Written by Andrew J. Winzenz, LORD Corporation Monday, 01 December 2008 14:06

Continuous monitoring for and correction of centrifugal-fan imbalances during operation is an especially cost-effective way of eliminating vibration problems.

From the time centrifugal fans first entered the marketplace, they have been subject to vibration-related problems. These problems range from simple unbalance conditions caused by mass variations on the fan rotor to more complex issues related to shaft alignment, bearing fatigue and resonance. In many cases, excessive vibration levels in fans lead to unplanned outages to perform maintenance. While these outages are necessary, they also can be very costly from both a maintenance and lost-production standpoint.

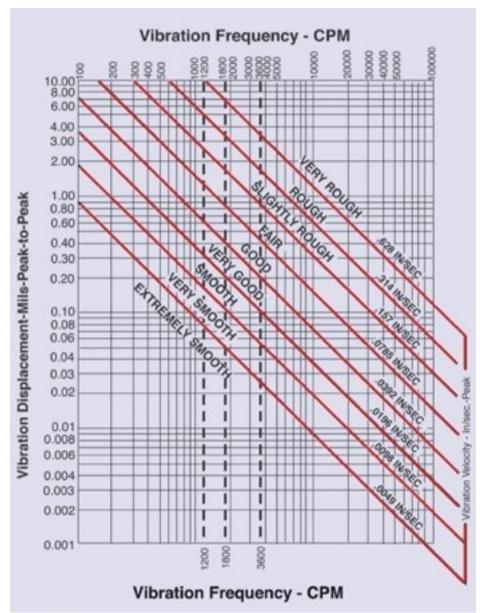


Fig. 1. This vibration severity chart shows the commonly accepted criteria for vibration levels in most rotating equipment. Some levels of vibration are acceptable—and standards have been established for these acceptable levels at corresponding operating speeds. The chart in Fig. 1 reflects commonly accepted criteria for vibration levels in most rotating

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equipment. To effectively deal with vibration issues in such equipment, however, it is necessary to implement a condition-based maintenance program that can identify problems before they turn catastrophic.

#### **Condition-based maintenance**

A condition-based maintenance program requires an initial review of the following common causes:

### Shaft misalignment...

Proper alignment between a drive motor shaft and a fan shaft needs to be addressed during new fan installation or if a shaft/rotor assembly is replaced. Misalignment between a drive motor shaft and fan shaft typically results in a 1X and 2X harmonic component of vibration.

Often, misalignment conditions will lead to excessive levels of axial vibration. Because most fans are not equipped with axial vibration probes, this is often not detected unless the 2X vibration component exists. Misalignment can be caused by careless installation of new equipment, but is more commonly caused by bent shafts or improperly seated bearings.

#### Resonance...

Resonance problems are often two-fold on large fan assemblies. The first component to address is critical speed. Mapping of critical speed typically is handled during new fan design. Most fans operate below first critical speed. The factors in avoiding critical speed in fan design include overall rotating mass, span between bearings and necessary operating speed to produce the required airflow. If a fan operates above first critical speed, careful attention must be paid to vibration levels as the fan accelerates to operating speed and coasts down to a stop from operating speed. Excessive levels of vibration while passing through a critical speed can lead to severe damage to bearings, seals and other equipment.

The second factor to address is structural resonance, which can be quite challenging to predict. Every structure has a natural frequency at which it will resonate. If a fan operates at a structural resonance point that is not corrected, it can lead to component failures. Structural resonance can occur at 1X operating speed or at a harmonic frequency (2X, 3X, ...). Structural resonance will vary, depending on operating speed. It can be identified through a signature plot that maps vibration amplitude versus frequency versus rotational speed.

# Mechanically loose connections...

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Looseness in any mechanical connection between bearing caps, bearing pedestals or foundations can cause excessive vibration levels or amplify an already existing unbalance problem. A mechanically loose connection will yield harmonic levels of vibration (2X, 3X, ...) and may also yield sub-harmonic levels of vibration (X/2, X/3, ...). Vibration caused by mechanically loose connections frequently is misdiagnosed due to the presence of sub-harmonic vibration levels.

A second type of vibration caused by mechanically loose connections can take place if there is looseness in the connection between the fan rotor and fan shaft. This will induce an extremely high unbalance-related vibration level that is not necessarily at 1X operating speed. In most cases, properly designed interference fits between the rotor hub and the fan shaft can be implemented to avoid this condition.

#### Cracked shafts or rotors...

Crack propagation in either a fan shaft or rotor can lead to one of the most dreaded failure modes in any type of rotating equipment: catastrophic failure. Luckily, early crack detection is possible if vibration trending and analysis is done on a piece of equipment.

The common symptoms of a crack propagating in a fan are an emergence and growth of a 2X component of vibration along with a change in the phase and amplitude of the 1X vibration component.

#### Rotor mass unbalance...

Rotor mass unbalance is the most common cause of excessive vibration in rotating equipment and fans. The primary symptom of rotor mass unbalance is a high 1X vibration level.

Rotor mass variation leading to an unbalanced condition usually stems from the following:

- 1. Variations in manufacturing that lead to unevenly distributed mass in the fan rotor
- 2. Exposure to high air stream temperatures that cause uneven growth of the fan rotor
- 3. Deterioration of the fan rotor caused by either high-speed particle collisions or corrosive material passing through the fan
- 4. Uneven material accumulation or fouling on the fan rotor. Large chunks of material flaking off and causing sudden, excessive vibration can compound this issue.

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Excessive amounts of rotor mass unbalance can have two detrimental effects on fans. The primary concern is the excessive long-term, fatigue-inducing beating forces incurred by running at elevated vibration levels. The second (although uncommon) concern in fans is related to the equipment's passing through critical speeds on startup or coastdown. Excessive amounts of rotor mass unbalance also can amplify other vibration conditions, such as a loose bearing cap or instability in a foundation.

## Correcting unbalance in fans

Removing particulate build-up from the rotor or performing a mechanical balance of a fan are ways to reduce the amount of unbalance in these types of units. Both of these actions, however, require that the fan be stopped.

Two methods for making a mass unbalance correction to compensate for 1X vibration include using a manual balancing system, often portable, that can be deployed on multiple pieces of equipment, or using a dedicated active balancing system.

#### Manual balance corrections...

A manual balance correction—or off-line balancing procedure—is a common action that takes place during new equipment installation or during a maintenance procedure in a planned outage. This six-part process is as follows:

- 1. Clean the impeller of any particulate build-up.
- 2. Measure the initial vibration phase angle and magnitude.
- 3. Stop the fan and add a known trial mass at a known location.
- 4. Start the fan and measure the resultant vibration phase angle and magnitude. Use this information to compute the fan sensitivity or response to unbalance.
- 5. After completing the foregoing calculation, stop the fan and determine the proper amount of mass for the balance weight and where to attach the weight.
  - 6. Attach the weight and restart the fan.

Steps three to six may be repeated multiple times depending on the operator experience level and the equipment sensitivity.

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Although a manual balance correction typically is necessary for new equipment installation and during planned outages, it does have drawbacks—especially if there is a need to employ this technique regularly between planned maintenance intervals.

- The amount of time required to perform a manual balance correction can be difficult to determine.
- Multiple starts and stops may lead to shortened life expectancy of the motor and other associated equipment.
- Variable-speed applications can result in different balance corrections needed for different operation speeds.
- Although uncommon in most fan applications, the excessive vibration levels experienced while equipment passes through a critical speed can lead to excessive bearing and seal wear.



Fig. 2. The balance ring in an automatic or active balancing system is permanently attaced to the fan's shaft, and contains internal weights that can be repositioned as needed to offset imbalance. Automatic or active balancing systems allow users to continuously monitor fan vibration levels and make balance corrections without shutting down the fan. They consist of a control system, balance rings, actuators and vibration sensors. The balance ring, permanently attached to the fan's shaft, contains internal weights that can be repositioned to offset the mass unbalance and compensate for excessive 1X vibration levels (Fig. 2).

Because active balancing systems continuously monitor fan vibration levels, the user must program a fixed tolerance range for the vibration level. When vibration levels reach the upper limit of the tolerance range, the control system determines the necessary magnitude and phase angle of the required balance correction. The control system sends power and data to a stationary actuator that communicates with the rotating balance ring. The actuator commands the internal weights in the balance ring to move to new positions to offset the unbalance and bring the 1X vibration level back within the tolerance range. Fig. 3 provides a schematic of a typical system configuration.

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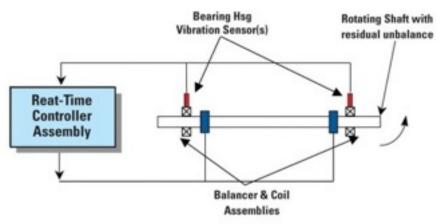


Fig. 3. A typical active balancing configuration — Active balancing systems are used primarily on three types of induced draft (ID) fans: overhung single-inlet, center-hung single-inlet and center-hung double-inlet. The most important reason to use an active balancing system on these fans is that such a system allows the operator to maintain low levels of vibration as the fans continue to run. That can have an enormous impact on both production and maintenance.

The most visible benefit is the ability to improve fan reliability and availability. This leads to reductions in both scheduled and unscheduled maintenance outages used for more conventional means of correcting unbalance problems, as well as the potential for extensions in planned maintenance outages. Secondary benefits include extended equipment life—*i.e.*, motors, bearings and seals last longer

—and reduced fuel and power consumption from limiting the number of starts and stops of the process.

One of the most useful pieces of information obtained from an active balancing system is an event log that tracks use of the balancing system. The log will display beginning and ending vibration levels and phase angle, as well as the amount of time required to complete a balance correction. This information can be accessed through Windows-based control software.

The balancing system also can be accessed via a remote interface module that allows the system to be linked to a plant's network through an Ethernet connection. This provides a secure connection for remote users to download history data, access and change parameters, and monitor vibration levels.

## A vibrating fan solution

When running 121-in. diameter, 13-ton double-wide, double-inlet ID fans, it is particularly inefficient to have emergency shutdowns for unplanned maintenance. At U. S. Steel's Fairfield Works in Fairfield, AL, the level of vibration on fans responsible for pulling air, gases and materials off the basic oxygen furnace would creep to unacceptable levels during operation.

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With furnaces heating steel to nearly 2800 F, these enormous fans are critical in successfully turning out product.

At this facility, imbalance and high vibration levels caused by excess build-up of particulate on the fan rotors resulted in chunks of build-up falling off the rotor. Maintenance team members had to clean and manually balance the fans at least every three months. Moreover, it took three to five balance attempts to successfully perform a manual fan balance. This often resulted in a violation of the time recommended between starts on the motor, creating a high potential for motor failure. And, when a fan was stopped due to high vibration, it would result in a production shutdown.

Since the installation of balancers, Fairfield Works has averaged one scheduled maintenance shutdown and one interim cleaning per year. Because a typical shutdown can last eight to 12 hours, savings are significant. Beyond saved revenue and time from reduced shutdowns, the online balancing technology continuously maintains the balance level of the fans below 0.8 mils, as compared with the previous 1.0 mils low-level field balance. Additionally, motor and bearing life was increased, resulting in fewer motor rebuilds at roughly \$200,000 each.

# What's in it for you?

Active balancing systems can help solve one of the most common causes of excessive vibration in rotating equipment by compensating for rotor mass unbalance. These corrections, made while equipment remains in service, help a company avoid costly outages. Reductions in 1X vibration amplitudes, caused by rotor mass unbalance, also help minimize the effects of other vibration conditions, such as looseness in bearings or inadequate stiffness in bearing pedestals or foundations.

An active balancing system provides detailed trending information for outage planning and for identifying other vibration problems that are not strictly displayed at 1X operating speed. Proper use of these types of systems allows organizations to increase equipment availability, while running more stable production processes and safer, more reliable operations. **MT** 

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