

BALANCE and VIBRATION

Rad Ganesh Ph.D, P.E, Twin City Fan Companies

Learning Objectives

- Balance and vibration characteristics are used as indicators of quality
- Understanding the terminology and specifications is important to users and those selecting fans

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Learning Objectives…cont'd

- Balance
  - This is a property of the fan and stays the same at any location
  - Imbalance is present even if the fan is not running
- Vibration
  - Strongly influenced by the fans environment and operating speed
- Do not mix these two concepts!

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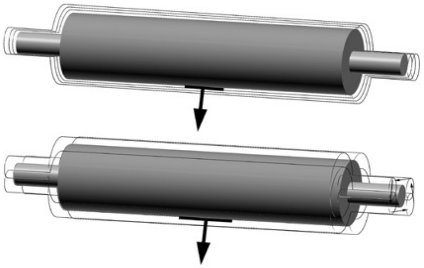
Balance Terminology

- Balancing
  - The process of adding or removing weight on a rotor in order to move the center of gravity towards the axis of rotation
  - The purpose of balancing is to reduce the unbalance forces

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Static Unbalance

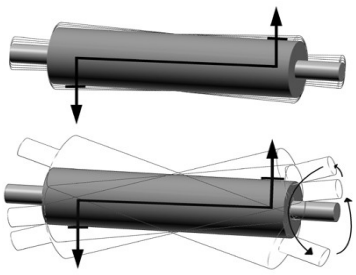
- Static unbalance can be corrected by adding a single weight
- Heavy spot will "bottom out" when rotor is placed in bearings



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Dynamic Unbalance

- Dynamic (couple) unbalance requires correction in two or more planes
- Heavy spot will not "bottom out" when rotor is placed in bearings



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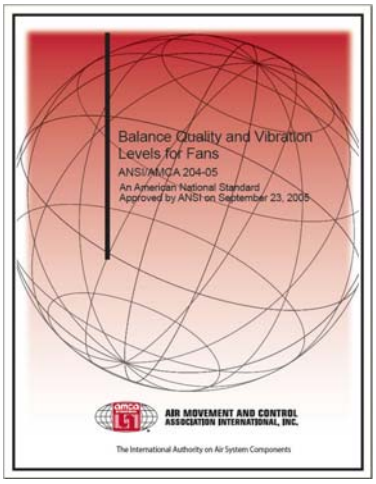
Balance Tolerances

- Defines the maximum amount of residual unbalance remaining after balancing
- Originally defined in international standard ISO 1940/1
- Adapted to fans in AMCA 204-96
  - The latest version of this document is AMCA 204-05 (R2012)

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Recommended Tolerances Guide

- Use AMCA 204 to specify balance tolerance
  - All relevant terms are defined
  - Tolerances are realistic
  - Allows for different categories of fans
  - Provide for long life and reliable operation without excessive cost



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AMCA 204 Fan Categories

APPLICATION	EXAMPLES	DRIVER POWER LIMIT kW (HP)	FAN APPLIC. CATEGORY
RESIDENTIAL	Ceiling Fans, attic fans, window AC	<=0.15 (0.2) >0.15 (0.20)	BV-1 BV-2
HVAC & AGRICULTURAL	Building vent. and air cond.; commercial systems	<=3.7 (5.0) >03.7 (5.0)	BV-2 BV-3
INDUSTRIAL PROCESS & POWER GENERATION, ETC.	Baghouse, scrupper, mine, conveying, boilers, comb.air. pollution control, wind tunnels	<=298 (400) >298 (400)	BV-3 BV-4
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TRANSIT/TUNNEL	Subway emergency ventilation., tunnel fans, garage ventilation Tunnel jet fans	<=75 (100) >75 (100) ANY	BV-3 BV-4 BV-5
PETROCHEMICAL PROCESS	Hazardous gases, process fans	<=37 (50) >37 (50)	BV-3 BV-4
COMPUTER CHIP MFG.	Clean Room	ANY	BV-5

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AMCA 204 Balance Tolerance

- Fans categorized by application category
  - BV-3 covers all but the smallest and largest fans that TCF makes
  - BV-4 used for larger industrial fans (over 400 HP) and certain special applications
  - BV-5 applies to computer chip manufacturing

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AMCA 204 Balance Tolerance

- BV-3 tolerance is G6.3
- BV-4 tolerance is G2.5
- BV-5 tolerance is G1.0

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What is "G6.3"

- "G" values refer to the maximum speed that the shaft center would rotate about the center of gravity if suspended in free space
- G = e x ω (mm/second)
  - e = distance between center of gravity and center of rotation (mm)
  - ω = angular velocity at max design speed (rad/sec)
- "G" has units of velocity, but is not appropriate for specifying vibration tolerances

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Converting "G" Level to Unbalance

- Multiply "G" value by the rotor mass and divide by the angular speed to get the allowable unbalance.
- Divide by two for dynamic unbalance
- Residual weight can be extremely small for small rotors at high speed
- Balancing machines have a lower limit that will not allow ultra low "G" values

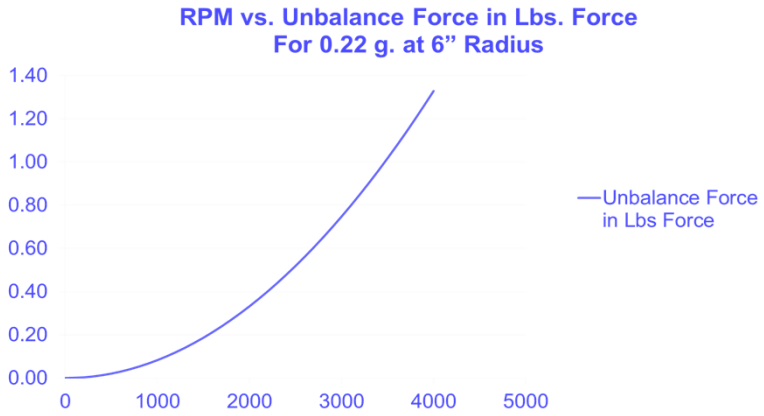
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Example Unbalance Calculation

- G = 6.3 mm/sec = .248 in/sec
- RPM = 4000 (ω = 419 rad/sec)
- Weight = 10 lb (M = 4536 grams)
- Radius of rotor = 6 in.
- U = residual unbalance
  = .248 / 419 x 4536 = 2.68 gram-inch
- Allowable max. weight at rotor OD
  =2.68 / 2 / 6 = .22 gram (per plane)
  - A steel cube 1/8" in per side = .25 gram
  - A piece of paper about 2 1/8" square has the same weight

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Centrifugal Force From Unbalance



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Balancing Machines

- Sized to accommodate weight of rotor
- Fan wheels are usually balanced using a precision arbor to match bore of impeller



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Trim Balancing

- After fan assembly, fans are test run and checked for vibration
- If vibration is high, trim balancing is performed
  - This corrects for fit-up of assembled parts
  - Most fans use welded on trim weights
- Two plane balancing is normally not required for trim balancing

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Vibration

- What is vibration?
  - Forces that vary in amplitude or direction over time cause repetitive motions called vibration
- When is vibration bad?
  - All fans must generate some vibration.
  - Only vibration that exceeds certain amplitudes is bad.



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Types of Vibration

- Bending vibration refers to fan parts such as blades bending in a cyclic manner
  - This is covered in the Level 2 training session
- Torsional vibration refers to a periodic twisting of the fan shaft due to a multiple components with high inertia in the drive train
  - This is covered in the Level 2 training session
- Linear vibration refers to motion of an assembly in a radial or axial direction
  - This is our topic for this session

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Vibration Terminology

- Amplitude
  - The measure of cyclic energy or movement in a vibrating object
  - Three common ways of expressing:
    - Displacement in mils peak to peak
    - Velocity in inches/second peak
    - Acceleration in g's rms
  - Amplitude measurements can be converted between the different units if the frequency is known

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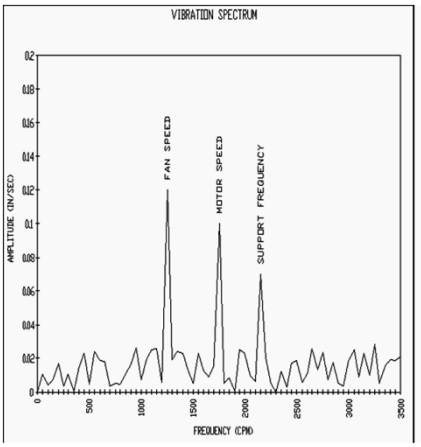
Vibration Terminology

- Frequency
  - The number of times that a vibrating object repeats its motion per unit of time
  - The fan rotational frequency in Hertz equals the RPM / 60
  - The rotational frequency is often called 1X
  - Other frequencies are often identified as multiples of 1X, such as 2X, 3X, 3.6X, 19.2X, etc.

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Vibration Terminology

- Vibration Spectrum:
- (a display of frequency vs. amplitude)
- The horizontal axis is linear, not logarithmic or in octave bands such as used with sound



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Vibration Terminology

- Rigidly Mounted
  - Generally applies to a fan mounted to a concrete slab
  - A very rigid steel structure may qualify
- Flexibly Mounted
  - Fan is mounted on springs or a spring isolation base
  - An inertia base is filled with concrete then the whole assembly is mounted on springs
    - If isolation is required, this performs best for vibration

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Vibration Measurement

- Vibration can be measured at any location
- Normally, only the vibration on the fan or motor bearings are of concern
- Normally, horizontal, vertical, and axial readings are taken on each bearing
  - This is also called a tri-axial set of readings

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Overall vs. Filtered Amplitudes

- Overall (filter-out) amplitude is a measure of the vibration energy over a wide frequency range
- Filtered (filter-in) amplitude usually refers to the vibration at 1X (the operating speed)
- Overall amplitude includes the effects of all sources —even those external to the fan

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Causes of Vibration

- Unbalance (the most common cause)
  - Fan impeller, sheaves, coupling, or motor
- V-belt drive induced vibration
  - Sheaves not concentric
  - Belts which are not uniform in length, worn or that have hard spots
  - Misaligned sheaves
  - Adjustable pitch sheaves often have unequal groove spacing

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Causes of Vibration

- Shaft induced
  - Shafts not straight
  - Keyways create local weak spots (center hung rotors)
  - Out-of-round shaft
  - Undersize shafting
- Bearing induced
  - Bearing flaws and non-symmetries
  - Bearing contamination
  - Distorted bearings (pinched)
  - Bearings which do not freely self-align
  - Distortions caused by set-screws
  - Grease or oil churning

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Causes of Vibration

- Fan construction induced
  - Imperfect fan wheel components (run-out)
  - Rubbing
  - Misalignment (bearing and coupling)
  - Resonance
- Aerodynamic
  - Turbulent and eccentric flow through the fan
  - Fan in stall

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Causes of Vibration

- Installation and environmental
  - Inadequate support (resonance)
  - Loose or missing anchor bolts
  - Loose access doors, rattling panels, etc.
  - Solids which impact the fan wheel
  - Fans with stacks vibrate due to vortex shedding
- Motor eccentricities (electrical and mechanical)

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Causes of Vibration Increasing with Time

- Abrasive wear or corrosion
- Build-up of water in airfoil blades
- Material or dirt build-up
- Deformed fan components due to impact
- Damage due to over temperature
- Bearing wear or deterioration

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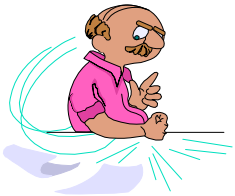
Causes of Vibration Increasing with Time

- V-belt drive wear
- Fatigue failure due to abnormal loads
- Loosening of hardware
- Change in RPM
- Lost balance weights

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Consequences of Excessive Vibration

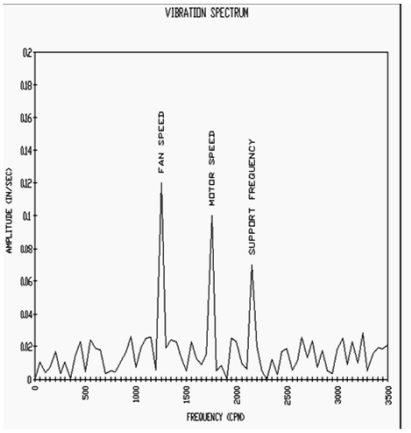
- Shortened bearing life
- Shortened lubrication life
- Structural damage to fan
- Increased noise
- Damage to adjacent processes
- Fasteners come loose



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Reducing Fan Vibration

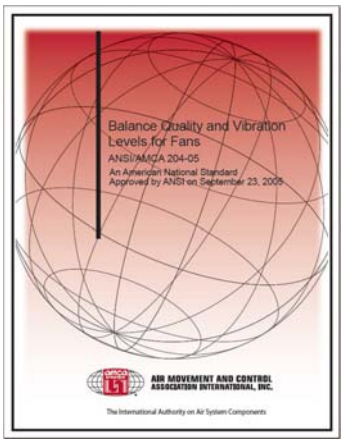
- Become a vibration detective
  - Check out all of the potential causes listed above
  - Use vibration spectrums to help identify the source
- Repair or replace components as required



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Recommended Vibration Tolerances

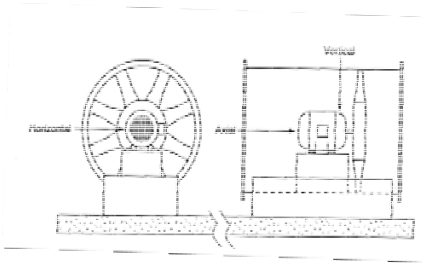
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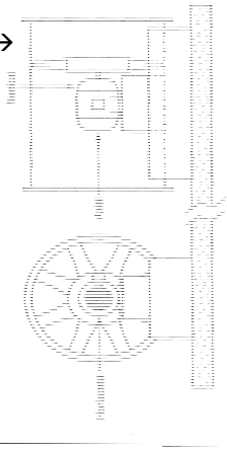
AMCA 204-Vibration Measurement

- The standard says where to take vibration readings



Horizontal Shaft Fan

Vertical Shaft Fan→



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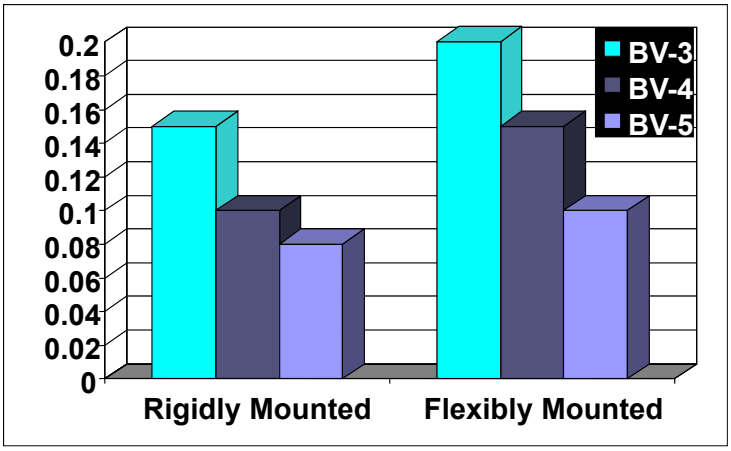
AMCA 204 Fan Categories

- The same category as for balance tolerance

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AMCA 204 Vibration Limits – Factory Test



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AMCA 204 Tests Conducted

On-Site

Condition	Application	Rigidly Mounted	Flexibly Mounted
Start-up	BV-3	0.25	0.35
	BV-4	0.16	0.25
	BV-5	0.10	0.16
Alarm	BV-3	0.40	0.65
	BV-4	0.25	0.40
	BV-5	0.20	0.30
Shut-down	BV-3	0.50	0.70
	BV-4	0.40	0.60
	BV-5	0.30	0.40

All values are inches/second peak

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Fan Foundations

- Design for static and dynamic loads
- Good foundations help keep the vibration levels low

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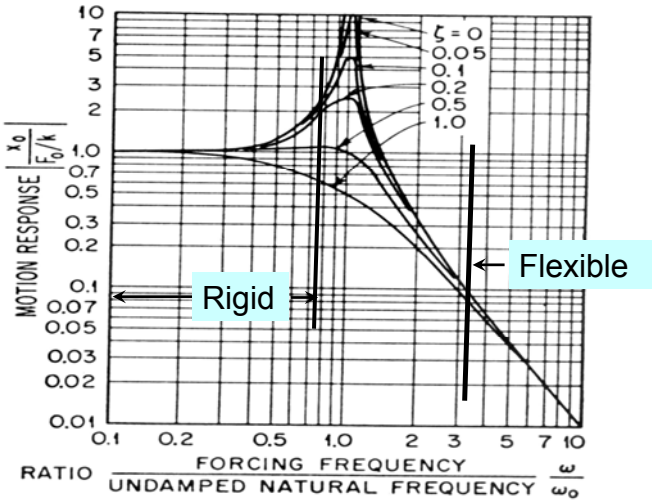
Rigid vs. Flexible Mounting

- Rigid mounting operates below the first fundamental frequency of the system
- Flexible mounting operates above the first fundamental frequency of the system

Don't Operate at the Fundamental Frequency

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Rigid vs. Flexible Mounting



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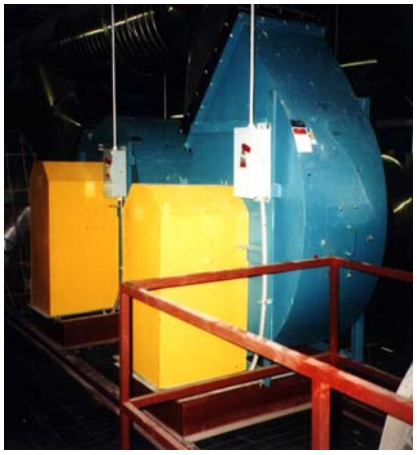
Rigid Foundation



- Employs massive concrete base
- Grout between bottom of fan and concrete

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Flexible Mounting with Steel Base



- Often uses structural C-Channel or I-Beam
- Shim between bottom of fan and steel base
- Isolators are shipped not mounted

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Flexible – Inertia Base



- Inertia base: similar to structural steel base, except the base is filled with concrete
- Isolators are shipped not mounted

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Flexible – Inertia Base – In Factory



- Fan and Motor can be shipped mounted when specified
- Concrete filled in field
- Isolators are shipped not mounted

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Questionable Rigid Foundation Design



- Fans mounted to long span beams
- Minimal diagonal support
- Low mass under fan
- Dynamic analysis of this structure is required to ensure problem free operation

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"Small" Fan Foundations

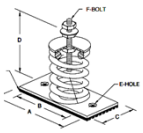
- Many small fans are mounted directly on isolators or have isolation built-in
- Bearing vibration may be quite high
- Low total vibration energy makes failure rates are low
- Lower installation costs make this construction common

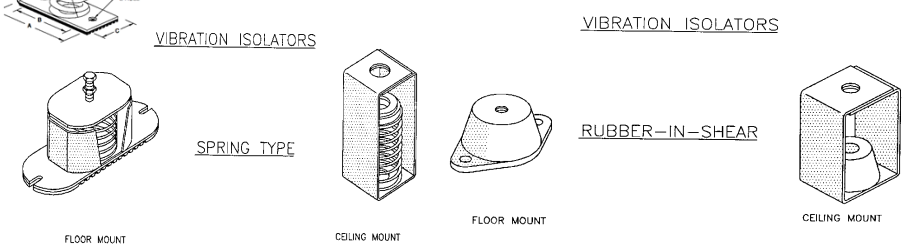
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Vibration Isolators

- Used to prevent fan vibrations from being transmitted to the support structure
  - Rubber in shear isolators are used for small fans with speeds of 1,000 rpm or higher

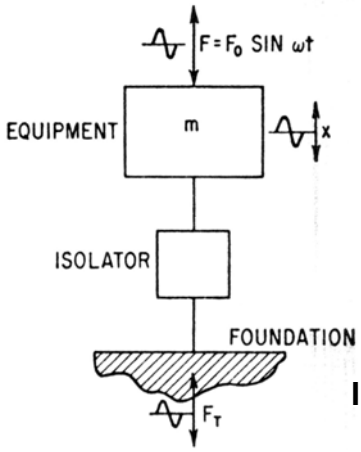
  For good isolation, use spring isolators are for large fans, with lower operating speeds.





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Model Used for Flexible Foundation



Single Degree of Freedom System

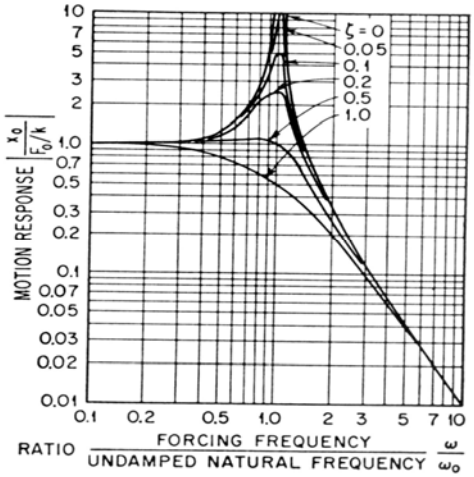
Fan, Motor, and Base

Springs or Rubber Pads

Infinitely Rigid Structure

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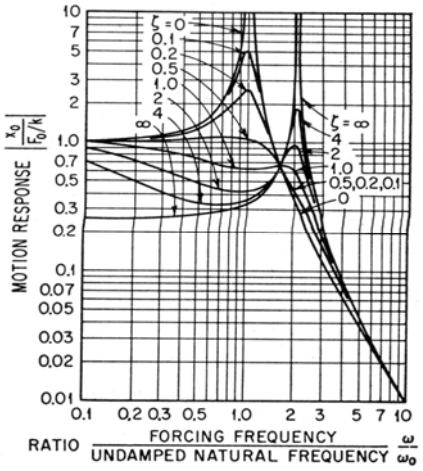
Ideal System Response



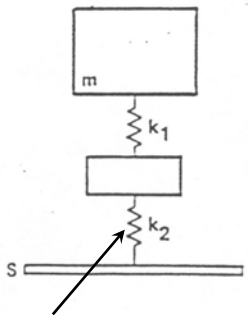
Single Degree of Freedom System

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Model with Flexible Foundation



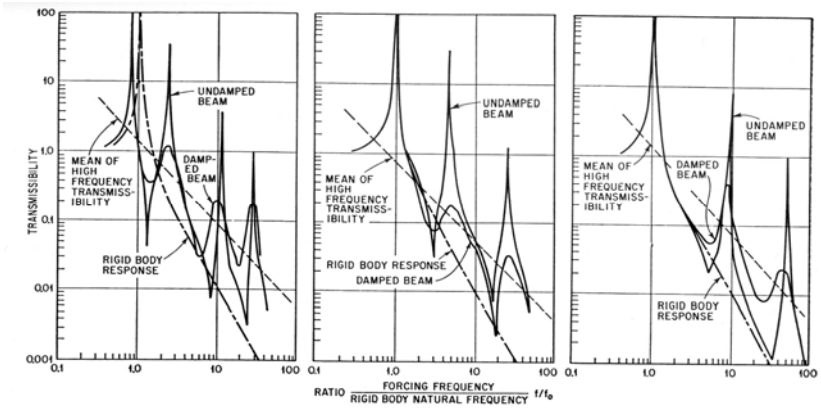
Two Degree of Freedom System



"Springy" support under fan springs

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Multi – Degree of Freedom System



Real Systems Have Many Frequencies Where Vibration Amplification Can Occur

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Characteristics of Flexibly Mounted Fans

- High reliability requires very sophisticated analysis
- Most operate with higher transmitted forces than calculated
- Almost all will "work" in spite of the potential for problems
- Bearing vibration will be higher (most specifications allow higher tolerances)

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Roof Mounted Fans



- Roof mounted fans are normally rigid mounted
  - Fans with stacks must be rigid mounted
- Low stiffness in roofs can cause vibration problems

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Preferred Foundation Design

- Rigid mounting is the most reliable
- Inertia type flexible mounting rarely has problems
- Non-inertia type steel "spring" bases may result in problems
- Use springs directly mounted to fans (or internal isolation) only on low power, non-critical applications

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Other Vibration Tolerances

- Come from many different sources in many different forms using varying terminology
  - Difficult to interpret
  - May be difficult or impossible to comply due to ultra low amplitude requirements
  - Can add significant cost to the fan
- Fan manufacturers recommend using AMCA 204

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Lower than Standard Vibration Tolerances

- Do not specify ultra-low vibration limits unless absolutely necessary
- Adds cost with minimal extension of fan life

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Achieving Lower Vibration Levels

- Involves better precision of many components
  - Better balance of all rotating components
    - Fan wheel (balance with fan shaft), sheaves, couplings, and motor
  - Straighter shafts with precision diameter tolerance and roundness
  - Premium bearings with special construction
  - Bearing mounting surfaces machined flat
  - Premium quality v-belt drives with precise installation
  - Less hop and wobble in fan wheel
- All special modifications add cost

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Achieving Lower Vibration Levels

- Involves other special design considerations
  - Heavier and more rigid components: Use Class III instead of Class II
  - Aluminum fan wheel (reduced rotor weight)
  - Use inertia base for flexibly mounted fan
  - No variable pitched v-belt drives
  - Select lower speed fans
  - On Arrangement 3 — Avoid operation at ½ first critical speed
- Many of these special design considerations also may add cost

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Dealing with Ultra-Low Specifications

- Lower than standard filtered (1X) vibration can often be achieved with minimal difficulty
- Overall levels or "banded" frequency ranges may be very difficult to achieve
- We normally only commit to vibration levels measured in our factory
  - On-site conditions may have major effects
  - We may require start-up service to be part of the contract to commit

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Pricing for Special Vibration Compliance

- Costs vary widely with fan type and specification requirements
- Standard pricing for various options is not available
- Consult factory

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Thank you

Questions?

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