



## FAN BALANCE AND VIBRATION

### INTRODUCTION

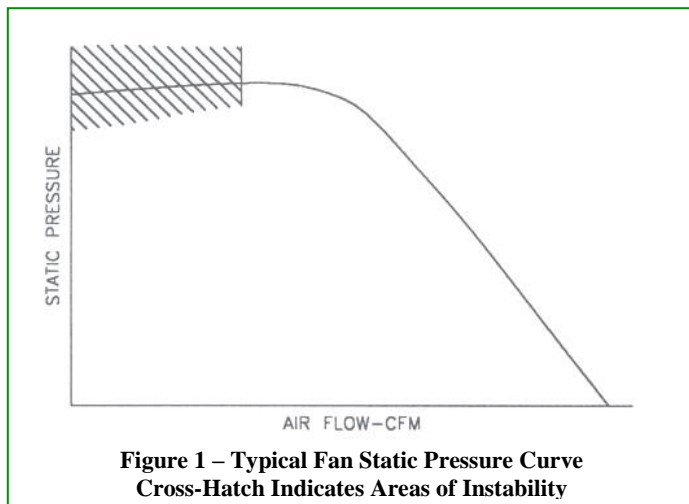
Vibration always has been a good indicator of how well a piece of equipment was designed, installed, and maintained. With sophisticated, computerized, preventative maintenance programs, vibration can now also be used as a precursor of future maintenance requirements.

Fans are subject to vibration because they have a high ratio of rotating mass to total mass and operate at relatively high speeds. Unlike most mechanical equipment, there are two major causes for vibration in fan equipment. These are aerodynamic, having to do with airflow, and mechanical, having to do with rotating components, fasteners, and structural support. This Engineering Letter will discuss both causes of vibration and provide guidelines for their reduction.

### AERODYNAMIC VIBRATION

Aerodynamic vibration, also referred to as aerodynamic pulsation, is one cause of fan-system vibration. It occurs when a fan operates to the left of its peak static pressure point. The vibration frequency, when checked with instruments, is at a frequency other than the wheel rotation speed.

This area of operation is illustrated in Figure 1. In this region the fan wheel does not move enough air to fill the blade passages. Aerodynamic vibration is most easily identified by increasing the volume of air flowing through the fan, thereby moving the fan's point of operation to the right. If the cause is aerodynamic, the vibration will usually disappear or be reduced significantly. Increasing the airflow is accomplished by opening dampers, cleaning filters and coils, or as a test, removing a section of duct near the fan. These actions will reduce system pressure and, correspondingly, increase the airflow.



Because of their inherent wheel geometry, some fans are more susceptible to pulsation when operating to the left of the peak on their static pressure curve. Centrifugal fans utilizing forward-curved or flat, backwardly-inclined blades are particularly subject to this phenomenon. However, fans with backwardly-inclined airfoil blades, such as the AcoustaFoil™ wheel, are designed to be stable left-of-peak. Figure 2 illustrates this area of unstable operation in a typical fan performance table (cross-hatch area). These points of operation indicate fan instability.

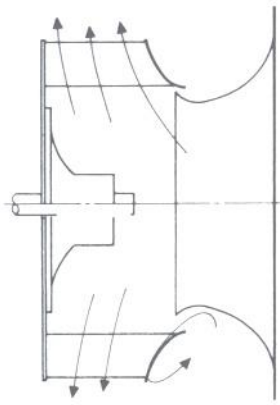
Operation left-of-peak may be due to an error in system pressure calculations, less than optimal system installation, or poor maintenance practice. The fan's point of operation may have also changed because the process/system has been modified since installation. For example, a drying system may have initially been designed to pull air through a 2" bed of material. Subsequent system changes now require a 6" bed of material with a significantly higher pressure drop. This will cause the fan to operate at a different point on its curve which may be left-of-peak.

Refer to Engineering Letter 7 to better understand how to take system measurements to determine a fan's point of operation.

If it is determined that the vibration is aerodynamic, there are several steps that can be taken to restore the fan to an acceptable operating point. If some type of blockage is causing the problem, dampers can be opened, filters and coils cleaned, and the process can be restored to a configuration more closely resembling the initial design. More expensive alternatives include increasing duct sizes, reducing duct lengths, and eliminating abrupt turns.

CFM	OV	1" SP		2" SP		3" SP		4" SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
1240	800	1207	0.17	1516	.032	--	--	--	--
1550	1000	1355	0.23	1620	0.41	--	--	--	--
1860	1200	1517	0.32	1757	0.52	2178	0.97	--	--
2170	1400	1690	0.42	1904	0.65	2288	1.15	2633	1.70
2480	1600	1867	0.56	2065	0.81	2415	1.35	2732	1.94
3100	2000	2239	0.91	2405	1.22	2708	1.87	2983	2.55
3720	2400	2620	1.40	2765	1.78	3032	2.54	3276	3.32
4340	2800	3007	2.06	3138	2.51	3378	3.40	3600	4.29
4960	3200	3401	2.92	3518	3.44	3736	4.45	3939	5.47
5580	3600	3797	4.01	3902	4.58	4104	5.74	4286	6.85
6200	4000	4196	5.35	4292	5.99	4476	7.26	4647	8.52

**Figure 2 – Typical Fan Performance Table**



**Figure 3 – Induced Air Recirculation**

If a redesign of the system is not practical but current air volume is adequate and the fan in question is a centrifugal, it may be possible to eliminate or reduce pulsation by adjusting the fan wheel toward the inlet cone. As shown in Figure 3, by adjusting the wheel so the edge of the cone is inside the wheel front plate, additional air will recirculate in the fan. The fan wheel will now receive a sufficient volume of air, allowing it to perform without pulsating; however, the efficiency of the fan will be reduced. In general, increasing the overlap by a distance equal to 2% of the wheel diameter will eliminate pulsation.

Aerodynamic vibration may also be caused by poor inlet connections to the fan. Inlet boxes and inlet elbows should be vanned to reduce losses. When air is forced to flow through a sharp turn as it enters the fan, it tends to load just a portion of the fan wheel. The result is always decreased performance but many times pulsation as well.

The same phenomenon can also develop, though generally to a lesser degree, at the discharge of the fan. Fans do not discharge air at an even velocity across their entire outlet. They generally operate best when the air is discharged into a long, straight duct, the minimum being three duct diameters beyond the outlet of the fan.

## MECHANICAL VIBRATION

Mechanical vibration is the most common type of fan vibration. It is caused by unbalanced wheels or other rotating fan components. Its negative impact is increased with loose fasteners and poor structural support. Two terms are important in understanding mechanical vibration.

Balance primarily refers to the fan wheel or other rotating components. The procedure of balancing involves adding or removing weight in an attempt to move the center of gravity toward the axis of rotation.

Vibration primarily refers to the complete fan. Fan vibration is measured during a “run test” and is the vibration amplitude at the fan bearings expressed in units of displacement or velocity. The vibration level for new fan equipment is a result of the design and construction by the fan manufacturer. For operating fan equipment, the installation and subsequent maintenance practices can have a major effect on fan vibration.

There are a number of causes for wheel unbalance:

**Construction** - in new fan wheels unbalance exists because of the nature of the fabrication and assembly process. Part and assembly tolerances, material density variations, and warpage during welding all contribute to non-concentric wheel assembly. Balancing compensates for these factors.

**Material build-up** - even a thin layer of dirt can cause a surprising amount of wheel unbalance. Using solvent, wire brushes, scrapers, etc., wheels can typically be cleaned and restored to a balanced condition.

**Abrasion/corrosion** - in material conveying applications or applications handling corrosive fumes, abrasion or corrosion of the wheel will cause unbalance. For safety reasons, this condition is more serious than simple vibration and the fan manufacturer’s representative should be contacted for repair recommendations, up to and including wheel replacement.

**Drive components** - sheaves, belts, couplings, and motors can have their own unbalance resulting in fan vibration. Check components for alignment, examine the grooves of sheaves, and check the surfaces of belts. Replace worn components. Couplings can shift even a few thousandths of an inch in shipment, causing misalignment and vibration.

Several drive components can be easily checked to determine if they are the cause of vibration. Disconnect the drive or coupling and run the motor with one sheave or half-coupling in place. If this assembly runs rough, remove the sheave or half-coupling and run the motor alone.

It is much more difficult to determine if the fan wheel or the driven sheave/coupling is causing the vibration without removing it and sending it to a balancing facility. Sheaves and couplings should have been dynamically balanced originally. Unless it is important to determine whether the wheel or drive component is out of balance, it is probably best to balance the wheel, shaft, and drive component as an assembly.

**Fasteners** -wheel and drive component setscrews, bearing bolts, and the fan base mounting hardware are all subject to loosening, especially when some vibration is present. Without attention, loose components will add to the overall fan vibration magnitude.

**Structural support** - too frequently, fans are mounted on supports that have a natural vibration frequency near that of the fan. At this frequency, the structure will tend to continue to vibrate once it has been set in motion. Under such conditions it is almost impossible to balance all of the rotating components finely enough to prevent an objectionable amount of vibration. Adding mass or stiffeners will move the structure’s natural frequency out of the range of the operating fan.

Optimum mounting structures include thick concrete slabs, steel bases supported by isolators, or heavy, all-welded steel structures. Structures must have adequate sway bracing, with no long, unsupported spans. They should be designed to be heavier than if they were designed merely to support a static load. All vertical supports should be directly underneath the fan and the fan should not be located in the middle of beam spans.

**Bent shaft** - can cause significant vibration which usually results in a vibration magnitude that is proportional to the amount by which the shaft is bent. Using a simple dial indicator, the shaft can be checked for trueness. It should not be out more than one or two thousandths of an inch on a short shaft or two or three thousandths on a longer shaft. If the shaft is bent, it can be straightened, replaced, or compensated for trueness by balancing.

**BALANCE CRITERIA**

Major fan manufacturers balance fan wheels prior to assembly on precision balancing machines (see Figure 4). The balancing procedure involves detection of and compensation for ounce-inches of unbalance.

For most HVAC, agricultural, and industrial applications, an ISO balance quality grade of G6.3 is adequate. Using this balance grade, the permissible residual unbalance is calculated as follows:

$$U_{per} = \frac{6.01 \times G \times W}{N}$$

Where:

- $U_{per}$  = permissible unbalance per balance quality grade (oz.-in.)
- $W$  = wheel weight (lbs.)
- $N$  = wheel operating speed (RPM).
- $G$  = balance quality grade (6.3)

For example, using a Size 264 Series 20 DH wheel:

Where:

$$W = 78 \text{ lbs.}$$

$$N = 2280 \text{ RPM}$$

$$G = 6.3$$

$$U_{per} = \frac{6.01 \times 6.3 \times 78}{2280}$$

$$U_{per} = 1.3 \text{ oz. - in.}$$

**VIBRATION CRITERIA**

After wheel installation, assembled fans are “trim balanced” as a complete unit before shipment (see Figure 5). Manufacturers have some limitations on what fans can be run tested based on electrical requirements, test speeds, and customer furnished components.

To perform a vibration run test, the fan is mounted on a rigid base. The base may be more or less rigid than that which the customer will use. Because of this difference, vibration limits determined from the factory vibration run test cannot be used as a guarantee of the minimum level of vibration once the fan is installed in the system. To account for this difference in vibration sensitive applications, more and more fans are being mounted on vibration absorption bases. These bases contain springs or rubber-in-shear isolation and may or may not be filled with concrete for additional mass. The purpose of these bases is to allow the fan to vibrate without transmitting the vibration to the building structure.

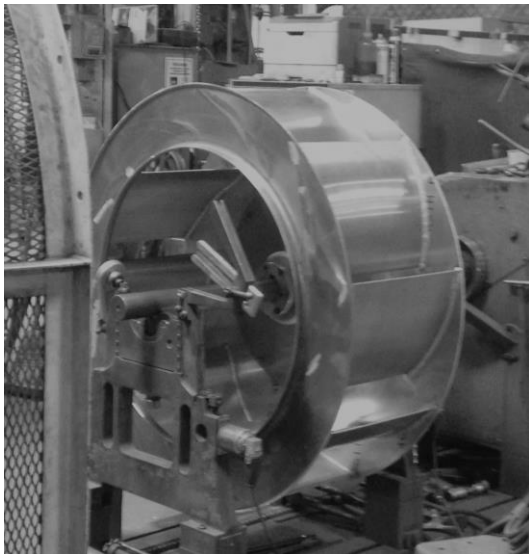


Figure 4 – Fan Wheel Balance

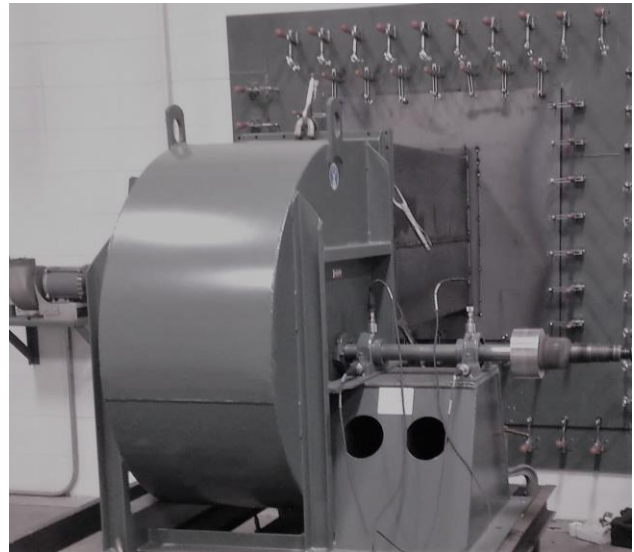


Figure 5 – Fan Vibration Run Test

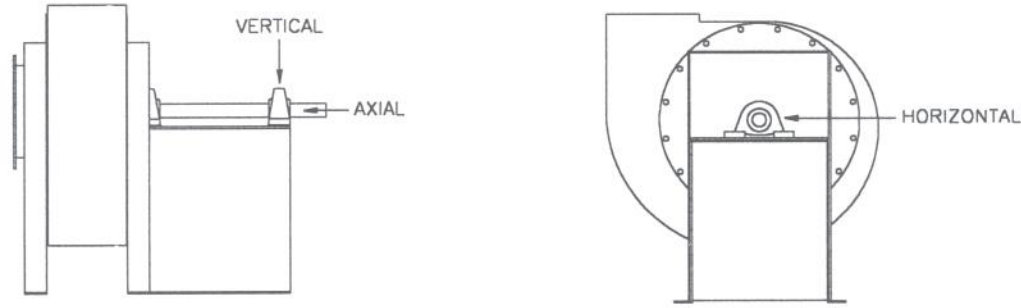


Figure 6 – Three Axis of Measurement

Fan assembly vibration is typically measured in the horizontal direction with “filter in”. *Filter in* refers to the vibration being measured only at the frequency of interest. This method provides an accurate measure of wheel unbalance. Transducer orientation may vary by product and/or test stand configuration at the discretion of the manufacturer (see Figure 6).

Major fan manufacturers have seismic vibration standards as part of their manufacturing/quality procedures. These limits will vary depending upon the fan manufacturer’s test facilities, balancing equipment, and fan type and size.

As a guideline for fans in HVAC, agriculture, and industrial applications, a peak velocity of 0.15 inches/second at the factory test speed is usually adequate.

For those more familiar with using displacement as a measure of vibration, displacement units can be converted to velocity units using the following equation:

$$V = \frac{\pi \times F \times D}{1000}$$

Where:

V = velocity (in./sec.)

F = frequency in revolutions per second (RPM/60)

D = displacement, peak-to-peak, (mils)  
(1 mil = .001 inch)

Example:

Convert .6 mils displacement to velocity in in./sec. with the fan running at 1200 RPM.

$$V = \frac{3.1416 \times 1200 \times .6}{60 \times 1000}$$

$$V = .0377 \text{ in./sec.}$$

## CONCLUSION

System designers and specifiers should observe the following specifications to ensure minimum, acceptable levels of fan vibration:

1. Wheels should be dynamically balanced prior to installation in the fan assembly to ISO 1940/ANSI S2.19 Quality grade G-6.3.
2. Fans should be given a run test and “trim balance” after wheel installation at the fan manufacturer’s plant to decrease vibration caused by other fan components and the overall assembly process whenever the fan configuration permits it.
3. Mounting structures must be rigid and sufficiently heavy to properly support the fan. Structures must have a natural frequency that is well out of the fan’s operating range.
4. For vibration sensitive applications, special consideration should be given to spring or rubber-in-shear isolation, or inertia bases.
5. Utilizing computerized fan selection programs and the manufacturer’s representative, fans should be selected to avoid unstable operating points and resulting aerodynamic pulsation.
6. Alterations to the overall system design should include consideration of changes in the fan’s point of operation and possible aerodynamic pulsation.
7. Proper maintenance practice, including periodic wheel inspections and inspection of drive components and fasteners, will assure reduced vibration levels.