ACC Vibration Limits and Control

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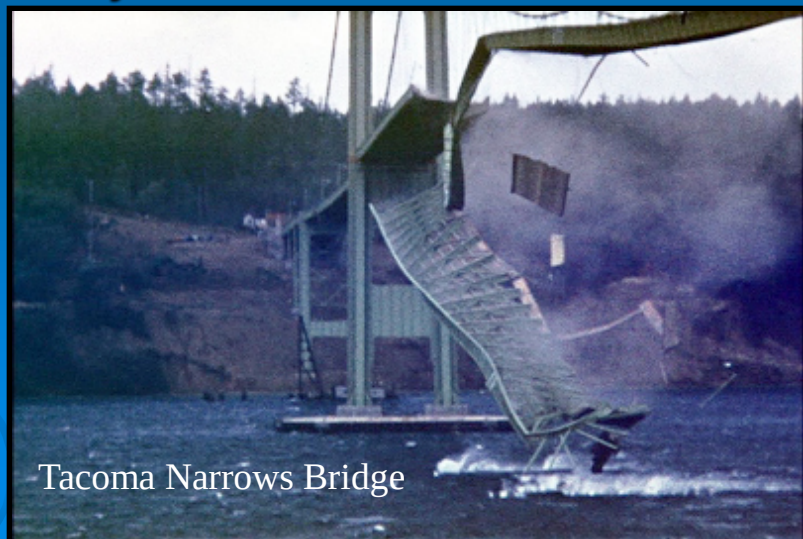
Vibration & ACC's

What Is Vibration?

- Repeating motion of matter or object
- Caused by a force
- May be sustained by a repeating force
- Intensity may increase significantly

Resonant Amplification



Tacoma Narrows Bridge

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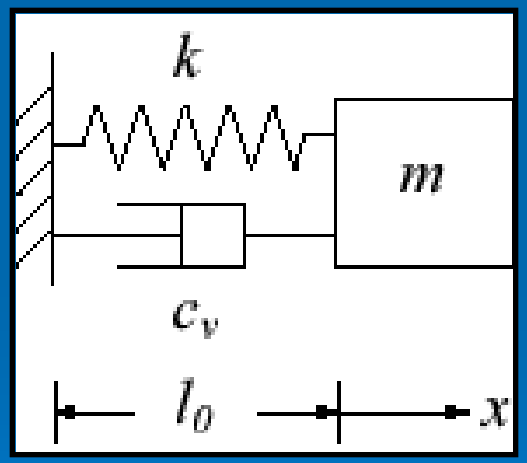
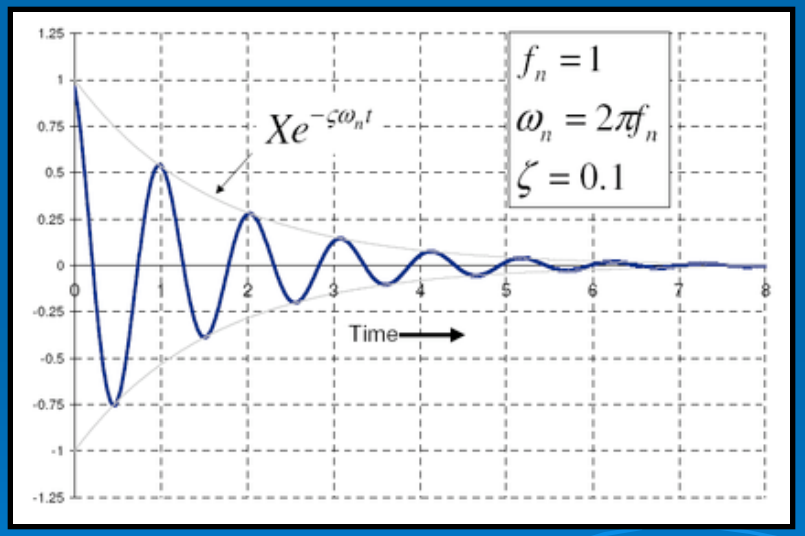
Vibration & ACC's

Types of Mechanical Vibration

- Free Vibration

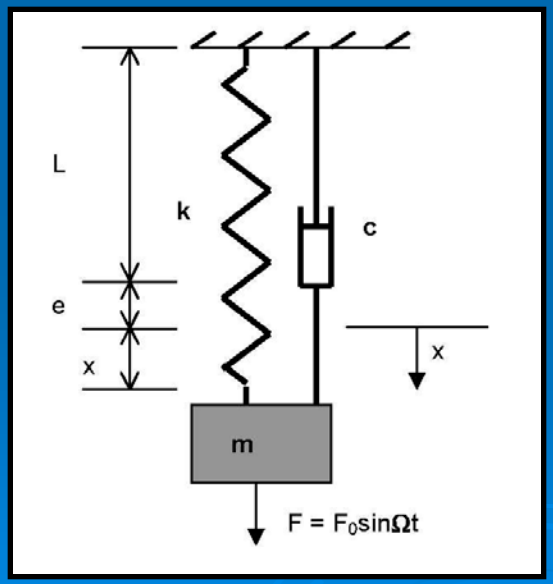


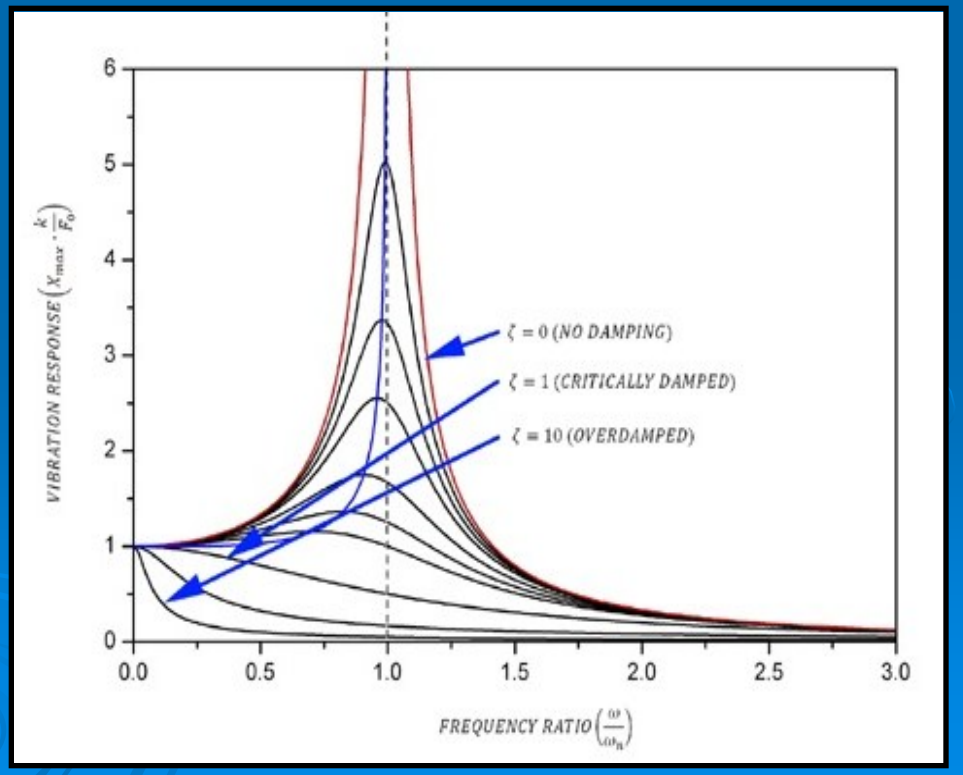


Vibration & ACC's

Types of Mechanical Vibration

- Forced Vibration
- Resonant Vibration





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Vibration & ACC's

Sources of Mechanical Vibrations

- Imbalance of Rotating Components
  - Cooling Fans
  - Gears and Shafts
- Misalignment of Components
  - Motor Coupling
  - Bearing Bores
  - Fan Blades

Vibration & ACC's

Sources of Mechanical Vibrations

- Mechanical Joint Looseness
  - Blade attachment bolts
  - Gear and motor hold down bolts
- Structure Flexibility
  - Loose bolts
  - Design

Vibration & ACC's

Measuring Vibration Levels

- Overall Vibration Level

  Unfiltered or "all pass"

- Spectrum Analysis

  Vibration levels at key frequencies

Vibration & ACC's

Overall Vibration Level

- Measure on key machines

  Side of motor, side of gear box, support structure

- Measurement devices

  Vibrometer – most simple, low cost

  FFT Analyzer – expensive, versatile

  Accelerometer, Velomitor

Vibration & ACC's

Relationship of Measurements

- Velocity is the integral of acceleration
- Displacement is the integral of velocity
- $V_{peak} = 52.3 \times D \times F \times 10^{-6}$ in/sec

  D = Displacement in mils (peak to peak)

  F = Frequency of vibration (cycles/minute)
- $V_{rms} = V_{peak} \times .707$

Vibration & ACC's

Vibration Standards & Guidelines

- *ISO 14694:2003E*
- *"Industrial fans – Specifications for balance quality and vibration levels"*
- *Applies to industrial fans < 300kW (402 HP)*

Table 1 — Fan-application categories

Application	Examples	Limits of driver power kW	Fan-application category, BV
Residential	Ceiling fans, attic fans, window AC	⩽ 0,15	BV-1
		> 0,15	BV-2
HVAC and agricultural	Building ventilation and air conditioning; commercial systems	⩽ 3,7	BV-2
		> 3,7	BV-3
Industrial process and power generation, etc.	Baghouse, scrubber, mine, conveying, boilers, combustion air, pollution control, wind tunnels	⩽ 300	BV-3
		> 300	See ISO 10816-3
Transportation and marine	Locomotive, trucks, automobiles	⩽ 15	BV-3
		> 15	BV-4
Transit/tunnel	Subway emergency ventilation, tunnel fans, garage ventilation, Tunnel Jet Fans	⩽ 75	BV-3
		> 75	BV-4
		none	BV-4
Petrochemical process	Hazardous gases, process fans	⩽ 37	BV-3
		> 37	BV-4
Computer-chip manufacture	Clean rooms	none	BV-5

NOTE 1 This standard is limited to fans below approximately 300 kW. For fans above this power refer to ISO 10816-3. However, a commercially available standard electric motor may be rated at up to 355 kW (following an R20 series as specified in ISO 10816-1). Such fans will be accepted in accordance with this International Standard.

NOTE 2 This Table does not apply to the large diameter (typically 2 800 mm to 12 500 mm diameter) lightweight low-speed axial flow fans used in air-cooled heat exchangers, cooling towers, etc. The balance quality requirements for these fans shall be G 16 and the fan-application category shall be BV-3.

Vibration & ACC's

Vibration Standards & Guidelines

- ACC's are not the same as "Air Cooled Heat Exchangers"
- ACC fan balance limit must be closer than G16.
  - G16 allows 1000 micrometers eccentricity @ 150 rpm
  - G6.3 allows 400 micrometers eccentricity @ 150 rpm
- Suitable BV category for large ACC's is between BV 2 and BV 3

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Table 5 — Seismic vibration limits for tests conducted *in situ*

Condition	Fan-application category	Rigidly mounted mm/s		Flexibly mounted mm/s	
		Peak	r.m.s.	Peak	r.m.s.
Start-up	BV-1	14,0	10	15,2	11,2
	BV-2	7,6	5,6	12,7	9,0
	BV-3	6,4	4,5	8,8	6,3
	BV-4	4,1	2,8	6,4	4,5
	BV-5	2,5	1,8	4,1	2,8
Alarm	BV-1	15,2	10,6	19,1	14,0
	BV-2	12,7	9,0	19,1	14,0
	BV-3	10,2	7,1	16,5	11,8
	BV-4	6,4	4,5	10,2	7,1
	BV-5	5,7	4,0	7,6	5,6
Shutdown	BV-1	Note 1	Note 1	Note 1	Note 1
	BV-2	Note 1	Note 1	Note 1	Note 1
	BV-3	12,7	9,0	17,8	12,5
	BV-4	10,2	7,1	15,2	11,2
	BV-5	7,6	5,6	10,2	7,1

NOTE 1 Shutdown levels for fans in fan-application grades BV-1 and BV-2 should be established based on historical data.

NOTE 2 The r.m.s. values given in this Table are preferred. They are rounded to a R20 series as specified in ISO 10816-1. Peak values are widely used in North America. Being made up of a number of sinusoidal wave forms, these do not necessarily have an exact mathematical relationship with the r.m.s. values. They may also depend to some extent on the instrument used.

Vibration & ACC's

Vibration Standards & Guidelines

- Startup Limit 8.8 mm/s = .35 in/s peak
- Alarm Limit 16.5 mm/s = .65 in/s peak
- Shutdown 17.8 mm/s = .70 in/s peak

Vibration & ACC's

Vibration Standards & Guidelines

- At 1775 cpm (Motor speed)
  - 0.35 in/sec = 3.77 mils peak to peak
  - 0.65 in/sec = 7.00 mils
  - 0.70 in/sec = 7.50 mils
- At 135 cpm (30 ft dia fan speed)
  - 0.35 in/sec = 49.57 mils peak to peak
  - 0.65 in/sec = 92.06 mils
  - 0.70 in/sec = 99.14 mils

Vibration & ACC's

Vibration Standards & Guidelines

- Wind effects on ACC's
  - Increased vibration level at fan speed
  - 50% to 100% increase over nominal levels is common
  - Up to 12 mm/sec rms (17mm/sec peak) velocity during wind
- At 135 cpm (30 ft dia fan speed)
  - 17 mm/sec peak = 93 mils peak to peak displacement
  - Fan movement of less than 1/10"
  - Tip clearance is typically 2"

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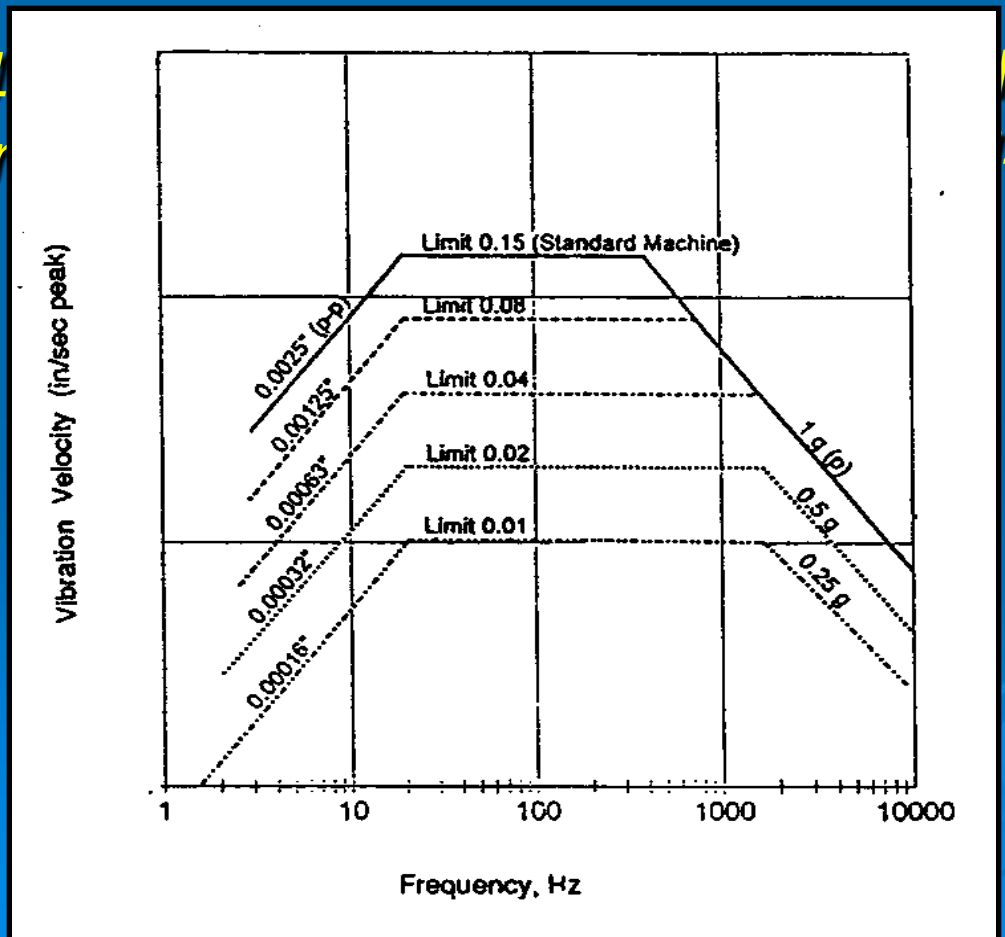
Vibration & ACC's

Vibration Standards & Guidelines

Below 1 *lowable*
vibratior *-band levels*

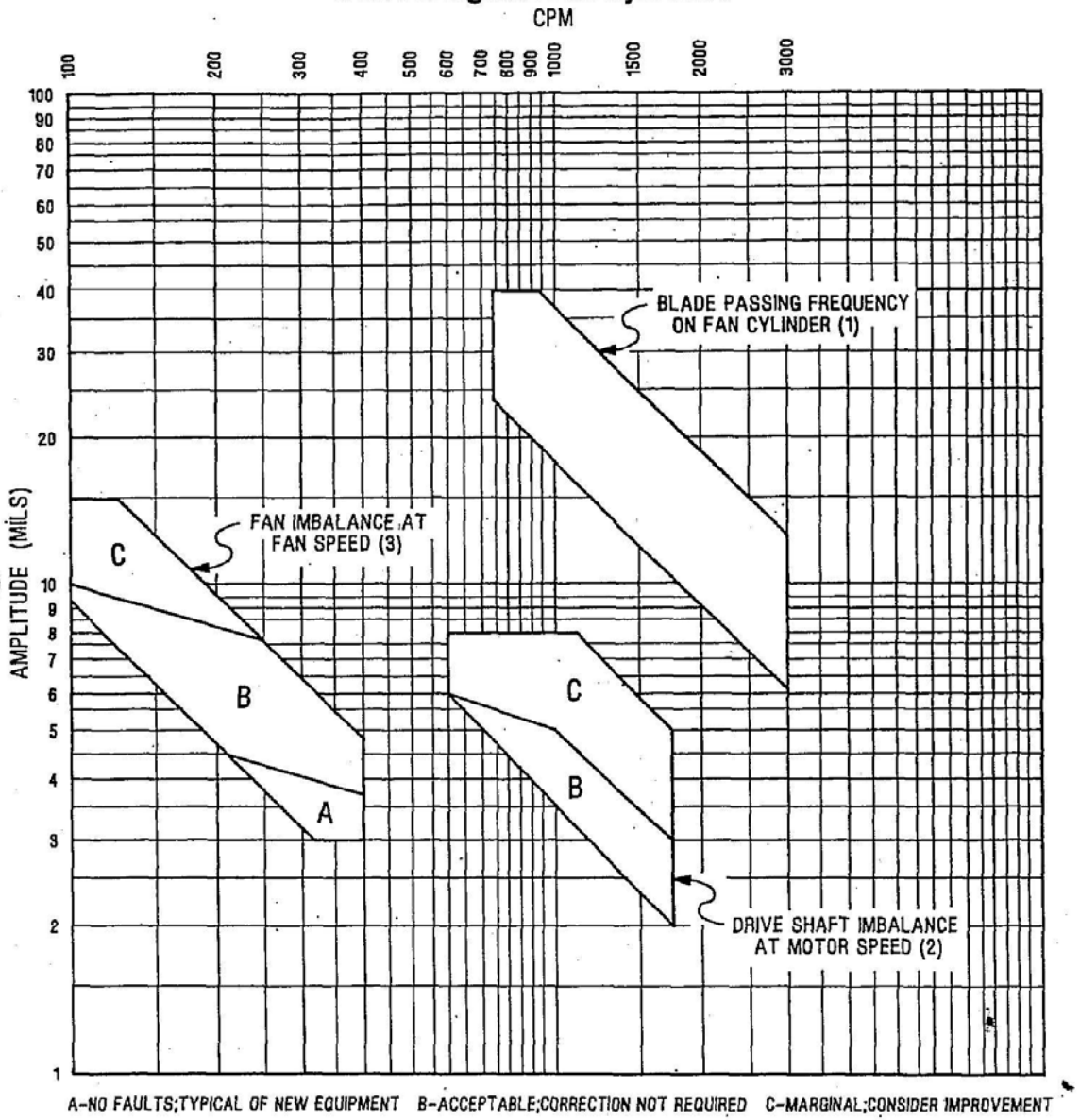


Vibration & ACC's

Vibration Standards & Guidelines

- ISO 14694-2003E
  - Vibration limits for insitu fans on industrial machines only apply to unfiltered (broadband) measurements
  - Vibration limits established for discrete operational frequencies must be determined by experience
- Cooling Technology Institute (CTI)
  - Chapter 10 of the Cooling Tower Manual
  - Typical vibration levels for field erected cooling towers

Typical Operating Vibration for Wood Framed Field Erected Cooling Towers with Fiberglass Fan Cylinders



A-NO FAULTS;TYPICAL OF NEW EQUIPMENT B-ACCEPTABLE;CORRECTION NOT REQUIRED C-MARGINAL;CONSIDER IMPROVEMENT

(1) HORIZONTAL AT FAN ROTATIONAL PLANE
(2) HORIZONTAL AND AXIAL AT MOTOR INBOARD BEARING.
(3) HORIZONTAL AT LOW SPEED SHAFT BEARING

$V_{peak}=52.3xDxFx10^{-6}$
V=VELOCITY IN INCHES PER SECOND
D=DISPLACEMENT IN MILS
F=CYCLES PER MINUTE

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Support Structure Flexibility

- Flexible Structure
  - The first fundamental natural frequency of the structure is near or below any operating frequency of the machine.
- Rigid Structure
  - The fundamental f_n of the structure is well above key machine operating frequencies.
- Are ACC mechanical supports flexible or rigid?

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Vibration & ACC's

Support Structure Flexibility

8.2 Fan support system

Fan installations are classified for vibration severity according to their support flexibility. To be classified as rigidly supported, the fan and support system should have a fundamental (lowest) natural frequency above the running speed. To be classified as flexibly supported, the fan and support system should have a fundamental frequency below the running speed. Generally, a large well-designed concrete foundation will result in a rigid support, whereas a fan mounted on vibration isolators will be classified as flexibly supported. Fans mounted on a steel framework can be in either category, depending on the structural design. In case of doubt, analysis or tests may be required to determine the fundamental natural frequency. Note that, in some cases, a fan could be classified as rigidly supported in one measurement direction and flexibly supported in another.

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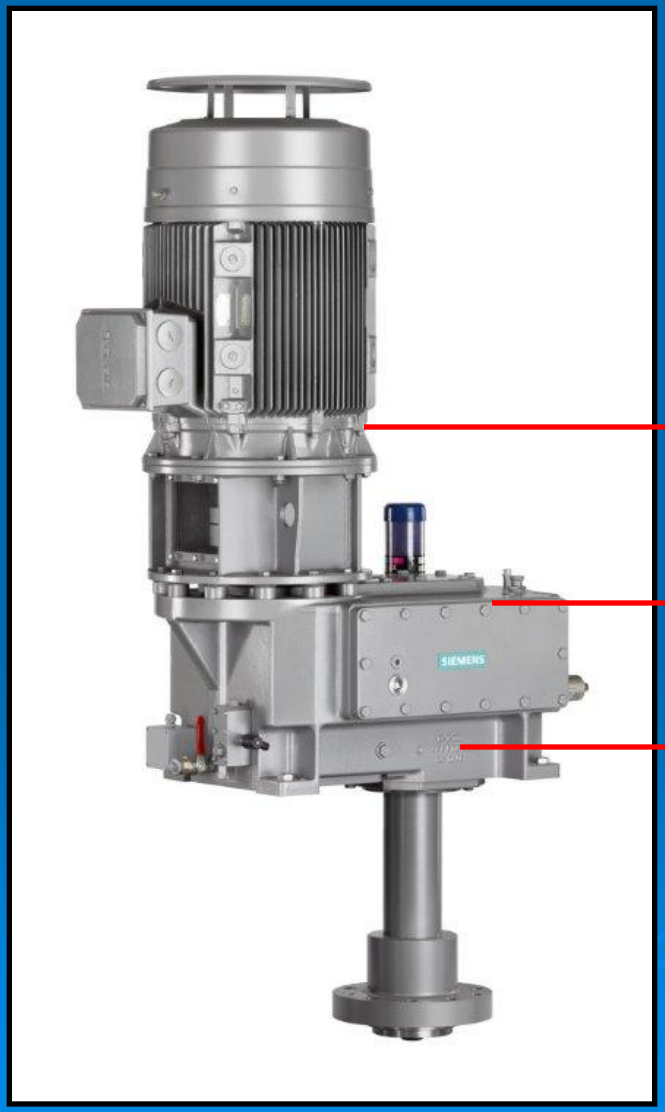
Vibration & ACC's

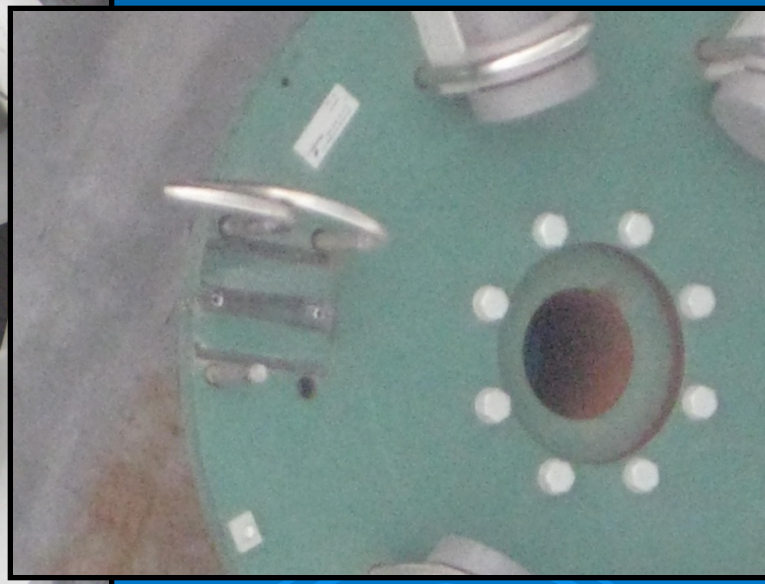


- *Where to take measurements?*

  At machine bearings - perpendicular to weak structure axis

Vibration & ACC's

Results of Excessive Vibration



Photos courtesy of Howden North America

Vibration & ACC's

Results of Excessive Vibration

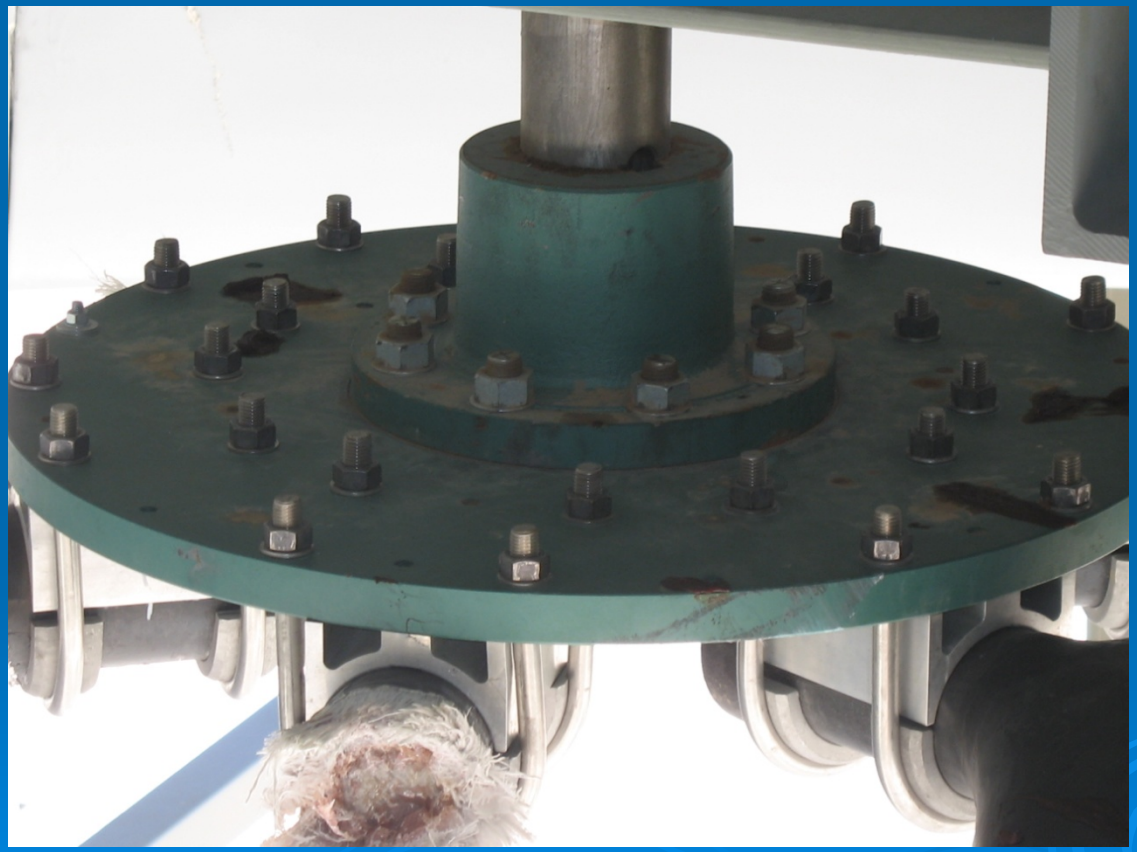


Photo courtesy of Howden North America

Vibration & ACC's

Results of Excessive Vibration

- Fan Imbalance
  - Loosening of attachment bolts
  - Rocking of support structure
  - Fan blade contact with stack
- Aerodynamic Fan Pulsation
  - Fan blade bolt loosening from variable stress
  - Fan bell bolts loosening from blade pass pulsation

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Vibration & ACC's

Results of Excessive Vibration

- Motor speed, coupling alignment
  - Attachment bolt loosening
  - Failure of coupling flex elements, resulting in…
  - Coupling destruction, motor and gear shaft damage
- Gear mesh vibration
  - Bad gear alignment
  - Gear teeth spalling or breakage
  - Bearing spalling and failure

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Vibration & ACC's

ACC Design for Vibration Control

- Check natural frequency of motor bridge
  - Insure operating speeds do not coincide with structural natural frequencies
- Limit fan tip speed to 55 m/sec (10,800 ft/min) for ACC's
- Limit fan blade loading to 20 kW (27 HP) per blade
- Avoid even number of fan blades (double excitation)

Vibration & ACC's

Vibration Measurement Instruments

- Vibrometers
  - Measure overall vibration levels
  - Hand held, low cost devices
  - Must filter high and low freq for accurate broadband measurement

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Vibration Measurement Instruments

- FFT Vibration Analyzers
  - High cost - $10,000 to $30,000
  - Magnetic base accelerometer
  - Display all key frequencies in spectrum
  - Required for fault analysis

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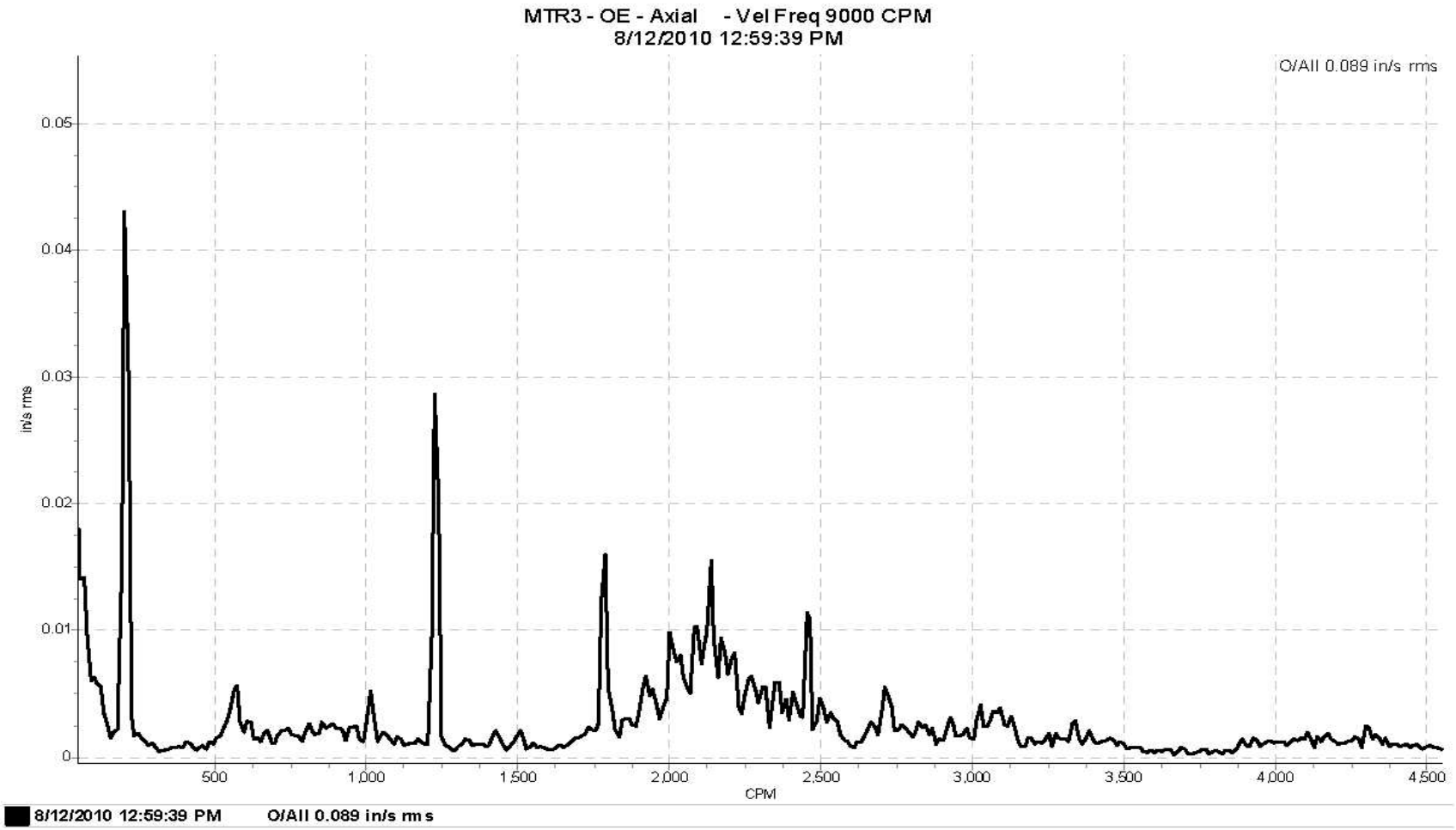
Vibration Analysis Display



Vibration & ACC's

Frequency Bands in ACCs

Fan Speed	100 – 300 cpm
Blade Passing on Shroud	400 – 3,000 cpm
Motor Speed	1,450 – 1,775 cpm
Gear Output Bearing	1,500 – 4,500 cpm
Gear Mesh	15,000 – 75,000 cpm
Motor Bearings	30,000 -120,000 cpm

Vibration & ACC's

Vibration Cutout Switches

- Prevention of catastrophic equipment failure
  - Low cost devices measure acceleration
  - Switch trips when vibration acceleration exceeds switch setting
- Solid state devices
  - Measure velocity or displacement
  - Use accelerometer in switch or on machine
  - Signal is integrated for velocity output
  - May include remote monitoring and reset

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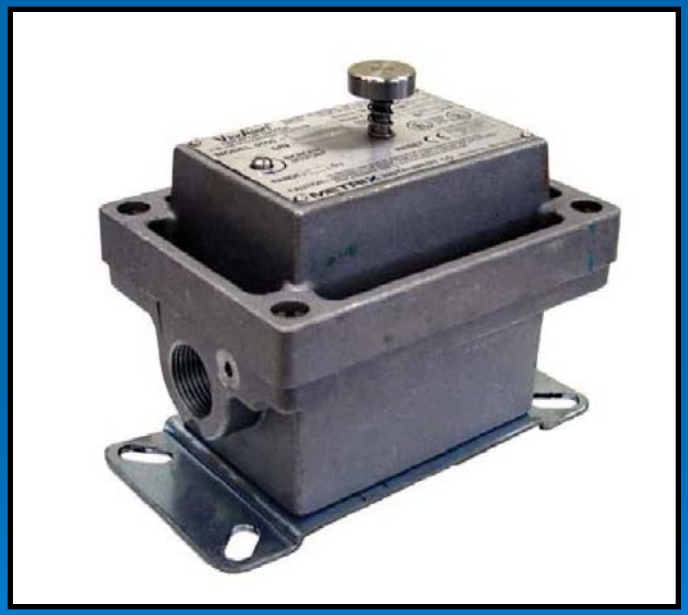
Vibration Cutout Switches

- Example of basic acceleration cut out switch



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Vibration Cutout Switches

- Example of solid state cutout switch

Vibration & ACC's

Vibration Cutout Switches

- Where to locate
  - Mechanical support adjacent to machine element
  - Mounting plate perpendicular to weak axis of support
- Remote accelerometer mounting
  - Solid state switch only
  - Mount accelerometer on machine
  - Mount near bearing and perpendicular to weak support axis

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Vibration Monitoring & Predictive Maintenance

- Excellent method to determine machine health
- Determine high value machines to monitor
- Establish baseline vibration levels at key frequencies
- Record vibration levels at each measurement point
- Significant vibration increase alerts need for service or repair
- Will reduce repair costs dramatically over time

Vibration & ACC's

Thank You!

David M. Suptic
EvapTech, Inc.
8331 Nieman Road
Lenexa, KS 66214
dsuptic@evaptech.com
913.428.1035