PRODUCT APPLICATION

A technical bulletin for engineers, contractors and students in the air movement and control industry

Balance, Vibration, and Vibration Analysis of Fans and Blowers

Many factors can have a substantial effect on the vibration level of air movement equipment (fans) such as wheel balance, rotational speed, drive components, motor operation, and wiring. Providing equipment that operates well within acceptable vibration levels requires consistent quality in production and attention to detail. Only quality-driven companies spend the extra time and money required to make this kind of commitment. In this article, we will discuss wheel balancing, define the parameters and process of conducting vibration tests, and review some typical vibration analysis techniques. First, let's look at wheel balancing.

Balancing

Many fan manufacturers produce a full line of products ranging from small ceiling fans to large industrial centrifugal fans. There are many application standards for different sizes and types of fans.

Fan Application Categories			
Application	**Examples**	**Driver Power kW (HP) Limits**	**Fan Application Category, BV**
Residential	Ceiling fans, attic fans, window AC	<= .15 (0.2) > .15 (0.2)	BV-1 BV-2
HVAC & Agricultural	Building ventilation and air conditioning; commercial systems	<= 3.7 (5.0) > 3.7 (5.0)	BV-2 BV-3
Industrial Process and Power Generation, etc.	Baghouse, scrubber, mine, conveying, boilers, combustion air, pollution control, wind tunnels	<= 298 (400) > 298 (400)	BV-3 BV-4
Transportation and Marine	Locomotives, trucks, automobiles	<= 15 (20) > 15 (20)	BV-3 BV-4
Transit/Tunnel	Subway emergency ventilation, tunnel fans, garage ventilation, tunnel jet fans	<= 75 (100) > 75 (100) ANY	BV-3 BV-4 BV-4
Petrochemical Process	Hazardous gases, process fans	<= 37 (50) > 37 (50)	BV-3 BV-4
Computer Chip Mfg	Clean room	ANY	BV-5

Based on its particular operation and performance, every fan belongs to a Fan Application Category. *(See Fan Application Categories chart.)*

Fan Application Category	Balance Quality Grade for Rigid Rotors/Impeller
BV-1	G 16
BV-2	G 16
BV-3	G 6.3
BV-4	G 2.5
BV-5	G 1.0

Responsible fan manufacturers balance the fan impeller assemblies to allowable residual unbalance prior to assembly of the unit. These limits are based on ANSI S2.19 "Mechanical Vibration - Balance Quality Requirements Of Rigid Rotors."

This standard establishes allowable residual unbalance based on the balance quality grade, impeller weight, and impeller rotational speed. *Refer to ANSI S2.19 and the Air Movement and Control Association International, Inc. (AMCA) Standard 204-20 "Balance Quality And Vibration Levels For Fans" for further information on balancing standards.*

Balancing is defined as "the process of adding (or removing) mass in a plane or planes on a rotor in order to move the center of gravity toward the axis of rotation." As the definition of balancing implies, material is either added to or removed from the rotating element to attain an acceptable balance level. In most cases adding weight is preferable, and depending on the type of fan and the fan design duty, different methods of adding weight are employed. In some cases, weight is added utilizing a metal clip placed on the blade or wheel tip. Typically, this method is used for lighter-duty fans operating at low speeds. As the speed and size of the fan increase, stainless steel bolts, nuts, or washers on aluminum products are used as balancing weights instead of clips.

These methods are employed on the impellers that are balanced after they have been painted because the added weight of the paint could affect the overall balance of the assembly. In other cases where the weight of the paint is negligible compared to the weight of the impeller, metal plates of varying sizes are welded onto the impeller in the appropriate location to attain adequate balance and the impeller is painted.

In some cases, notably those units with very small unpainted fan rotors weighing less than eight ounces, residual unbalance can be difficult to determine accurately. Therefore, the fabrication process alone of these products must ensure that the weight is distributed equally about the axis of rotation because these smaller fan rotors do not undergo the same balancing process.

It is important to understand the difference between static and dynamic balancing.

Static balancing is usually used on a very thin rotor, like a flywheel, where most of the mass lies in a single plane. Static balancing does not require that the rotor rotates. An example of static balancing is that of a “bubble balance” on an automobile tire. Here the wheel assembly is placed horizontally on a pivot point and weight is added to the front of the rim until the wheel is level.

Permanently secured stainless steel bolts, nuts and washers used as balancing weights after paint

Dynamic balancing is used on most rotors where more than one correction plane is required to balance the rotor. The rotor must be rotated to detect and correct “couple unbalance” where two equal unbalance masses are spaced 180º apart at opposite ends of the rotor. An example of dynamic balancing is a “spin balance” on an automobile tire. Here the wheel assembly is rotated and weights are attached to both the front and back of the wheel rim.

Welding balance plates to a centrifugal wheel prior to painting. (Shown on dynamic balancing stand)

A rotor that is dynamically balanced is also statically balanced. For this reason, a meaningful specification only requires dynamic balancing. Static balancing would be redundant.

Vibration

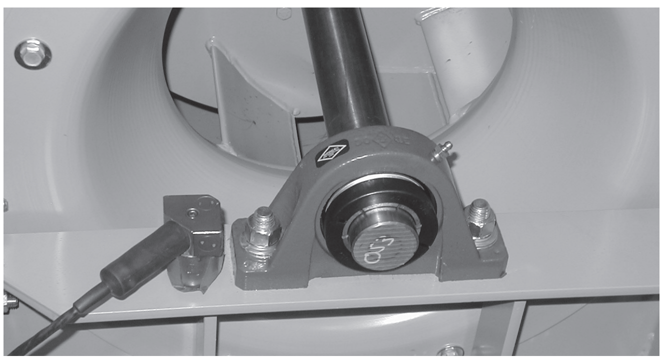
Vibration analysis is a cost-effective and useful diagnostic tool to ensure smooth running fans. Smaller units may not be vibration tested after assembly because the vibratory energy is much lower and has little impact on the installation or the life of the fan. Vibration is defined as “the alternating mechanical motion of an elastic system, components of which are amplitude, frequency, and phase.” The two components of vibration that fan manufacturers are most concerned with are amplitude and frequency. Amplitude defines how far the rotating body moves from the center rotating axis, and the frequency is the number of cycles or revolutions that occur within a specified time period.

Frequency is most often measured in either Hz (cycles per second) or CPM (cycles per minute). Amplitude can be measured in displacement (mils), velocity (in./sec.), or acceleration (g’s). Of these three, velocity is typically used to describe the vibration of a fan because it represents a fairly constant level of vibration severity independent of the fan RPM. A velocity measurement gives a vibration severity description that can be compared at any rotational speed. In contrast, displacement measures the maximum distance of a vibrating body from its neutral position. This gives a vibration severity description at only one specific speed and cannot be compared without measuring across a range of different speeds. Acceleration measures amplitude at the time rate of change of velocity, which again, is not a particularly useful description of vibration severity except for some special analysis applications.

Vibration Testing

When a fan is ready to undergo vibration testing, it is first mounted on the test bed as either a rigidly supported or a flexibly supported installation. A rigidly supported system should have a natural frequency above the running speed. (An example of a rigidly mounted fan is one mounted directly to a heavy concrete foundation.) A flexibly supported system should have a natural frequency below the running speed. (An example of a flexibly mounted fan is one mounted on spring isolators.)

A tri-axial accelerometer is placed near each bearing, which measures the vibration in the horizontal, vertical, and axial directions. The vibration is measured and recorded as either filter-in or filter-out. A filter-in vibration reading is taken only at one frequency, typically the fan RPM. A filter-out vibration reading measures the vibration over a wide frequency range and is calculated as the square root of the sum of the squares of the filter-in readings over that particular frequency range.



A tri-axial accelerometer measures the velocity amplitude in the horizontal, vertical, and axial directions.

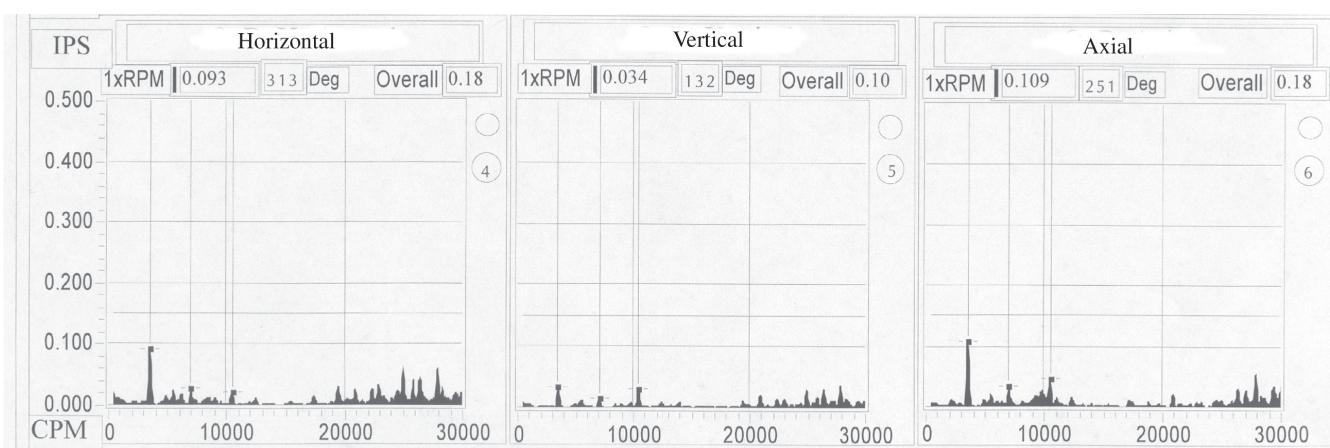
Vibration Limits for Tests Conducted in the Factory

Values shown are peak velocity, inches/second, filter-in, at the factory test speed.

Fan Application Category	Rigid Mounted in./sec.	Flexibility Mounted in./sec.
BV-1	0.50	0.60
BV-2	0.20	0.30
BV-3	0.15	0.20
BV-4	0.10	0.15
BV-5	0.08	0.10

Once the unit has been prepared for vibration testing, it is operated at the design speed and tested to ensure the unit falls below the maximum allowable vibration. The chart shown above shows the maximum allowable vibration corresponding to each appropriate fan application category.

Responsible fan manufacturers do not ship a fan assembly from their facility until the vibration level is within specified acceptable limits. If the maximum allowable vibration level is exceeded, various balancing and vibration elimination techniques are used to correct the unit.



All Greenheck centrifugal, vane axial, industrial and laboratory exhaust fans are vibration-tested prior to shipment. The vibration signature of each fan (shown above) becomes a permanent record with the fan serial number, available to the customer upon request.

Analysis

Examination of a fan's vibration signature can reveal possible sources of excessive vibration or vibration peaks. Identifying the specific frequency at which the vibration occurs is one way to begin an analysis. For example, a vibration peak occurring at the fan speed is most likely a sign of wheel unbalance and can most often be remedied with minor trim balancing. A vibration spike that occurs at the motor RPM could be an indication of motor pulley unbalance. A spike at two times the fan RPM could indicate looseness, bearing misalignment, or a bent shaft. Other possible sources of vibration, which are not always easy to distinguish, are those due to external factors such as electrical vibrations (torque pulses that occur at two times the line frequency). Another example would be a vibration spike caused by a bearing fault in the raceway. This type of spike would occur at a frequency that is a function of the bearing geometry and fan speed.

Specifications

Fan vibration specifications should be reviewed carefully to identify any special requirements. Special requirements can add significant labor hours and costs to the vibration testing process. It is important to write a meaningful vibration specification that will ensure your fan system will operate without excessive vibration, but also one that is not so stringent that it is difficult to meet without adding significant cost and time to the project. Following are some recommendations to consider in reviewing or composing a meaningful vibration specification:

- Select the appropriate "Balance and Vibration Grade." This will not only ensure a smooth-running unit but will also help to avoid additional time and costs involved with meeting unnecessarily stringent vibration levels. For example, it would not be practical or beneficial to expect a light-duty fan to meet the same vibration requirements as a large, heavy-duty industrial unit.
- Specify that the vibration testing be conducted at the fan manufacturer's shop and not at the jobsite. Conducting a vibration test at the jobsite introduces additional variables which are outside the fan manufacturer's control.
- Specify whether the unit is to be rigidly mounted or flexibly mounted to the vibration test stand. A rigidly mounted unit is the standard configuration and is the only option if the fan is manufactured less motors and drives. A unit can be vibration tested while flexibly mounted upon request if the fan manufacturer is supplying the entire unit, including the motor, drives, isolation, or isolation base.
- Specify that the readings be measured in velocity amplitude (inches per second, peak) at the design RPM (filter-in). Filter-in readings guarantee a good level of fan construction and reasonable residual fan unbalance. Filter-out readings become more involved and costly due to additional components that have to be controlled to attain the desired vibration level.
- Specify that the vibration readings be taken in the horizontal, vertical, and axial directions on each fan bearing. Measuring the vibration levels in all three planes and at each of the bearings is important in getting an accurate picture of a fan's actual vibration levels.

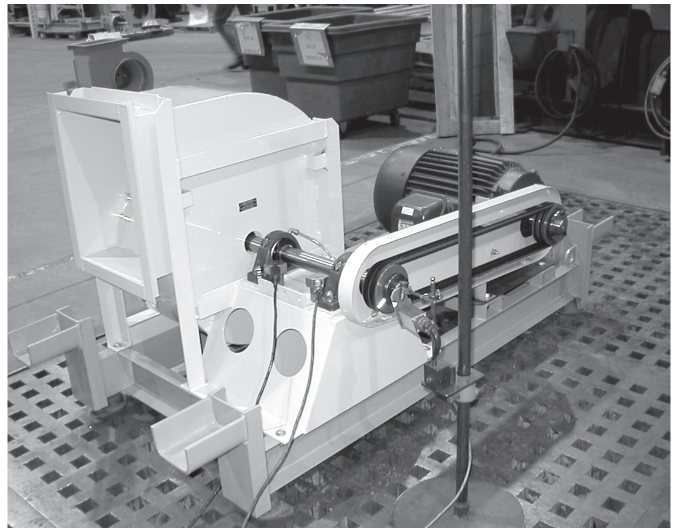
Sample Specification

The following is a typical specification example for a belt-driven centrifugal fan in Application Category BV-3:

> Each fan shall be vibration tested before shipping, as an assembly, in accordance with AMCA 204-20. Each assembled fan shall be test run at the factory at the specified fan RPM. Vibration signatures shall be taken on each fan bearing in the horizontal, vertical, and axial directions. The maximum allowable fan vibration level shall be 0.15 in./sec. peak velocity, filter-in, at the fan RPM when the fan is rigidly mounted. The manufacturer shall submit a vibration signature report for each fan tested.

Summary

We have discussed many factors that affect the vibration levels of operating air movement equipment. It is a complex subject but it should be apparent that there are numerous factors contributing to the overall vibration level of an assembled fan. The main reason to specify and approve only complete fan assemblies (fan, motor, base drive, bearings accessories, etc.) as a vibration-tested assembly is to ensure the unit will run within allowable vibration limits. With a complete factory-tested fan assembly, there are only a few additional external factors that can adversely affect the vibration level of the fan once it is installed at the jobsite. Purchasing a complete tested assembly gives you one less thing to worry about.



AMCA Certified Ratings

A manufacturer that participates in AMCA's Certified Ratings Program (CRP) assures the industry that the products and equipment will perform as stated by the manufacturer. The program stipulates the various rules and regulations for presenting cataloging data: AMCA 211 for aerodynamic performance and AMCA 311 for acoustic performance.

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