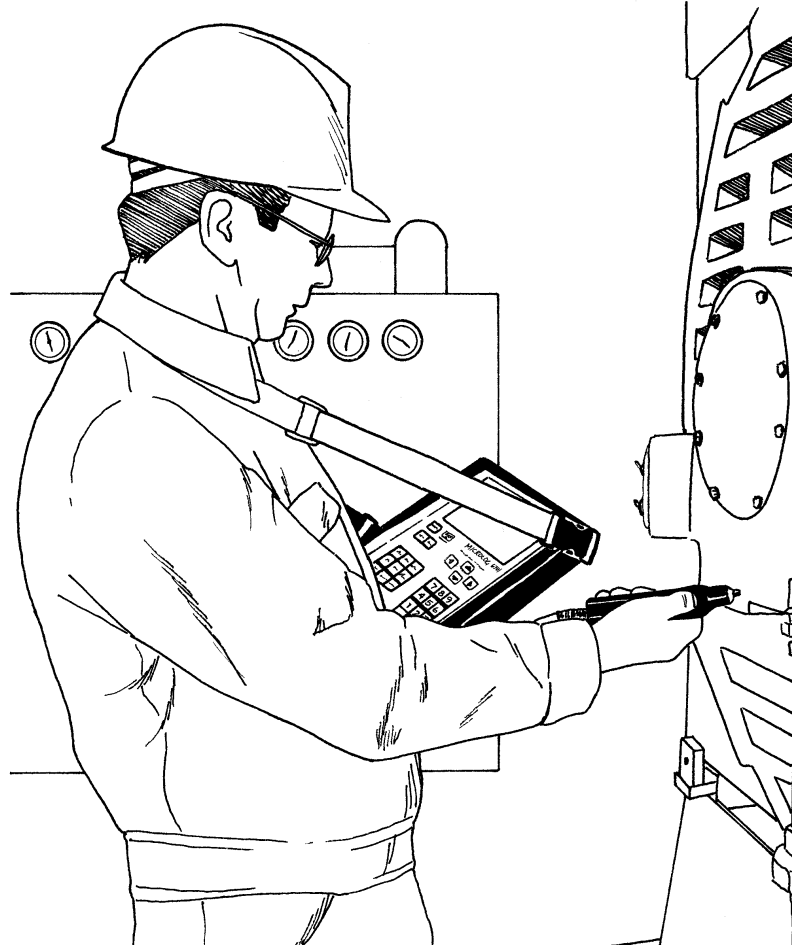


Hand-held/Probe Mounting

**Rapid and
convenient.**

**Subject to
many sources
of error.**

**Use only as a
last resort.**



Setting Alarms

Types of Alarms

- Overall Vibration Limits
- Spectral Enveloping
- Spectral Bands
- Phase Alarms

Acceptable Vibration Levels

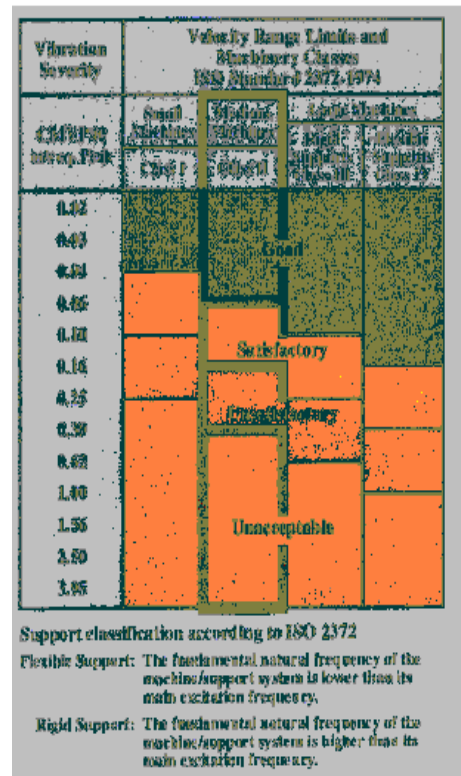
Acceptable Vibration Levels

Tables are published that show overall vibration levels as a function of rotational speed or vibration frequency for the purpose of determining whether vibration levels are acceptable. As a general rule for compressors operating at 3600 RPM an overall vibration level of 0.3 ips RMS would be cause for concern

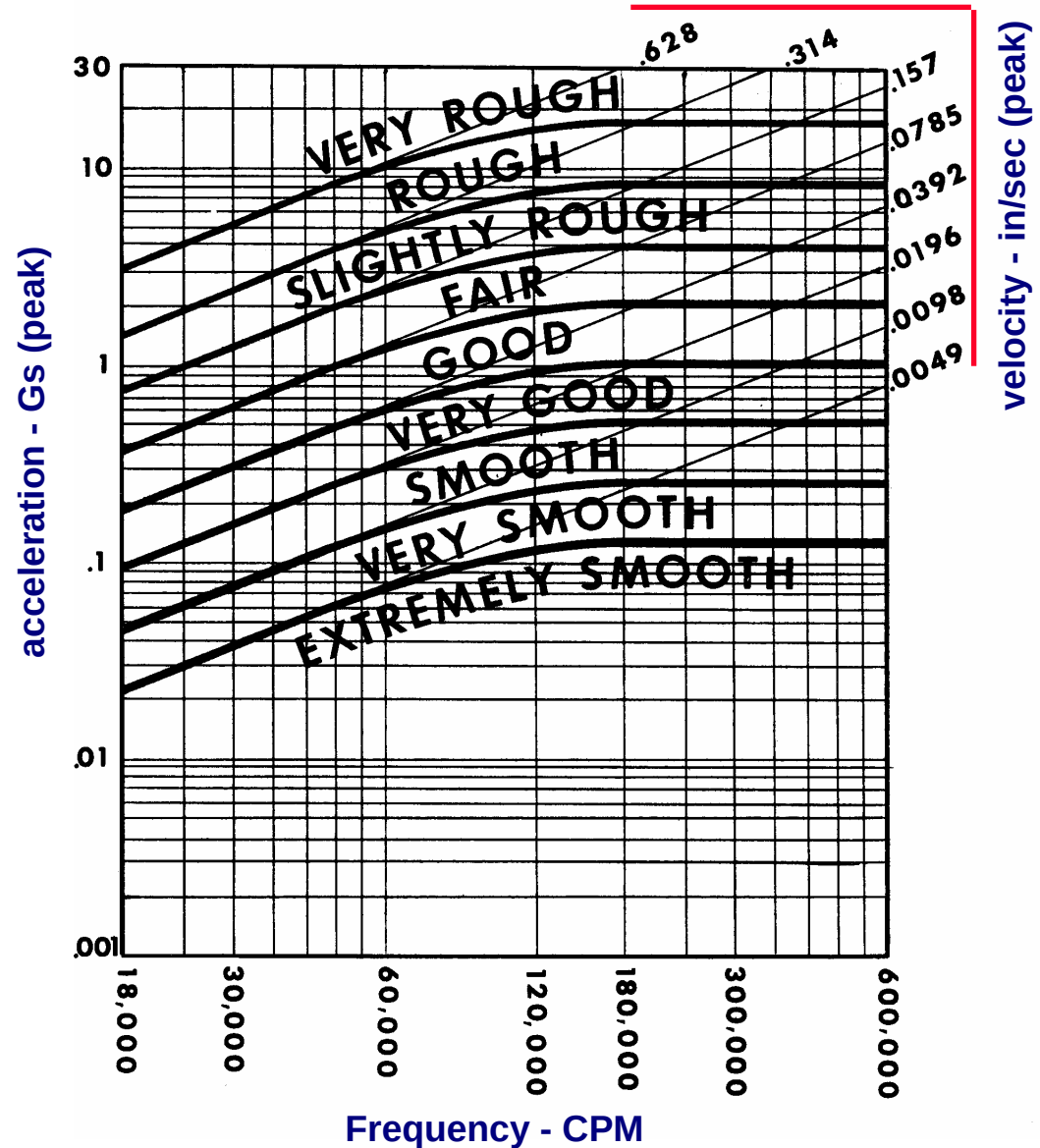
For piping and valves overall readings exceeding 1.0 ips RMS would be cause for concern though actual stress values induced by the vibration may be quite low and no corrective action needed. Some engineering evaluation should be conducted to determine this.

ISO Guidelines

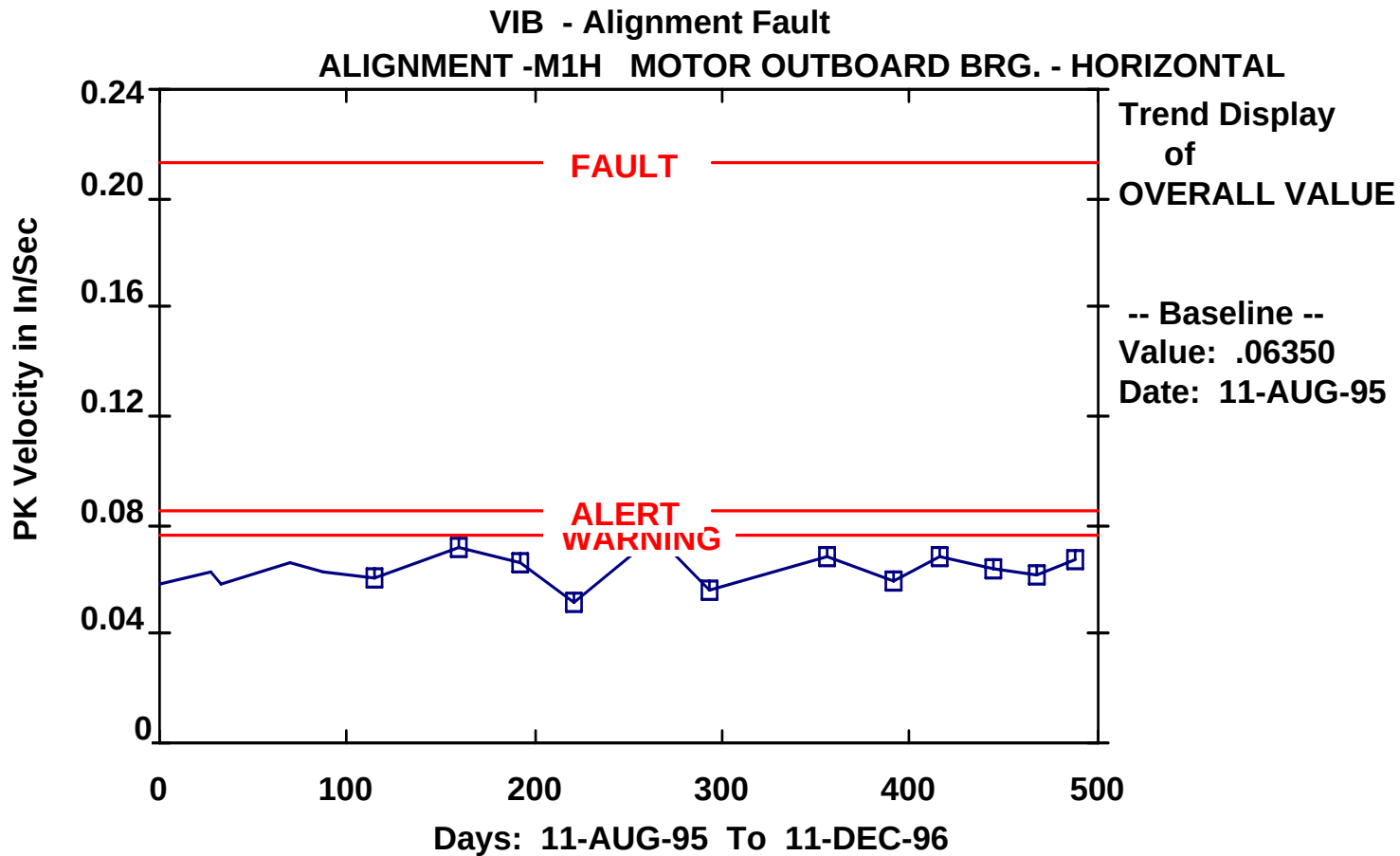
ISO 2372 overall velocity vibration guidelines



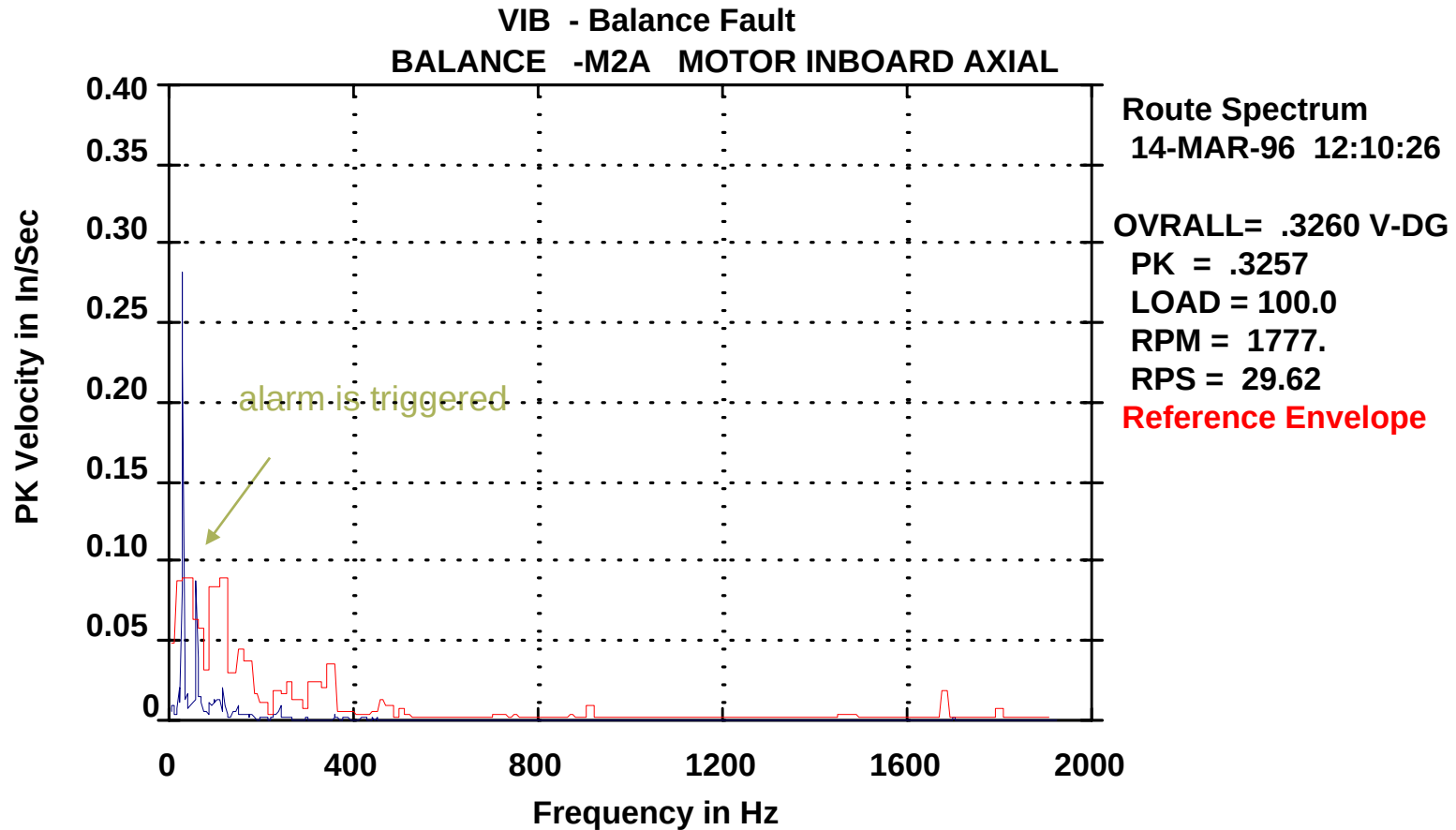
Assessing Overall Vibration Severity



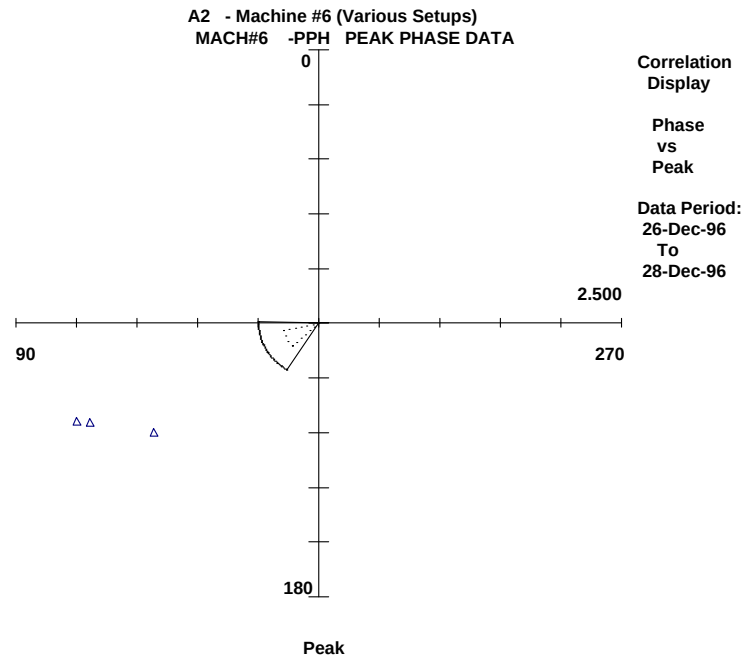
Overall Vibration Trend Plot



Spectral Enveloping



Phase Alarms



Acceptable Vibration Levels

Motor and compressors with sleeve bearings do not lend themselves well to readings with accelerometers and for dependable information a device such as a proximity probe should be used to measure vibration in mils displacement. Probes should be oriented in two planes 90 ° apart and displacement cannot exceed the shaft to bearing clearance.

Acceptable Vibration Levels

For Individual spectrum peaks limits are set by their perceived cause but some general limits are shown below:

Compressors:

Rotational speed 1X, 2X, 3X	0.25 ips RMS
Gas Pulsation at compressor	0.27 ips RMS
Bearing fault frequencies	0.15 ips RMS
Roller bearings (2000-3000 Hz)	2.5 g's

Acceptable Vibration Levels

Motors:

Rotational Speed 1X, 2X, 3X

0.25 ips RMS

Line Frequency 1X, 2X

0.13 ips RMS

Bearing fault frequencies

0.15 ips RMS

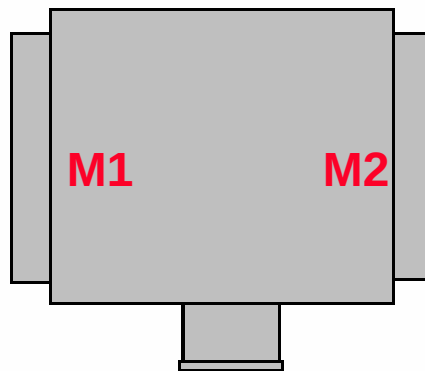
Readings-How Often?

- At start up - Baseline
- Six months after start up unless a problem is suspected. After that every 6 month to one year after that unless a deteriorating trend is observed.
- At 25000 hours readings should be taken every three months to extend the time before an internal inspection is required.
- Anytime an unusual noise or vibration is noticed.

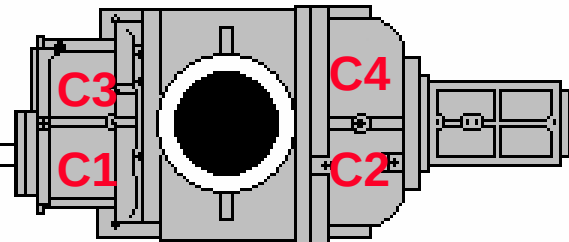
Spectrum Analysis Techniques

- Collect Useful Information
- Analyze

500 HP/3570 RPM
Motor



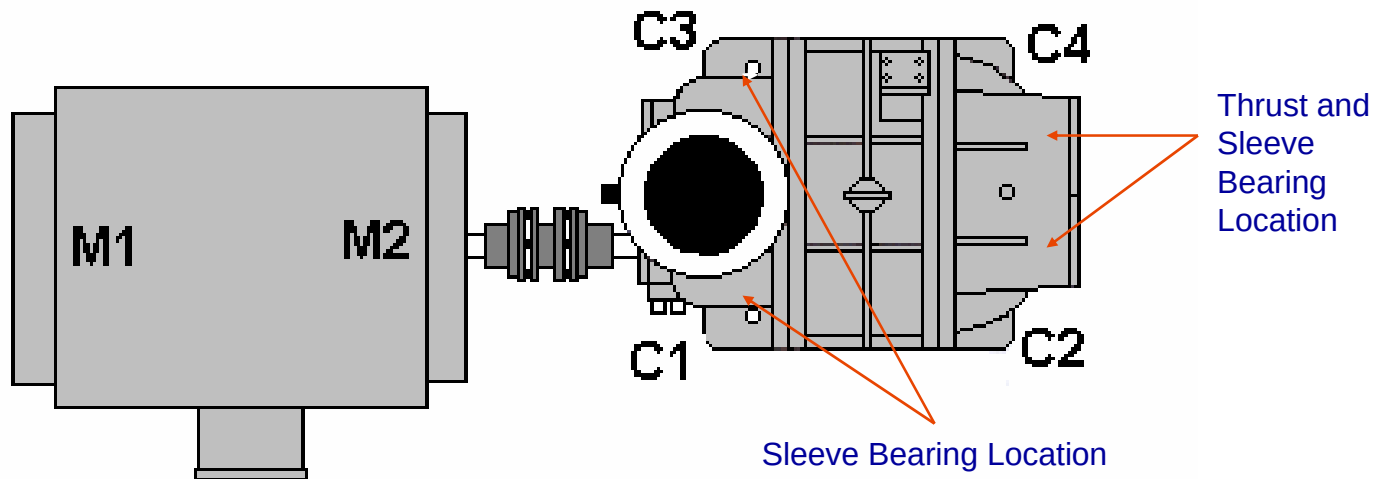
Model 23LE



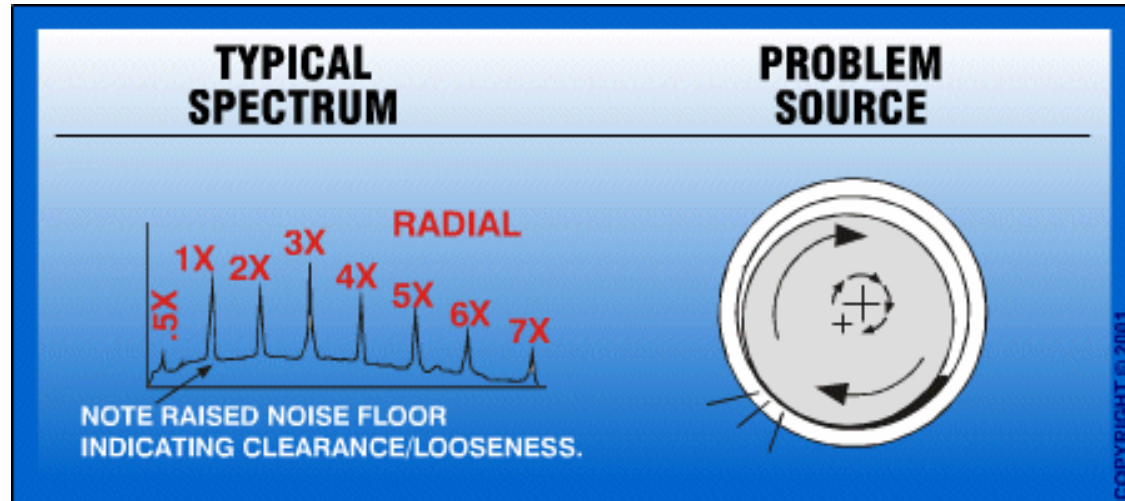
Spectrum Analysis Techniques

Some compressors have a combination of sleeve bearings and ball thrust bearings that require different analysis techniques.

FES Model GL Series Compressors



Sleeve Bearing Wear Pattern

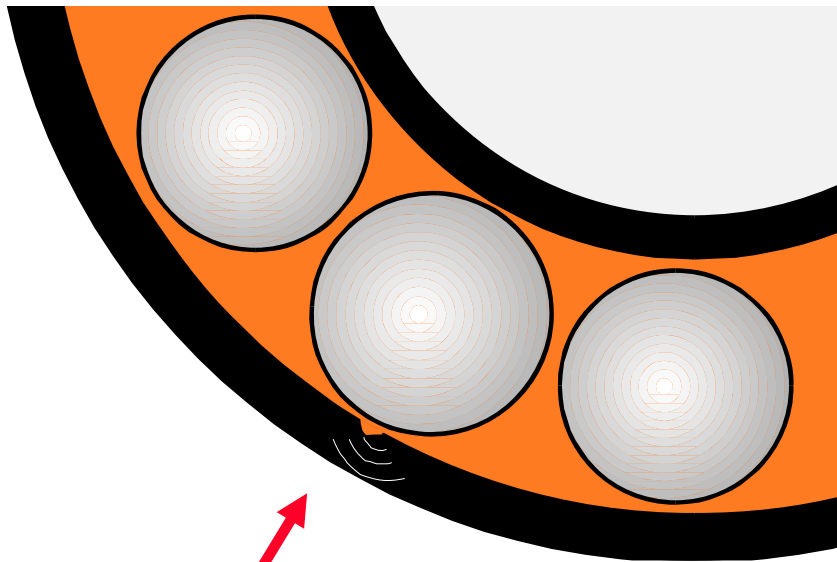


Latter stages of journal bearing wear are normally evidenced by presence of whole series of running speed harmonics (up to 10 or 20). Wiped journal bearings often will allow high vertical amplitudes compared to horizontal, but may show only one pronounced peak at 1X RPM. Journal bearings with excessive clearance may allow a minor unbalance and/or misalignment to cause high vibration which would be much lower if bearing clearances were set to specifications.

Source: Technical Associates Inc.
Illustrated Vibration Chart

Monitoring Rolling Element Bearings

Why Do Bearings Fail?



Spall On Outer Race

Inadequate Lubrication

- too much
- too little
- contaminated

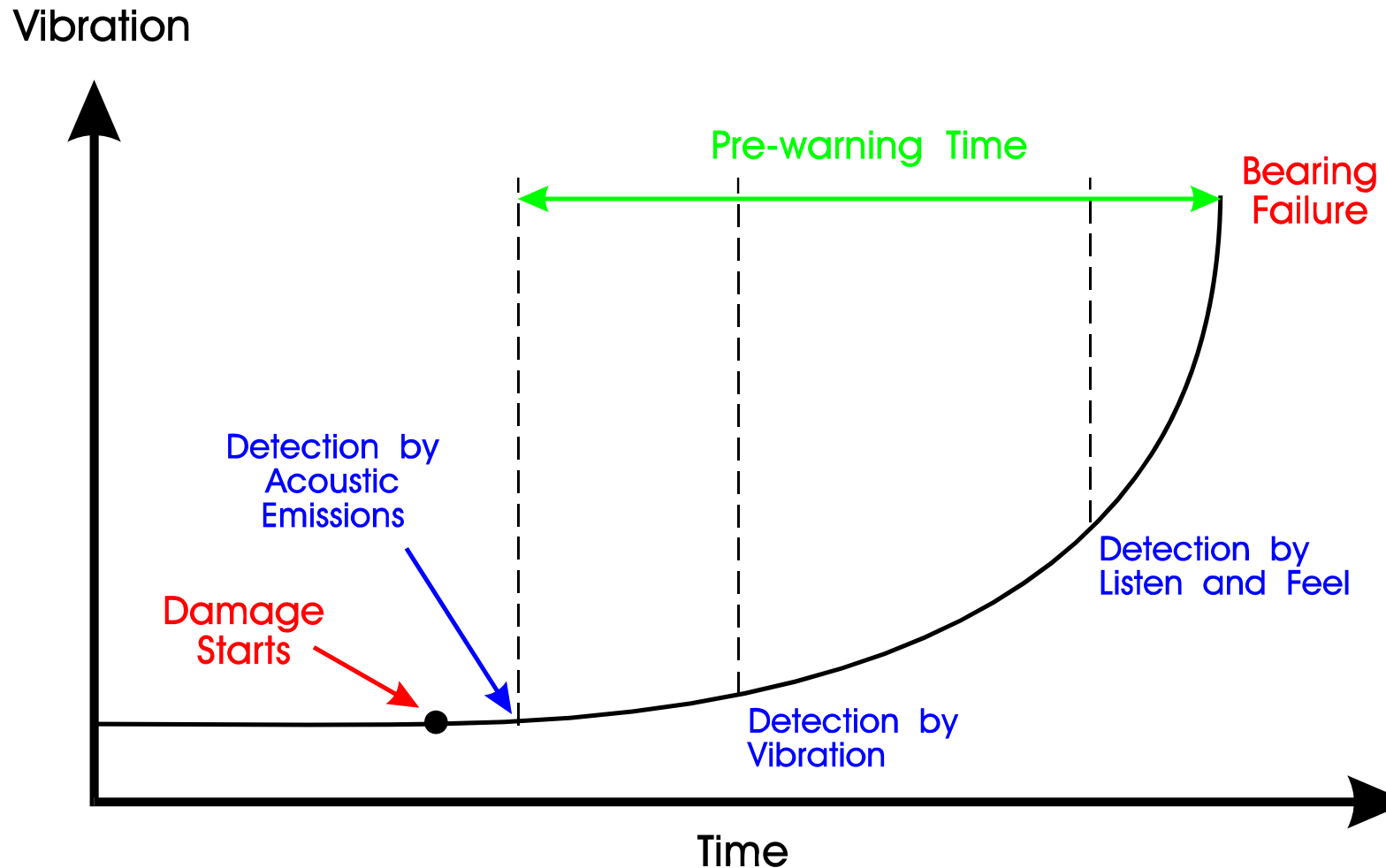
Excessive Load Caused by:

- misalignment
- imbalance
- bent shaft
- etc.....

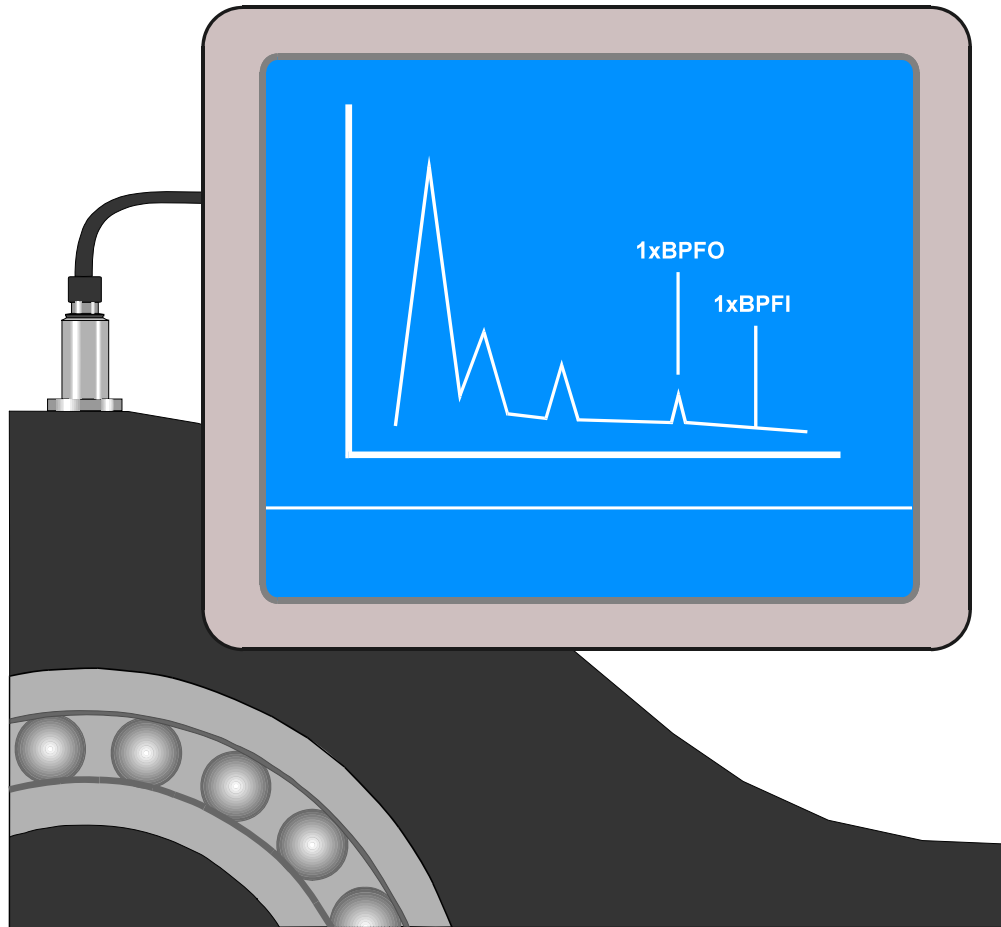
Improper Handling or Installation

Age

Typical Bearing Failure Rate



Bearing Defect Frequencies



BPFO

Ball Pass Frequency Outer Race

BPFI

Ball Pass Frequency Inner Race

BSF

Ball Spin Frequency

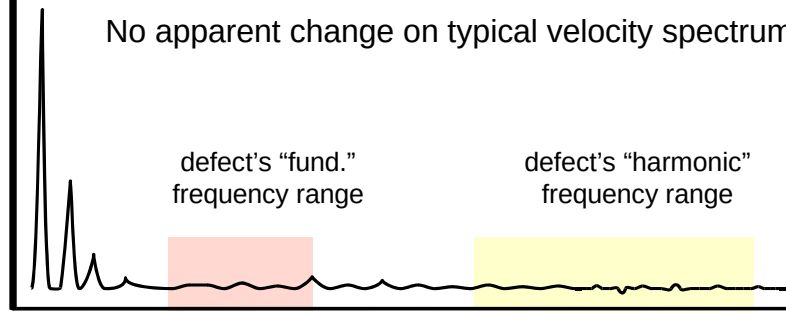
FTF

Cage Frequency or
Fundamental Train Frequency

Bearing Failure Stages

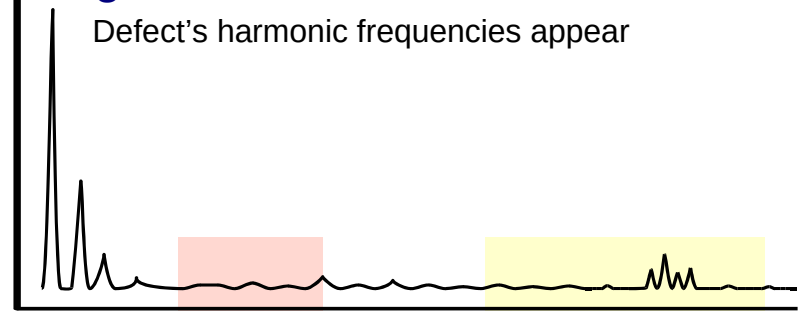
Stage 1

No apparent change on typical velocity spectrum



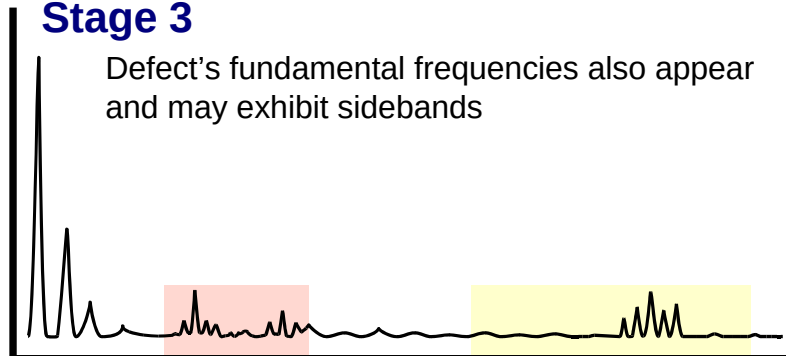
Stage 2

Defect's harmonic frequencies appear



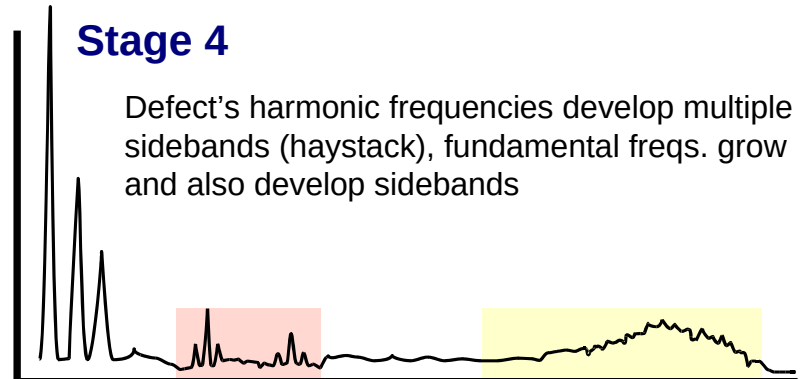
Stage 3

Defect's fundamental frequencies also appear and may exhibit sidebands



Stage 4

Defect's harmonic frequencies develop multiple sidebands (haystack), fundamental freqs. grow and also develop sidebands



Sidebands

VIB - Alignment Fault

ALIGNMENT -M2H MOTOR INBOARD BRG. - HORIZONTAL

Route Spectrum

01-AUG-96 15:15:26

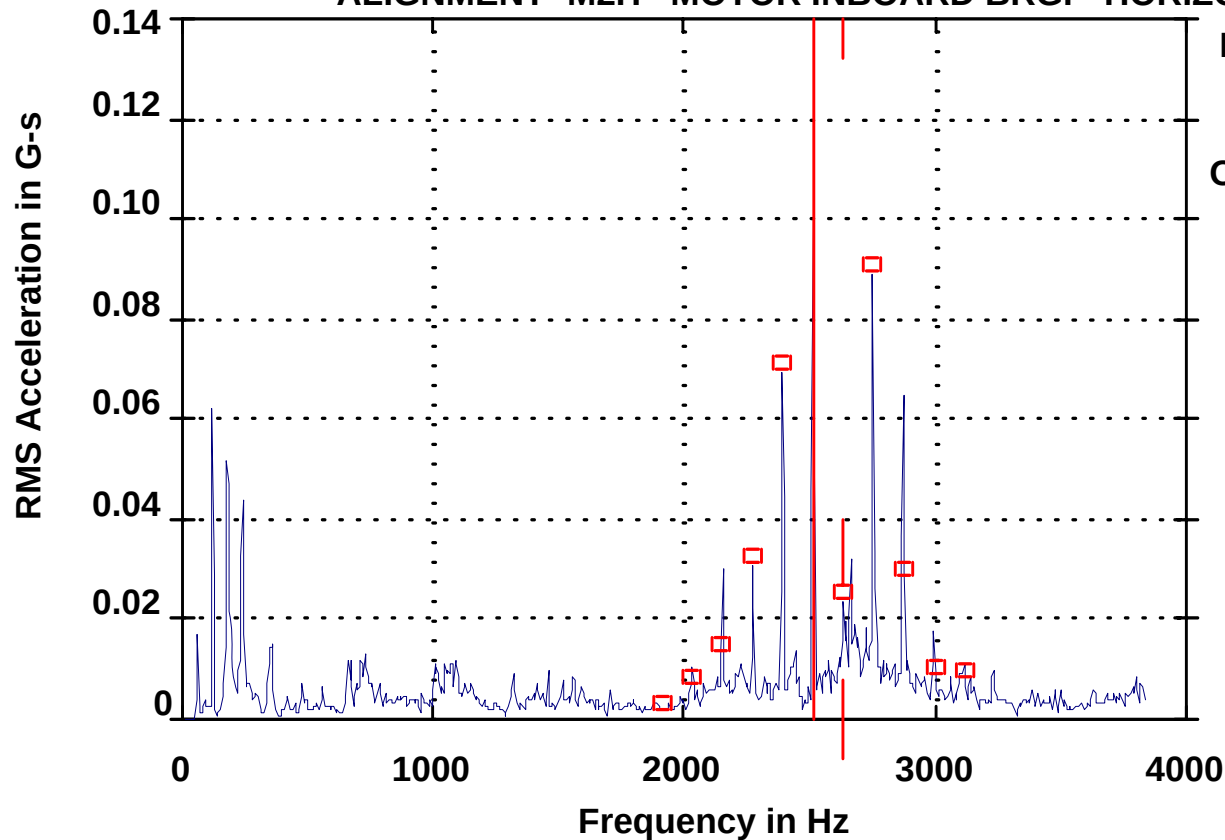
OVRALL= .0665 V-DG

RMS = .2506

LOAD = 100.0

RPM = 3606.

RPS = 60.10



Freq: 2634.6

Ordr: 43.84

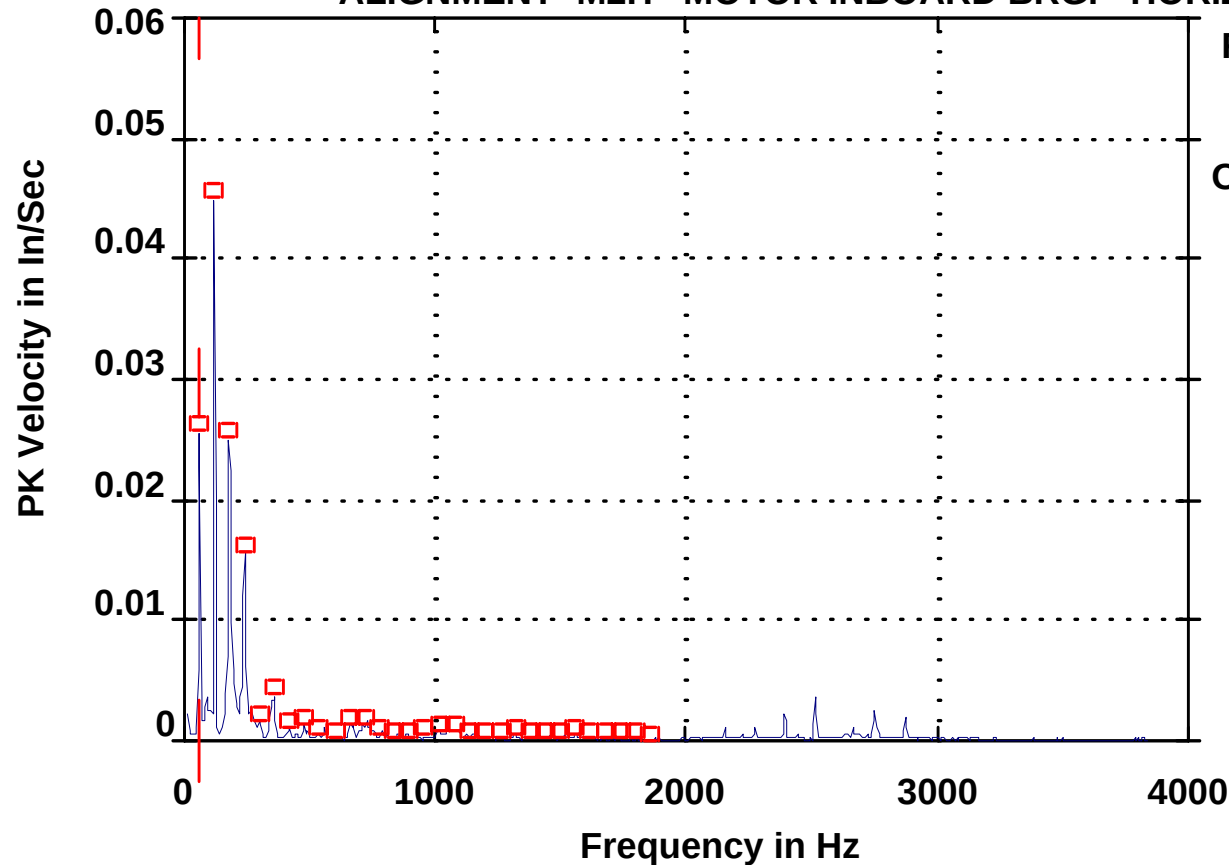
Spec: .02417

Dfrq: 120.19

Harmonics

VIB - Alignment Fault

ALIGNMENT -M2H MOTOR INBOARD BRG. - HORIZONTAL



Route Spectrum

01-AUG-96 15:15:26

OVRALL= .0665 V-DG

PK = .0660

LOAD = 100.0

RPM = 3606.

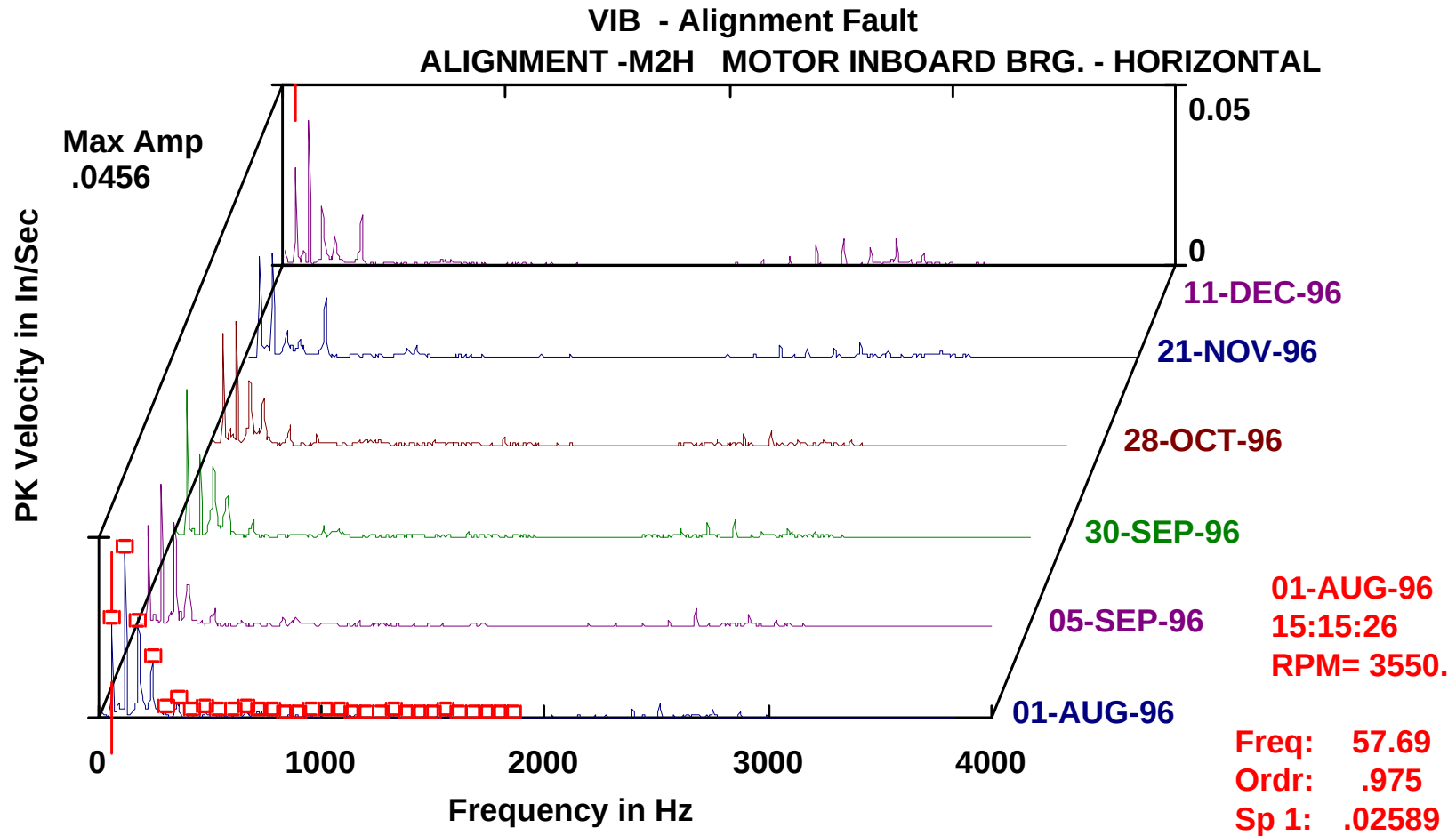
RPS = 60.10

Freq: 57.69

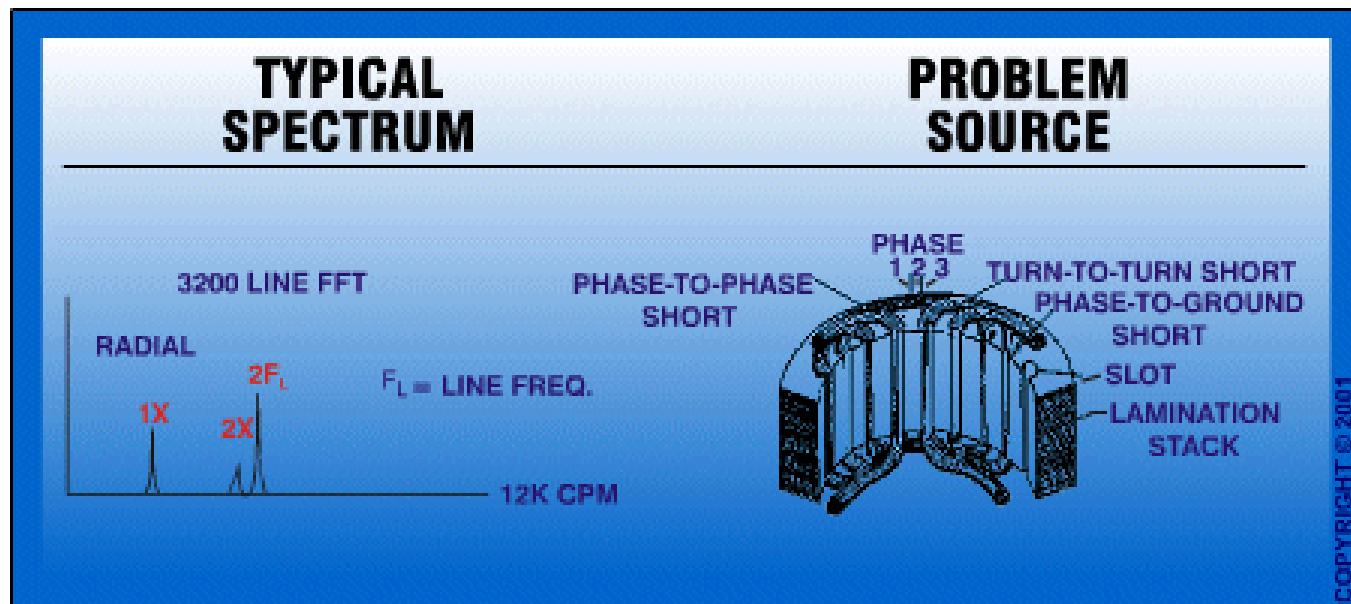
Ordr: .960

Spec: .02572

Waterfall Plot

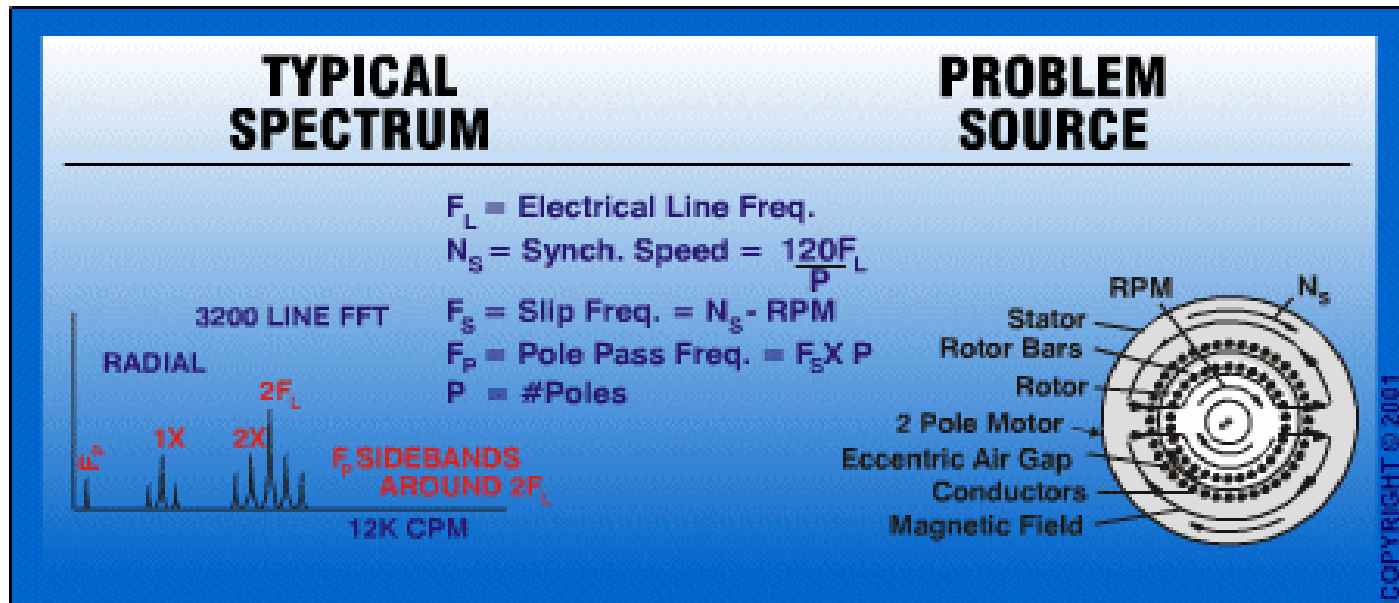


Analyzing Potential Motor Problems



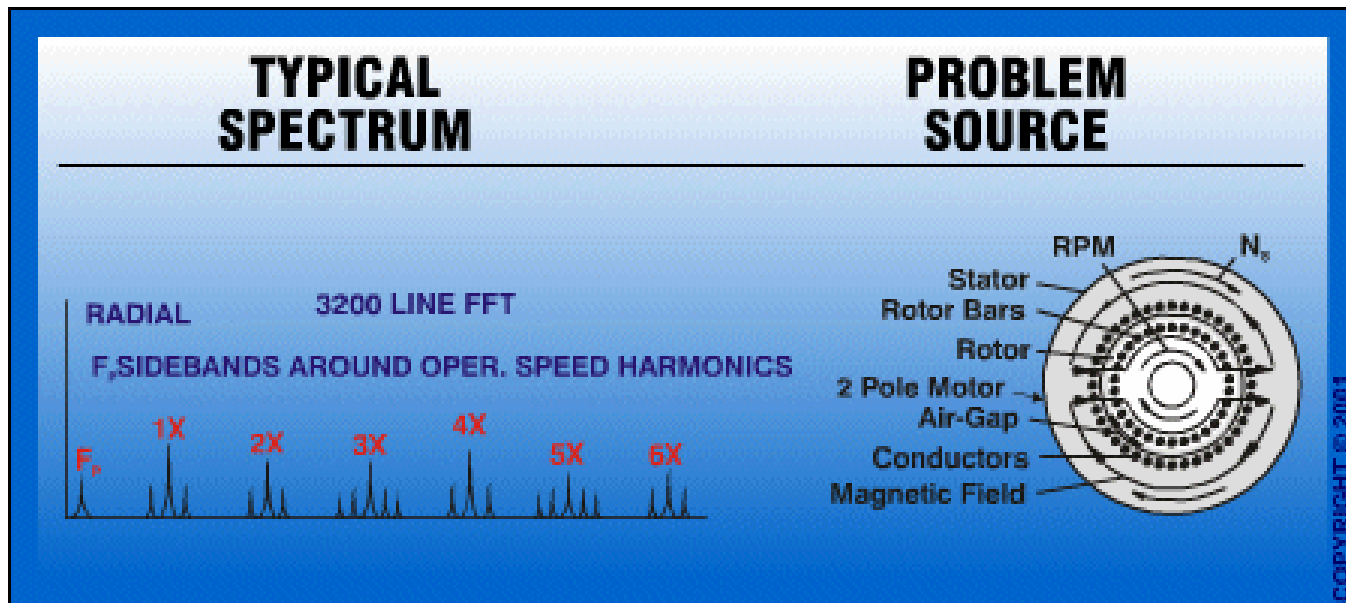
Stator problems generate high vibration at 2X line frequency ($2F_L$). Stator eccentricity produces uneven stationary air gap between rotor and stator which produces very directional vibration. Differential Air Gap should not exceed 5% for induction motors and 10% for synchronous motors. Soft foot and warped bases can produce an eccentric stator. Loose iron is due to stator support weakness or looseness. Shorted stator laminations can cause uneven, localized heating which can distort the stator itself. This produces thermally-induced vibration which can significantly grow with operating time causing stator distortion and static air gap problems.

Source: Technical Associates Inc.
 Illustrated Vibration Chart



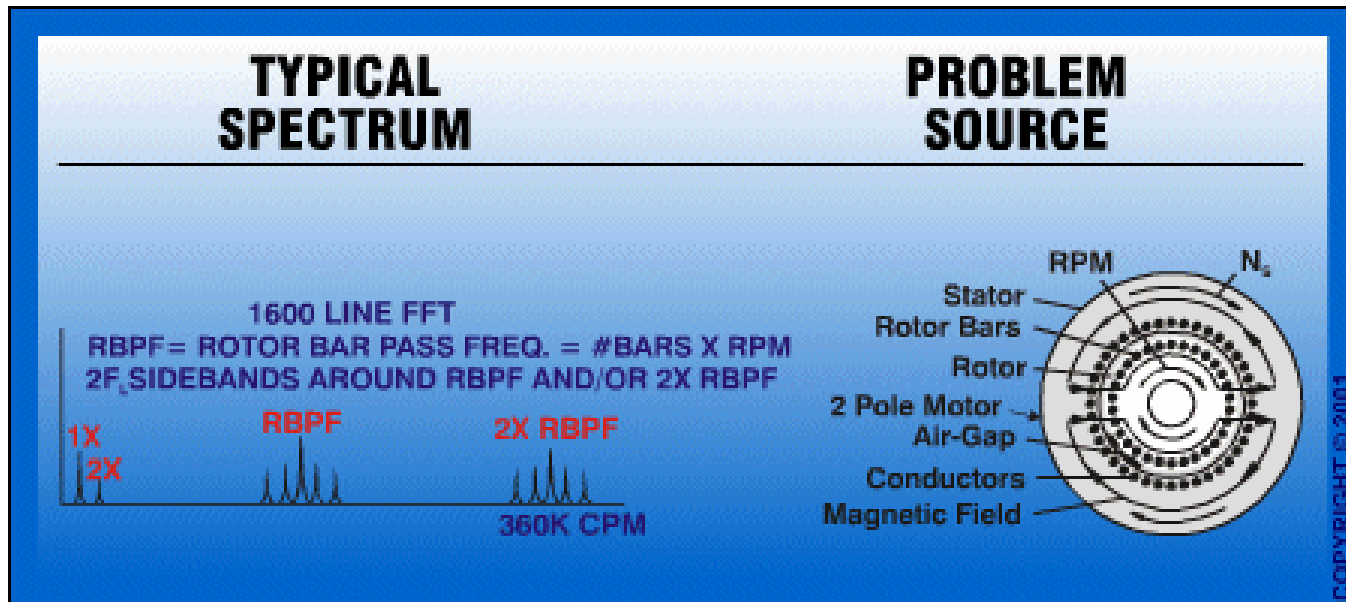
Eccentric Rotors produce a rotating variable air gap between the rotor and stator which induces pulsating vibration (normally between $2F_L$ and closest running speed harmonic). Often requires "zoom" spectrum to separate $2F_L$ and running speed harmonic. Eccentric rotors generate $2F_L$ surrounded by Pole Pass frequency sidebands (F_p), as well as F_p sidebands around running speed. F_p appears itself at low frequency (Pole Pass Frequency = Slip Frequency X #Poles). Common values of F_p range from about 20 to 120 CPM (0.3 - 2.0 Hz). Soft foot or misalignment often induces a variable air gap due to distortion (actually a mechanical problem; not electrical).

Source: Technical Associates Inc.
Illustrated Vibration Chart



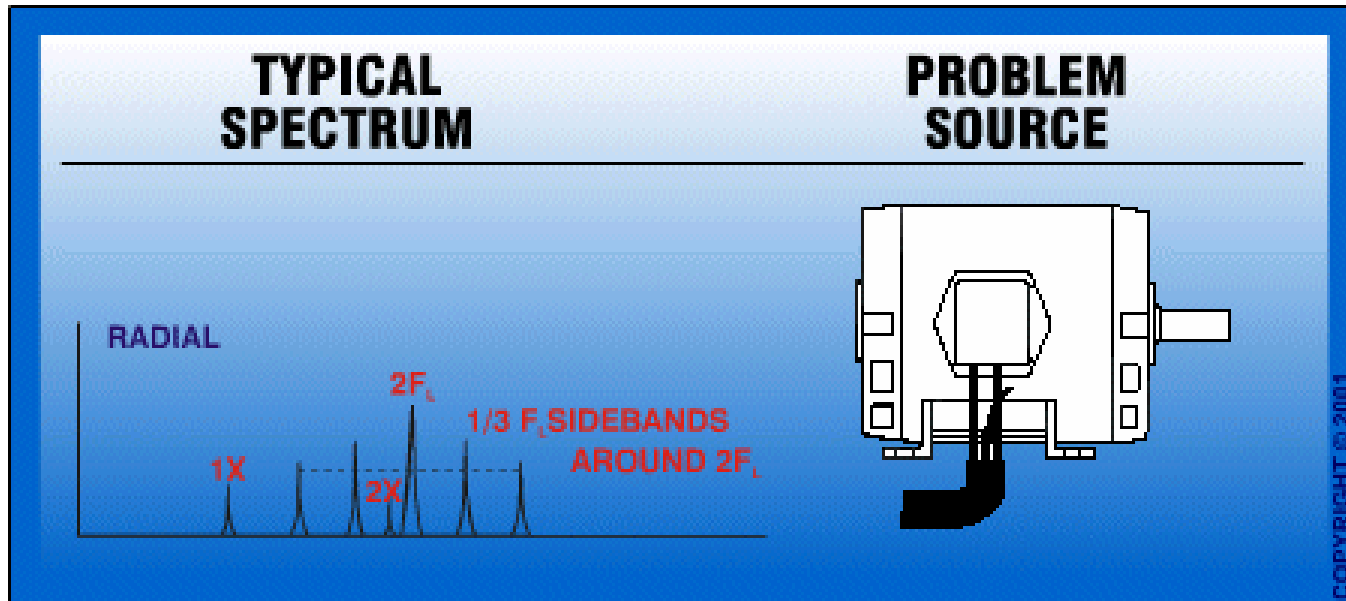
Broken or Cracked rotor bars or shorting rings; bad joints between rotor bars and shorting rings; or shorted rotor laminations will produce high 1X running speed vibration with pole pass frequency sidebands (F_p). In addition, these problems generate F_p sidebands around the second, third, fourth and fifth running speed harmonics.

Source: Technical Associates Inc.
Illustrated Vibration Chart



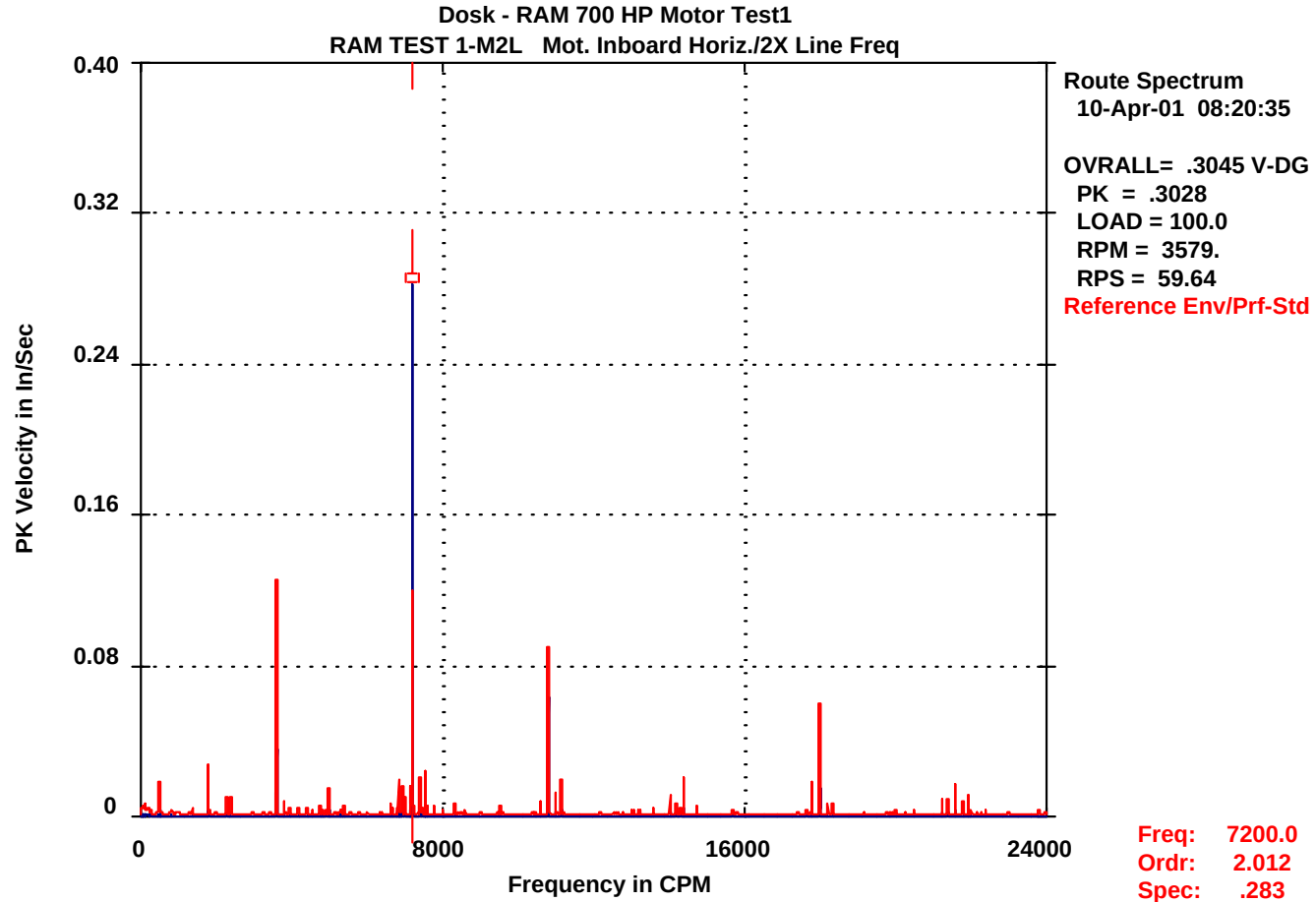
Loose or open rotor bars are indicated by 2X line frequency ($2F_L$) sidebands surrounding Rotor Bar Pass Frequency (RBPF) and/or its harmonics ($RBPF = \text{Number of Bars} \times RPM$). Often will cause high levels at 2X RBPF, with only a small amplitude at 1X RBPF. Electrically induced arcing between loose rotor bars and end rings will often show high levels at 2X RBPF (with $2F_L$ sidebands); but little or no increase in amplitudes at 1X RBPF.

Source: Technical Associates Inc.
Illustrated Vibration Chart

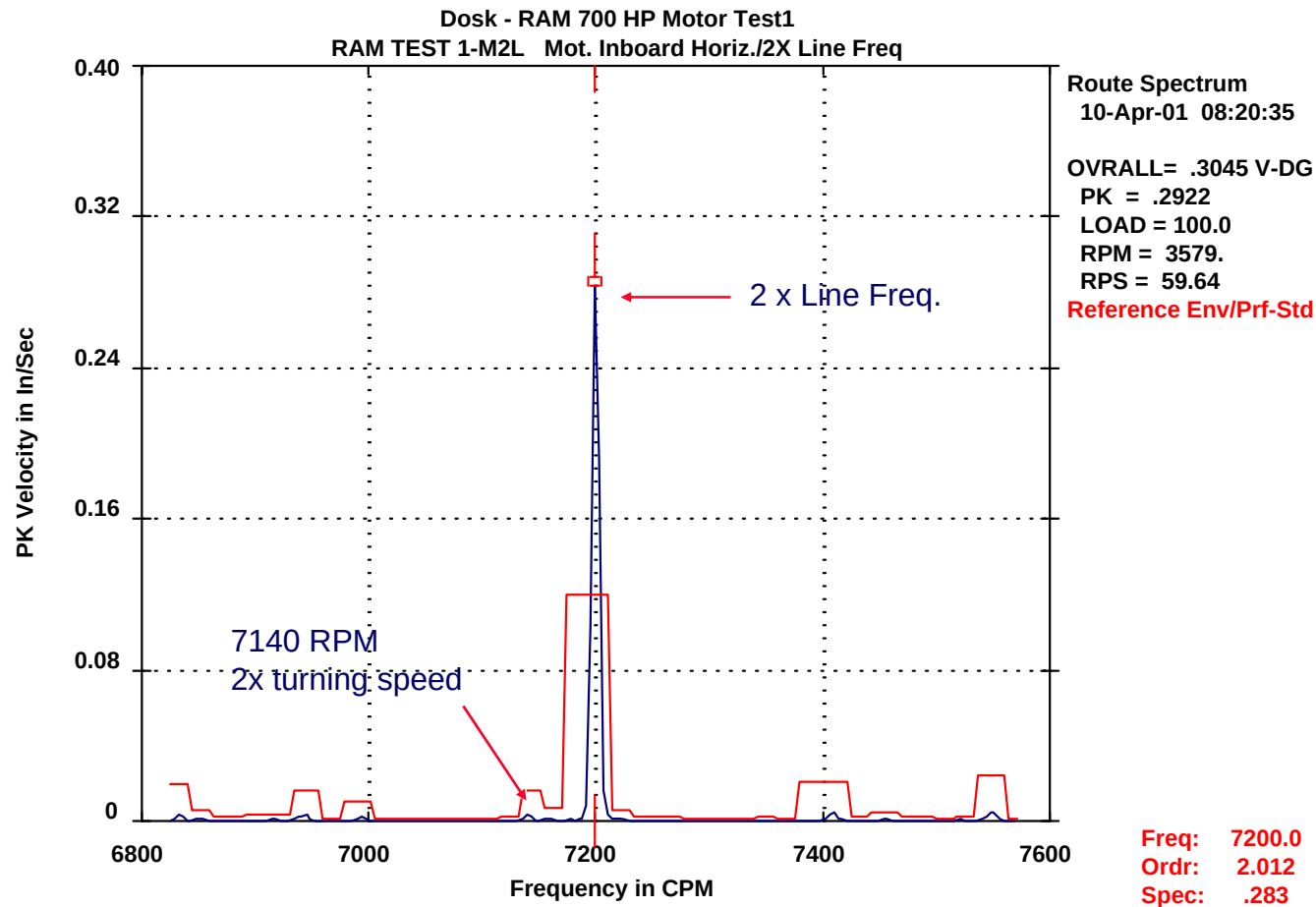


Phasing problems due to loose or broken connectors can cause excessive vibration at 2X Line Frequency ($2F_L$) which will have sidebands around it spaced at 1/3 Line Frequency ($1/3 F_L$). Levels at $2F_L$ can exceed 1.0 in/sec if left uncorrected. This is particularly a problem if the defective connector is only sporadically making contact. Loose or broken connectors must be repaired to prevent catastrophic failure.

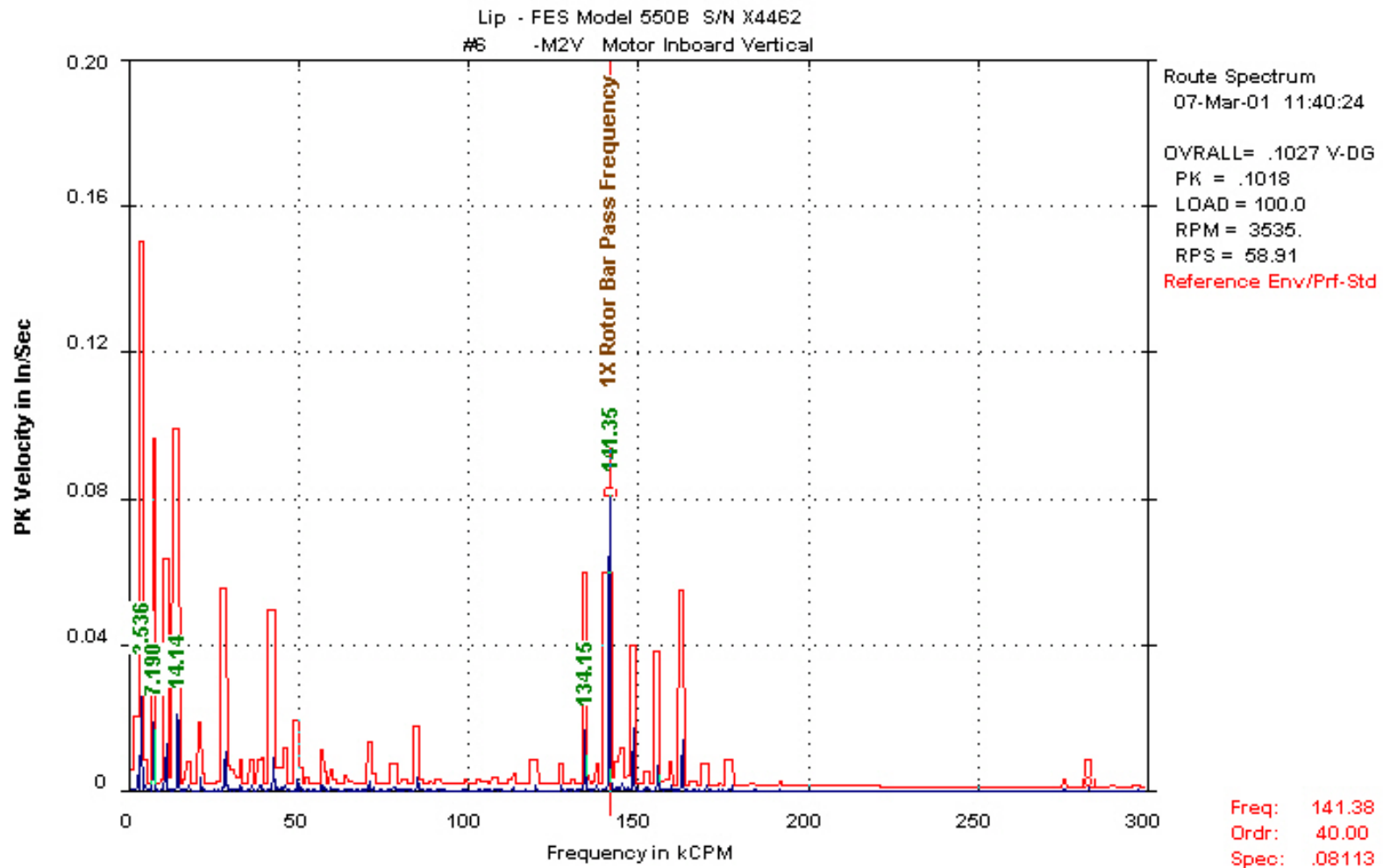
Source: Technical Associates Inc.
Illustrated Vibration Chart



The 2x Line frequency on this motor is .283 in/sec.
this indicates a stator eccentricity problem.
The spectrum was taken at 6400 lines of resolution.



The 2 x Line Frequency must be separated from 2 x turning speed to determine rotor or stator problems. The data collector must be set to a sufficient number of lines of resolution to separate these two frequencies



**Vibration analysis can be used to determine rotor problems in motors.
The rotor bar pass frequency has penetrated the narrow band alarm.**



Refrigeration Division

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Vibration Analysis Services