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Controlling Fan Vibration with Active Balancing to Solve Serious Reliability and Maintenance Problems

By Andrew J. Winzenz, LORD Corporation

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SYNOPSIS

This paper will discuss common vibration problems experienced on large centrifugal fans that lead to forced outages and unscheduled maintenance. This paper describes the use of an Active Fan Balancing System used to control unbalance related vibration levels in fans. The paper will also detail several active balancing installations and describe the benefits these users have experienced.

COMMON CAUSES OF VIBRATION IN CENTRIFUGAL FANS

Ever since centrifugal fans have been manufactured they have been subject to vibration related problems. These problems range from simple unbalance conditions caused by mass variations on the fan rotor to much more complex issues related to shaft alignment, bearing fatigue, or resonance issues. In many cases excessive vibration levels in fans lead to unplanned forced outages to perform maintenance. While these outages are necessary to maintain safe operation of fans, they typically are costly both from a maintenance and lost production standpoint.

Standards have been set as to what are acceptable vibration levels for corresponding operating speeds. The chart below (Figure 1 – Vibration Severity Chart) is commonly accepted as criteria for vibration levels in most rotating equipment. Other sources that outline acceptable balance and vibration levels for fans include ANSI/AMCA 204-96, “Balance Quality and Vibration Levels for Fans” and ISO 14694:2003, “Industrial Fans – Specifications for Balance Quality and Vibration Levels”.

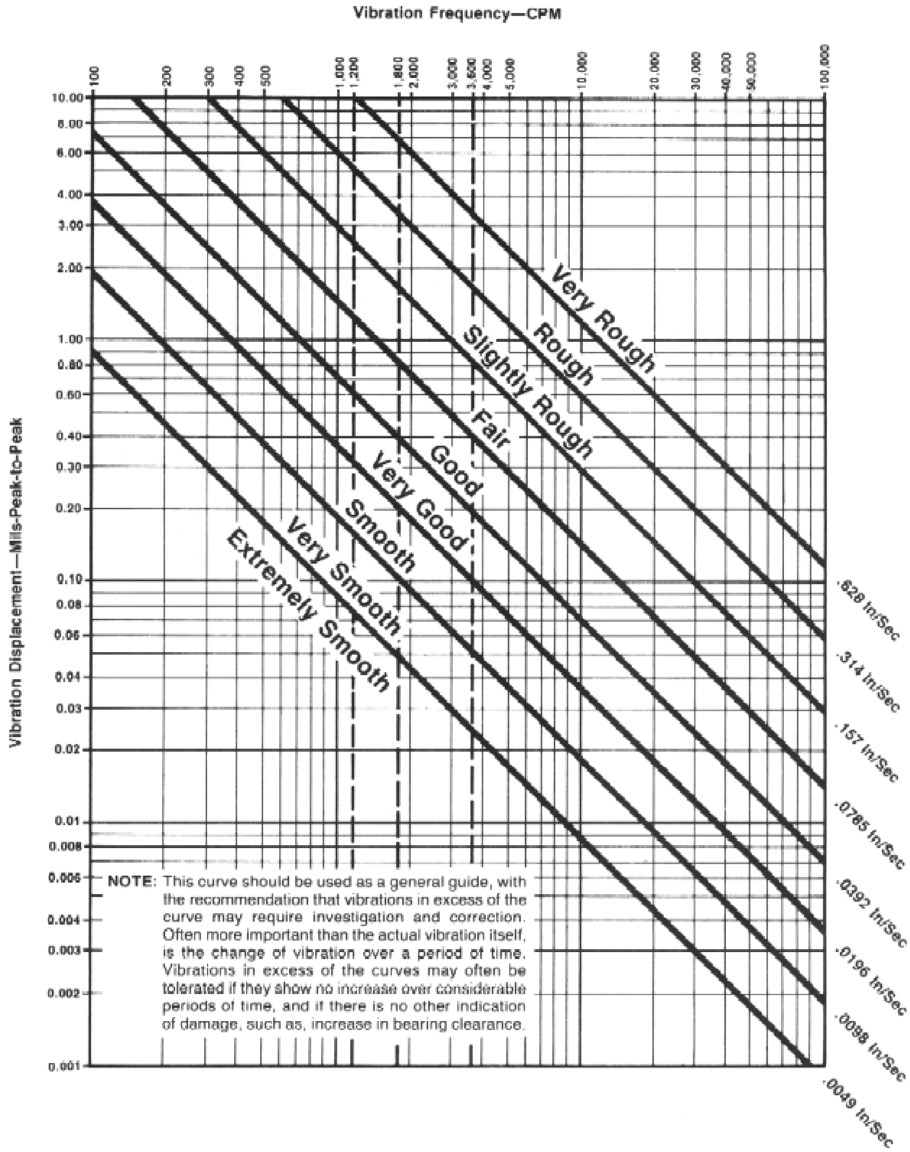

Figure 1. Vibration Severity Chart

Below are brief discussions of the most common causes of vibration in centrifugal fans along with the corresponding symptoms and methods for correction.

Shaft Misalignment

Proper alignment between a drive motor shaft and a fan shaft is an important step that needs to be properly 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 times, misalignment conditions will also lead to excessive levels of axial vibration. Since 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. Misalignment should be able to be detected prior to startup of a fan by using a laser alignment system to verify proper alignment between the drive motor shaft and fan shaft. However, a bent fan shaft may not be detected by a laser alignment system, which may allow the above symptoms to persist.

Resonance
Resonance problems are often two fold on large fan assemblies. The first component that has to be addressed is critical speeds. Critical speed mapping is typically a task that is addressed during new fan design. Most fans are designed to operate below first critical speed. The factors in avoiding critical speed in fan design are overall rotating mass, span between bearings, and necessary operating speed to produce the required airflow. If a fan operates above first critical speed then careful attention has to be paid to vibration levels as the fan accelerates up to operating speed and, more importantly, 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 related equipment.

The second factor, structural resonance, can be much more 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 also lead to component failures. Structural resonance can occur at 1X operating speed or at a harmonic frequency (2X, 3X, …). Structural resonance will vary dependant on operating speed and can be easily identified by performing a signature plot mapping vibration amplitude, versus frequency, versus rotational speed.

Mechanically Loose Connections
Looseness in any mechanical connection between bearing caps, bearing pedestals, or foundations can cause excessive vibration levels or amplify an already existing unbalance problem. In most cases, 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 is often 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. In many cases this will induce an extremely high unbalance related vibration level that is not necessarily at 1X operating speed. This type of vibration can be very difficult to determine, but easily corrected if found. In most cases, properly designed interference fits between the rotor hub and 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. If undetected, a crack in a shaft or rotor can eventually lead to catastrophic failure of the fan. Early crack detection can take place if vibration trending and analysis takes place on a piece of equipment. The common symptoms of a crack propagating in a fan are both 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 most 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 is typically caused by four primary factors; First, variations in manufacturing can lead to unevenly distributed mass in the fan rotor; Second, exposure to high air stream temperatures can cause uneven growth of the fan rotor; Third, deterioration of the fan rotor caused by either high speed particle collisions or corrosive material passing through the fan; Fourth, uneven material accumulation or fouling on the fan rotor. This final issue can be compounded by large chunks of material flaking off and causing very sudden, excessive vibration levels.

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 concern, although uncommon in fans, is passing through critical speeds on start-up or coast-down. Excessive amounts of rotor mass unbalance can also amplify other vibration conditions, such as a loose bearing cap or instability in a foundation.

Many of the unscheduled forced outages that take place due to excessive vibration are simply due to excessive amounts of rotor mass unbalance.

CORRECTING FOR UNBALANCE CONDITIONS IN FANS

Corrective actions can be taken to reduce the amount of unbalance, including removing particulate build-up from the fan rotor or performing a mechanical balance of the fan. However, both of the actions require a stoppage of the fan for some period of time. There are two methods for making a mass unbalance correction to compensate for 1X vibration. They are to use a manual balancing system that is often portable and can be used on multiple pieces of equipment or to use a dedicated active balancing system.

A. Manual Balance Corrections

A manual balance correction or off-line balancing procedure is a common action that takes place during new equipment installation or as a maintenance procedure during a planned outage. The balance correction is typically a six part process that follows these steps: 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 know location; 4) Start the fan and measure the resultant vibration phase angle and magnitude. This information is then used to compute the fan sensitivity or response to unbalance; 5) Once this calculation is made the fan is stopped and one can determine the proper amount of mass for the balance weight and what location to attach the weight; 6) The weight is attached and the fan is restarted. Steps 3-6 of this process may be repeated multiple times depending on the level of experience and sensitivity of the equipment.

Although a manual balance correction is typically necessary for new equipment installation and during planned outages, it does have drawbacks if you have to employ this technique regularly between planned maintenance intervals. The amount of time required to perform a manual balance correction can be very difficult to determine, particularly as it relates to permit issues, co-operation between services, and ease of balancing the fan. Multiple starts and stops of the motor may lead to shortened life expectancy of the motor and other associated equipment. Variable speed applications may find that different balance corrections are necessary for different operation speeds. And, although uncommon in most fan applications, for equipment passing through critical speeds, the excessive vibration levels experienced while passing through a critical can lead to excessive bearing and seal wear.

B. Automatic Balance Corrections

A second type of balancing system has been in use since the early 1980's and allows users to continuously monitor fan vibration levels and make balance corrections without shutting down the fan. These systems have been termed automatic or active balancing systems. Active balancing systems consist of a control system, balance rings, actuators, and vibration sensors. The balance ring permanently attaches to the shaft of the fan. The balance ring contains internal weights that can be repositioned to offset the mass unbalance and compensate for excessive 1X vibration levels (see Figure 2 below).

Figure 2. Active Balancing Systems

1. Operation of an Active Balancing System

Active balancing systems operate on a simple concept of sense, and then adjust. The balancing system is set up to continuously monitor fan vibration levels. Users program in a fixed tolerance range that they want to keep the vibration level within. 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 sends power and data to a stationary actuator that communicates with 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. Figure 3 (below) provides a schematic of a typical system configuration.

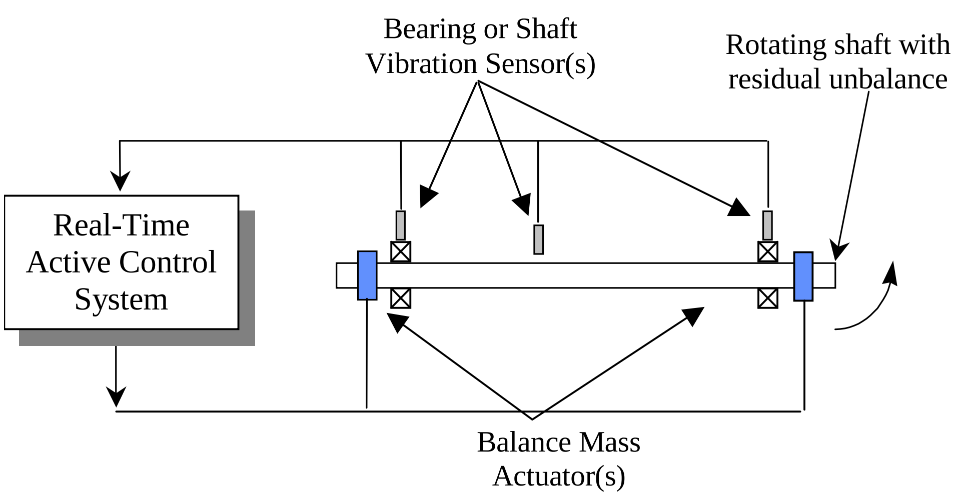

Figure 3. Active Balancing System Schematic

2. Applications for Active Balancing Systems

Active balancing systems have been applied to numerous types of rotating equipment. Their effectiveness in controlling 1X vibration levels caused by rotor mass unbalance in industrial ID fans continues to be a primary area of application. There are three primary types of ID fans that active balancing systems have been applied to. They are overhung single-inlet, center-hung single-inlet, and center-hung double inlet (see Figure 4 below).

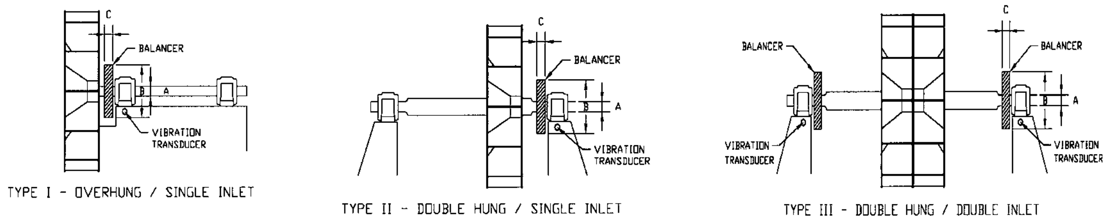

Figure 4. Typical Fan Configurations

The configuration of the fan defines the number of balance correction planes required. Variation in the size and operating speed of the fan as well as process conditions also dictate the necessary correction capacity that is built into the active balancing system.

3. Benefits of using Active Balancing Systems

The primary objective of an active balancing system is to maintain low levels of vibration while the process continues to operate. Maintaining very low vibration levels typically has positive impacts on a plant both from a production and a maintenance standpoint. The most visible benefit is the ability to improve fan reliability and availability. This leads to reductions in both scheduled and unscheduled maintenance outages that are used for more conventional means of correcting for unbalance problems. Many users also find that in additional to eliminating unscheduled intermittent maintenance outages they can often extend the period between planned maintenance outages. For plants that are looking to run 1-2 years between planned maintenance outages this can have a very positive impact.

Secondary benefits include extending equipment life, such as motors, bearings, and seals by operating for longer periods of time at low vibration levels as well as reducing fuel and power consumption by limiting the number of starts and stops of the process.

4. Interfacing with an Active Balancing System

One of the most useful pieces of information that can be obtained from an active balancing system is an event log that tracks the usage of the balancing system. This log will display beginning and ending vibration levels and phase angle as well as the amount of time required to complete a balance correction. The stored data can also be used effectively to calculate a required manual correction, therefore reducing the time and efforts required during a planned outage. This information can be accessed through Windows based control software. The system can also be tied into a plant Digital Control System (DCS) through a PLC interface. This puts control of the system and data in front of an operator at all times.

The balancing system can also be accessed via a remote interface module (see Figure 5 below) that allows the system to be linked to a plants network through an Ethernet connection. This remote interface provides a secure connection for remote users to download history data, access and change parameters, monitor vibration levels and permits complete control of the system from any location around the world.

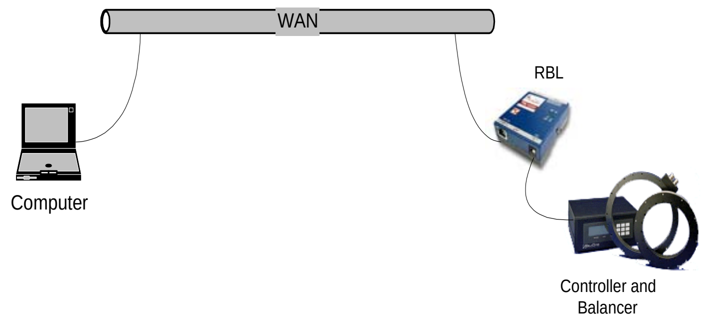

Figure 5. Remote Interface Module

APPLICATION CASE STUDIES

GCC Dacotah Cement

Background: A severe vibration problem was being experience in an ID fan that draws hot gas and cement particulate off the rotary kiln before sending it to the bag house for particulate removal. Since the fan is in the process airflow, some of the particulate would stick to the fan and cause a hard coating up to an inch thick. As temperatures and process conditions changed, large chunks would break off and cause the fan to go out of balance. Every two months it was necessary to shutdown to sand blast the fan. The cleaning time alone was six hours and by the time everything was ready to go back into service 12 hours of production had been lost.

Solution: A fan balancing system was installed on the Kiln ID Fan. Vibration levels that regularly reached levels of up to 25 mm/s at 1330 RPM are now kept to between 0.6-1.3 mm/s. Scheduled outages now take place every 6 months at which time cleaning is performed. Emergency outages, which regularly took place, have been eliminated.

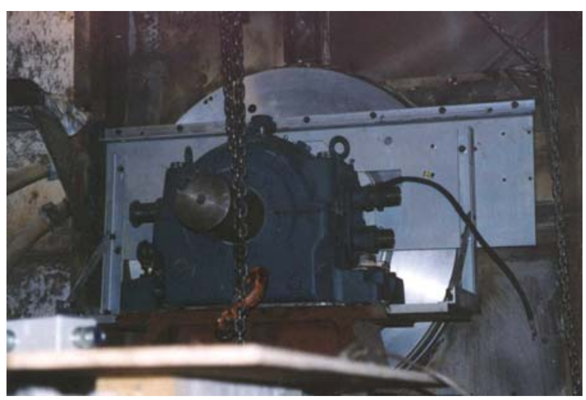

Figure 6. Installation at GCC Dacotah Cement

United States Steel – Gary Works

Background: The level of vibration on the 120” (305cm) diameter exhaust fans, which draw a mixture of air, coal, and miscellaneous gases through thousands of feet of ductwork in the pre-carbon (Coke) plant, would creep to unacceptable levels during operation. Even higher levels of vibration often occurred after the fan had been shut down for several days. Whenever the level of vibration reached 5.5 mm/s, the fan would automatically shut down. To keep the fan within acceptable levels of vibration, the rotor was manually balanced as often as twice per month at a cost of $1,000 each time and required at least a day of downtime and lost production. In addition to having to balance the rotor, the bearings were wearing out because of the vibration and had to be replaced almost every month during the maintenance shutdowns.

Solution: After balancer installation, vibration levels below 0.5 mm/s were maintained. The bearings that had previously been replaced every month are now lasting more than a year and saving US Steel more that $80,000 in parts and labor to change them out. Fan downtime for balancing and maintenance was significantly reduced. Emergency shut downs due to excessive rotor vibration were eliminated while increasing the amount of production per year. In all, US Steel estimates that they have saved over 1,000 hours of maintenance time or $45,000, which allowed them to concentrate on preventive maintenance instead of dealing with repairs in a crisis situation.

Figure 7. Installation at US Steel, Gary Works

SUMMARY AND CONCLUSIONS

There are many different causes of vibration in rotating equipment. In order to effectively deal with all of the causes it is necessary to implement an effective condition based maintenance program that can identify problematic situations before they turn into potentially catastrophic situations.

Active balancing systems help to solve one of the most common causes of excessive vibration in rotating equipment by compensating for rotor mass unbalance. These corrections are made while the equipment remains in service, avoiding costly outages. Reductions in 1X vibration amplitudes caused by rotor mass unbalance also help to minimize the effects of other vibration conditions such as looseness in bearings or inadequate stiffness in bearing pedestals or foundations. Active balancing system can provide detailed trending information that can be used for outage planning and to assist in identifying other vibration problems that are not strictly displayed at 1X operating speed. Proper use of an active balancing system allows users to increase equipment availability, run a more stable production process, and leads to a safer more reliable operation.

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LORD Corporation
World Headquarters
111 Lord Drive
Cary, NC 27511
Tel: 919-468-5981
Fax: 919-469-5811
www.lord.com