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Predictive Maintenance and Use of Vibration Analysis

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[Editor's Note: This is the sixth in a periodic series of articles on various aspects of preventive maintenance programs for grain elevators, feed mills and grain processing facilities. The first five articles in this series were published on Nov. 7 and Dec. 18, 2008, and on Jan. 15, Feb. 12, and March 12, 2009. You are encouraged to share these publications with those at your facility responsible for preventive maintenance and safety programs.]

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There are a variety of methods that can be used by grain, feed and grain processing facilities to monitor the operating conditions of equipment.

One such tool is vibration analysis – a predictive maintenance tool that may be used to measure machine vibration to assist in determining if operating conditions are within normal limits. By measuring and analyzing the vibration, maintenance personnel or technicians may detect changes or abnormal patterns in the machine's operating condition, and then use this information to take corrective action before a costly shutdown, machine damage or personal injury occurs.

Vibration analysis is characterized as a "predictive" maintenance tool because it is used to help determine the condition of in-service equipment and systems to anticipate when maintenance should be performed.

The ultimate goal of predictive maintenance is to perform maintenance at a scheduled point in time when the activity may be accomplished in the most cost-effective manner and before the equipment or system loses optimum performance. This approach may offer cost savings over routine or time-based preventive maintenance because tasks are performed only when warranted.

Machine Vibration

Most machine vibration is attributable to one or more of the following causes:

- **Repeating Forces:** The term "repeating forces" refers to those unbalanced forces that occur over and over again within a machine to create movement. Repeating forces in machines are caused mostly by the rotation of imbalanced, misaligned, worn or improperly driven machine components. Examples of machine conditions that may create a repeating force include uneven electrical motor windings, worn fan blades, drive component misalignment, bent drive shafts and worn drive components, such as bearings, gears and belts.

- **Looseness:** Machine parts that are loose may cause the machine to vibrate. If parts become loose, vibration that normally is acceptable may become excessive and damaging. Looseness often may occur because of improper mounting of the machine, excessive clearances between machine parts, inadequate machine foundation and improper tensioning of mounting bolts.

- **Resonance:** Resonance describes the tendency for an object, such as a machine, to vibrate more when the frequency of a repeating force matches the object's natural frequency of vibration. Most machines have at least one natural frequency of vibration, commonly referred to as natural oscillation rate. Although a repeating force may be small and result from the operation of a sound machine component, such a repeating force potentially may match the machine's natural oscillation rate and create resonance. When such a condition occurs, the effect of the repeating force may cause excessive and potentially damaging vibration within the machine.

What is Vibration and How Is It Described? One technical definition for vibration is the mechanical oscillation of an object about a reference position. The term "oscillation" describes the back-and-forth or harmonic motion of an object, typically measured in the time it takes for the object to move through one full cycle. Therefore, machine vibration may be defined as the back-and-forth movement of a machine component as compared to a reference point over a period of time.

The two main numerical descriptors of machine vibration are **amplitude** and **frequency**. Amplitude describes the severity of vibration, while frequency describes the oscillation rate of vibration.

- **Amplitude:** Amplitude describes the magnitude of machine movement during vibration. As amplitude increases, so does machine movement and the likelihood that the machine will experience damage. Generally, amplitude of vibration relates to: 1) the length of the machine movement; 2) the speed in which the movement occurs; and 3) the force associated with the movement. In many cases, it is the speed of the amplitude or amplitude velocity that provides the most useful indicator about the condition of a machine.

- **Frequency:** The number of times that a machine component completes a motion cycle during the period of one second is called frequency. Frequency is measured in hertz (Hz), which describes cycles per second. A machine component typically vibrates at more than one frequency. This occurs because a variety of forces generally act upon a machine component during operation. For example, the component may experience simultaneous forces from bearing movement, drive component interaction and other mechanical activity.

Vibration also is described and displayed through two common graphical means: **waveform** and **spectrum**. A waveform display illustrates how vibration changes over time, while a spectrum display shows the various frequency levels at which vibration is occurring.

- **Waveform:** Waveform displays graphically depict the change in velocity of vibration over a period of time. The value of the information displayed depends upon the duration and resolution of the waveform. To be meaningful, the duration time of the waveform display should be long enough to provide a good representation of the vibration. The resolution of the waveform is important because it provides a measure of the level of detail associated with how the vibration is displayed graphically.

- **Spectrum:** A spectrum is a display of both the amplitudes and frequencies at which a machine component is vibrating. Like a waveform display, the value of a spectrum typically depends on two primary factors: 1) measuring and displaying an appropriate frequency range; and 2) using a resolution level that adequately characterizes the shape of the spectrum.

How is Machine Vibration Measured?

Vibration is measured by placing a sensor on the machine that can detect vibration behavior. Various types of vibration sensors are available. But frequently, a type called an "accelerometer" is used to collect information for vibration analysis. An accelerometer is a sensor that produces an electrical signal proportional to the acceleration of the vibrating component to which it is placed into contact or attached. The acceleration measurement provides an indication of how quickly the velocity of the component is changing during vibration.

Maintenance personnel or technicians usually place or mount accelerometers near machine bearings associated with rotary mechanisms to obtain vibration measurements. Examples of machine designs that use rotary mechanisms include motors, pumps, compressors, fans, belt conveyors and gearboxes. The bearings that support the rotary mechanisms of such machines bear the forces associated with rotary motion and vibration. As such, bearings often are the first place where adverse machine symptoms may develop and, ultimately, where failure may occur.

Either hand-held probes or physically mounted accelerometers are used to obtain vibration measurements from machine components. In either situation, the sensor must be firmly in contact with the vibrating component to obtain an accurate measurement. A loose accelerometer may produce a distorted signal because of its own independent movements. When obtaining hand-held measurements, it also is important to place the accelerometer at the same location during each reading to minimize measurement inconsistencies that may lead to inaccurate results.

Various methods are available for physically mounting an accelerometer to a vibrating machine component. Such methods may include attaching the accelerometer with a threaded or cemented stud or using a strong magnet. Mounting the accelerometer to the measuring point in an appropriate manner is one of the most critical factors in obtaining accurate results from vibration measurements.

The signal produced by an accelerometer depends on the orientation in which the accelerometer is placed or mounted, since the amplitude of vibration varies in different directions. The accelerometer should be oriented to meet specific machine situations. For the purposes of vibration analysis, it often is beneficial to obtain vibration readings from several axes, such as horizontal, vertical, axial (the direction of the centerline of a shaft or rotor), and radial (a direction perpendicular to the centerline of a shaft or rotor).

The acceleration signal produced by the accelerometer is transmitted to an electronic instrument that converts the signal into a velocity measurement. Typically, the electronic instrument that receives the accelerometer signal has a variety of adjustable parameters. These parameters specify how the instrument will process the signal and present information to the user. Parameters that are adjustable commonly include: 1) how much information is obtained during the measurement, such as frequency range, duration and resolution; 2) the number of measurements to be averaged to produce a result; and 3) how the results will be graphically displayed. Depending upon the instrument, displays usually take the form of either a velocity waveform or a velocity spectrum. Generally, velocity spectrum displays provide the most useful information for vibration analysis. Such a display supplies information about the individual frequencies at which a machine component vibrates, as well as the amplitudes corresponding to those frequencies.

How Are Vibration Measurements Used? Machines seldom fail without warning. Usually, the signs of an approaching failure are present long before the breakdown actually occurs. Machine failure almost always is accompanied by an increased vibration level that can be measured on an external surface of the machine. By obtaining and studying vibration measurements, maintenance personnel or technicians can evaluate the cause of vibration and the condition of the machine.

Proper training and experience in obtaining vibration measurements and analyzing the results are essential to achieving a meaningful and useful vibration analysis. The operator of the vibration measurement and analysis equipment should know about the types of vibration measurements necessary to evaluate the condition of various machines and the variables that may affect measurements. The operator also should know how to compensate for such variables to ensure the accuracy and repeatability of results.

Once vibration measurements and analysis are complete, a basic question that maintenance personnel often need to address is: "What level of vibration is excessive?"

Generally, experience – acquired by monitoring machine vibration over time – is the best guide in determining what constitutes an excessive vibration level for a given machine component.

In the absence of experience, resources are available that provide guidance on acceptable vibration levels for several classes of common machines. Information used to compile such resources includes industry standards, published specifications, manufacturers' recommendations and field experience. Generally, the vibration levels recommended in such resources are economically achievable and represent values that will allow the machine to achieve a normal life in service.

How is Excessive Vibration Corrected? Vibration measurement and analysis provide a means to identify failing machine components. But how can a maintenance program prevent excessive vibration in the first place?

There are a variety of root causes that may create machine vibration. Among the potential root causes are:

- **Machine Component Design Defects:** Design defects relate to the improper sizing or proportioning of the part, or a fundamental structural flaw. Conducting a vibration analysis immediately after machine startup may help identify design defects.

- **Manufacturing Defects:** Defects in manufacturing may occur during the casting, machining, heat-treating or assembly of the machine component. These defects may cause the component to fail shortly after start-up or at a later point in time. As in the case of design defects, conducting a vibration analysis at machine startup may assist in identifying manufacturing defects.

- **Operational Stress:** Operational stress refers to the material build-up or erosion that may occur within a machine component as it operates. Such build-up or erosion may change the balance condition of the machine component, resulting in vibration. Thermal expansion is another operational stress that may occur and cause a change in component alignment that may lead to vibration.

- **Maintenance Actions:** Maintenance actions, or the lack thereof, may cause vibration and machine failure. Examples of improper maintenance actions may include excessive belt tensions, shaft and bearing misalignments, lack of or excessive lubrication, inappropriate installation (such as hammering a bearing), and improper tightening of fasteners.

- **Machine Aging:** Long-term machine operation produces aging effects that can lead to vibration. Over time, structural joints within a machine may wear and become out-of-tolerance. Shafts, gears, and other machine components may wear or bend and become a cause of vibration. An on-going vibration analysis program can assist in detecting these occurrences.

When Should Vibration Analysis Be Used?

There are a variety of potential applications for the use of vibration analysis to assist in determining the condition of machine components within grain elevators, feed mills and grain processing facilities.

Some of the machine conditions in which vibration analysis may be used include: 1) misalignment of couplings, bearings and gears; 2) unbalance of rotating components; 3) looseness; 4) deterioration of bearings; 5) gear wear; 6) aerodynamic/hydraulic problems in fans, blowers and pumps; 7) unbalance of magnetic forces in motors; and 8) resonance issues.

Generally, the types of machines that managers may wish to consider monitoring with vibration analysis include:

- Machines that require expensive, lengthy or difficult repairs if they break down.
- Machines that are critical to production or general facility operations.
- Machines that have experienced frequent breakdowns.
- Machines that are being evaluated for their reliability.

The following are examples of machines and machine components that may fit into the aforementioned categories:

- Fans and blowers.
- Reciprocating equipment.
- Pumps.
- Large motors.
- Large gearboxes.
- Air compressors.
- Critical processing equipment, such as a pellet mill or hammermill.

Conclusion

Managers of grain elevators, feed mills and grain processing facilities may wish to consider using vibration analysis as a component within their preventive maintenance program to monitor the operating condition of equipment so that necessary maintenance procedures may occur in a cost-effective and timely manner.

Coming Next:
Reliability Centered Maintenance – What's It All About?