COOLING TECHNOLOGY MANUAL

Chapter 10

MECHANICAL COMPONENTS FOR COOLING TOWERS

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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers.

Approved by the CTI Executive Board.

This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2016

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Mechanical Components for Cooling Towers

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Mechanical Components for Cooling Towers

10. 1 SCOPE

The mechanical equipment in a cooling tower is subjected to a harsh environment and usually a less than ideal inspection program. This chapter deals with the mechanical equipment for a cooling tower, associated equipment problems, and the different ways of access to the equipment for inspection and maintenance.

10.2 VIBRATION

One way rotating equipment can communicate its operating condition or health is by its mechanical motion or "vibration". By recording and analyzing this motion, a high percentage of problems can be accurately recognized, often allowing correction before catastrophic failure.

10.2.1 Glossary

10.2.1.1 Abbreviations

mil – 0.001 inch (25.4 um, um = 10 x - 6 meters, displacement)

cpm – Cycles per Minute (frequency)

G's – 32.2 ft. per second squared (9.81 meters per second squared)

Hz – Hertz (Cycles per Second, frequency)

mA – Miliamp

ips – inches per Second (in/sec) Vibration (amplitude)

Pk – Zero-to-Peak Vibration (amplitude)

Pk-Pk – Peak- to-Peak Vibration (amplitude)

RPM – Revolutions per Minute

RF – Resonant Frequency

BPF – Blade Pass Frequency

PWL- Sound Power Level

W – Weight of Rotor in Pounds

D – Vibration Displacement in Inches – Peak to Peak (Pk-Pk)

R – Radius at which the Trial Weight is added in Inches

RMS – Root Mean Squared (is that right? I'm not totally sure)

O – Original Vibration Data

O + T – Original Vibration plus Trial Weight Effect

T – Trial Weight Vibration Effect

TW – Trial Weight

10.2.1.2 Definitions

Accelerometer - A sensor made from a piezoelectric material which produces a charge output proportional to acceleration. When housed together with an electronic charge amplifier and charge-to-voltage converter, it is referred to as an "internally amplified" accelerometer.

Amplitude – The magnitude of periodic dynamic motion (vibration). Amplitude is detected (i.e. electronically measured) in terms of peak-to-peak, zero-to-peak, rms, or average.

Balancing – The process of adding or removing mass from a rotating object to minimize vibration.

Critical Machines – Machines required to maintain production. When they go down, that part of the process cannot operate.

Displacement – The change in distance, or position, of an object. It is usually a peak-to-peak measurement of vibration with units of mils or microns.

Dynamic Motion – Vibration of a rotor system.

Frequency – Repetition rate of a periodic vibration within a unit time. Normally expressed in units of cycles per minutes (CPM) or cycles per second (Hz or cps).

Gear Mesh Frequency – A potential vibration frequency on any machine employing gears. It is calculated by multiplying the number of gear teeth times the same gear shaft's RPM.

Hertz (Hz) – Unit of frequency in cycles per second. Divide shaft RPM by 60 for frequency in Hz.

Micron (µm) – Length or displacement equal to 10 x – 6 meters. One micron = 0.04 mil.

Mil – Length of displacement = .001 inch = 25.4 um

Monitor – An instrumentation term. For machinery, a "protection" monitor may accept inputs from a variety of sensors, including temperature, vibration, RPM, motor drive current and 4-20 mA output devices.

Peak-to-Peak – The difference between the maximum positive and maximum negative values of a vibration waveform.

Phase – A measurement of the timing relationship between two signals, or between a specific vibration signal and a once-per-shaft revolution event (phase angle).

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Radial – A direction of a machine which is perpendicular to the shaft centerline; in the XY plane; usually refers to direction of shaft or casing motion or measurement.

Radial (Lateral) Vibration – Shaft dynamic motion or casing vibration that is measured at 90 degree to the shaft centerline.

Unbalanced (Imbalance) – Unequal radial weight distribution on a rotor system; a shaft condition where the mass centerline (principal inertial axis) does not coincide with the geometric centerline.

Velocity – Time rate of change of displacement. Velocity is a widely used measurement for evaluating machine casing and other structural vibration response characteristics.

Velocity Sensor – A seismic sensor which converts velocity motion into a proportional electrical signal.

Zero-to-Peak Value (Peak, 0-Pk) – One half of the peak-peak value.

10.2.2 Instrumentation

Vibration instrumentation falls into two categories, Continuous on-line monitoring and periodic monitoring. Except for the high end critical equipment, most monitoring is of the overall vibration signal. Data collected with portable or walk-around instruments usually acquires both the overall signal value as well as the "filtered" signal, which is processed within the unit to determine the narrow band (spectrum) values. The following is a discussion of continuous on-line monitoring and periodic and/or portable data collection.

10.2.2.1 Continuous On-line monitoring

Continuous on-line monitoring has a tremendous advantage over periodic monitoring. One advantage is the ability for an automatic shut down when faced with a pending catastrophic failure. Legal ramifications regarding safety issues alone usually more then justify the cost to purchase, install and maintain a continuous monitor.

10.2.2.1.1 Mechanical Switch

The mechanical switch provides economical vibration protection for low to medium speed fans and motors. Most designs have an inertia sensitive mechanism that activates an internal switch with externally available contacts when the vibration set points are exceeded. The contacts can be used to activate an alarm or shut down the unit as the vibration reaches dangerous levels.

The unit can be mounted with effectivity in several locations such as the side of the gear box, side of the motor, the motor base plate, etc. Best results are usually achieved with the unit mounted on the side of the gear box. Because of the extreme environment in and around wet cooling towers, the selected unit must be weatherproof with the needed hazardous area rating.

10.2.2.1.2 Electronic Switch

The Electronic switch offers an excellent alterative to the mechanical switch, providing a more reliable and accurate device with its solid state detection circuit plus several added features. The 4-20 mA output, normally a standard feature, can accommodate remote meter readout as well as a signal for archiving the vibration levels on a trending device. A second feature, available on many of the electronic switches, is a buffered dynamic signal output available for connection to a vibration analyzer without shutting down the tower. Adjustable time delays in the alarm and shutdown circuits allow avoidance of nuisance alarms and/or shutdowns.

An additional benefit of most electronic switches is the ability to accommodate a remote vibration sensor. Incorporation of a hermetically sealed remote vibration sensor allows the placement of the electronic switch on the outside of the shroud (often at ground level) thus providing convenient access to the dynamic signal and greater safety to the Analyst.

10.2.2.1.3 Electronic Monitor with Trending

The optimum system, which often is justifiable primarily on larger cooling towers in critical service applications, is the electronic monitor with vibration trending. The ability to review a vibration trend of the rotating unit's mechanical motion for several days is of great value when problems arise.

Typically this type of system will have one or more sensors mounted on bearing flange(s) with the instrument enclosed in a stainless steel enclosure located at ground level outside the cell or in the control room. This level of instrument includes all the desired features of an on line monitor such as meter readout, independent alarm and shutdown relays, independent adjustment time delays, choice of 4-20 mA and/or digital outputs, and sensor OK circuit for each channel.

10.2.2.2 Periodic Monitoring and/or Portable Data Collection

There are numerous brands of data collection on the market capable of acquiring overall and spectrum (narrow band) vibration data. Unless you are setting up a program (or have one in place) that includes other machines, economics favor hiring a specialist with the experience and instrumentation needed to acquire and analyze the vibration data. If balancing the unit is necessary to reduce the vibration, the analyst should be able to do so using a portable instrument.

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10.2.2.2.1 Overall Level (Wide Band) Data Collection

This measurement closely resembles the vibration you might feel when standing next to a machine or hear when using a screwdriver with the tip resting on the machine case while holding the handle to your ear. The feel and sound is random in nature, sometimes with a predominate frequency detectable. It is usually the measurement seen when observing a meter readout of the vibration level. It may be displayed in acceleration (g's), velocity (ips) or displacement (mils). The simpler and/or older walk around units readout and sometime store overall levels only. The 4-20 mA sensor outputs are proportional to the overall vibration level.

10.2.2.2.2 Wide Band (Spectrum) Data Collection

For this measurement the data collector or portable vibration analyzer processes a sample of the signal acquired from the sensor. The process results in a display of the vibration levels across the sampled frequency range (vibration spectrum) allowing the user to determine how much of the vibration is occurring at operating speed, multiples of running speed, unrelated to running speed (usually resonance), and below running speed.

The vibration spectrum adds a new dimension for the user in terms of identifying root causes of vibration levels that are determined to be high. The data can be displayed in acceleration (g's), velocity (ips) or displacement (mils) vs. frequency.

Acquired data can be analyzed in the field as well as stored in the data collector for later transfer into a data base as part of a history for each point on each machine. The portable data collector most likely has an option for balancing. Phase data is derived either from a vibration strobe being triggered by the data collector or with the use of a tachometer input. With a tachometer, phase is measured by the instrument. Otherwise, phase is observed on the machine using the vibration strobe.

10.2.2.3 Vibration Sensor

The vibration sensor must operate well within the frequency range of the machinery being measured. For a fan running at 300 cpm (5 Hz) the low range should start below that frequency. For a motor running at 1200 RPM (20 Hz) there is a general rule of thumb that establishes 5 times that speed as a minimum for the upper range. In this case it would be 6000 cpm or 100 Hz.

A modern general purpose industrial accelerometer operates from 2 Hz to 8 kHz, so it is well suited for these measurements. The response requirements for accelerometers include both a tolerance for frequency response (flatness of the output curve) in the measurement range and a linearity standard in terms of the amplitude of the measurement. Modern accelerometers are very repeatable and reliable. Their output is typically 100 mV/g. The signal from the accelerometer is converted to G's, ips velocity, or mils displacement by the readout instrument.

A velocity sensor can also be used for field measurements. Its output is typically 100 mV/ips. The signal from the velocity sensor is converted to ips velocity or mils displacement by the readout instrument. Care should be taken to verify the operating frequency range of the velocity sensor as it is typically less than the accelerometer.

Mounting of the vibration sensors for periodic use is with a very strong magnetic mount or with the attachment of a stinger. The advantage of the stinger is that it can reach into tight spots but it must be held still for the duration of the measurement. If comparing readings the same mounting method should be used to minimize variance.

10.2.3 Vibration Data Collection Procedure

Most data for vibration analysis on a routine basis can be done outside the shroud on the motor, on the inboard motor bearing housing, however measurement at other locations (e.g. at the gear drive input and output bearing) can also provide good results. For units with motors internal to the cell (usually integral to the gearbox and main shaft), a vibration sensor should be mounted on an exposed bearing housing inside the cell, which requires shutting down the unit, entering the cell, mounting the sensor and signal cable, exiting the cell and restarting the fan.

Similarly fans with belt driven motor assemblies may have to be shut down in order to mount the vibration sensor to the assembly. For this type of assembly data should be taken at the inboard motor bearing housing as well as the fan shaft bearing assembly nearest the fan.

Data acquisition should be as follows:

1. Run motor until unit is warm and stable before taking readings. Readings may be taken as unit warms for added information, but final reading should be taken, if possible, at normal load.

2. Overall readings in velocity and displacement with filter out should be taken in the vertical, horizontal, and axial position on inboard and outboard motor bearings. At initial check each position should then be checked with "filter in" to establish vibration frequencies.

Note: After initial test, a comparison of "filter-out" overall readings may be used for trending. If a gradual increase is detected over a period of time, additional spectrum readings may be acquired for troubleshooting.

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3. If the filter-out vibration amplitude exceeds 2 mils displacement, refer to the charts for severity. It might be necessary to take filtered readings and record all distinct amplitudes and frequencies for reference. Note: 2 mils at 1200 cpm = 0.126 ips peak and 2 mils at 1800 cpm = 0.188 ips peak

4. If questions arise as to relation of vibration, a strobe light (for phase reference) may be used observing same position on shaft. It may be necessary to shut down and mark a spot using a felt tip pen. Alternately, a tachometer may be used to establish phase relationships among the various points.

5. Care should be taken to record all readings completely and accurately noting all amplitudes, frequencies, phases, and speed (if variable).

10.2.4 Diagnostic Procedure

Refer to Diagnostic Chart for details.

Diagnostic Chart

Amplitude	**Frequency Relative to Machine RPM**	**Cause**
Radial-steady	1 x RPM	Unbalance
High radial & High axial	1 x RPM	Bad sleeve bearing
High radial in bearing	RPM x # balls	Bad anti-friction bearing
High on bearing and/or on shroud area	RPM x # of fan blades	a. Blade pitch problem b. Blades out of track c. Fan natural frequency same as blade pass frequency d. Fan stack natural frequency (or some harmonic of) same as blade pass frequency
High axial	RPM x 2	Misalignment – locked
	RPM x # of gear teeth	Bad gear
Erratic	Belt RPM	Bad or loose belt
Steady at speed	1 x RPM	Electrical unbalance (Note: Disappears when power is off)

Note: In order to do proper diagnostics, the mechanical specifications are needed (i.e., # of teeth on gears, type of bearings, temperature, etc.).

10.2.5 Cooling Tower Vibration Levels

1. Ranges of typical cooling tower vibration levels are provided in Chart 1a, 1b, 1c and 1d. These vibration levels are based on measurements on operating towers and input from manufacturers and tower owners. Units are in mils p-p from seismic sensors. Today most users record vibration data in velocity units as with other plant machinery. Since the charts are in displacement units, take data in both. Note that filtered data can be converted from ips velocity to mils displacement and vice versa. This only applies to filtered data (vibration spectrum data). Also, levels on the charts can be converted to velocity units using a standard formula; Vpeak=52.3xDxFx10-6 (see charts).

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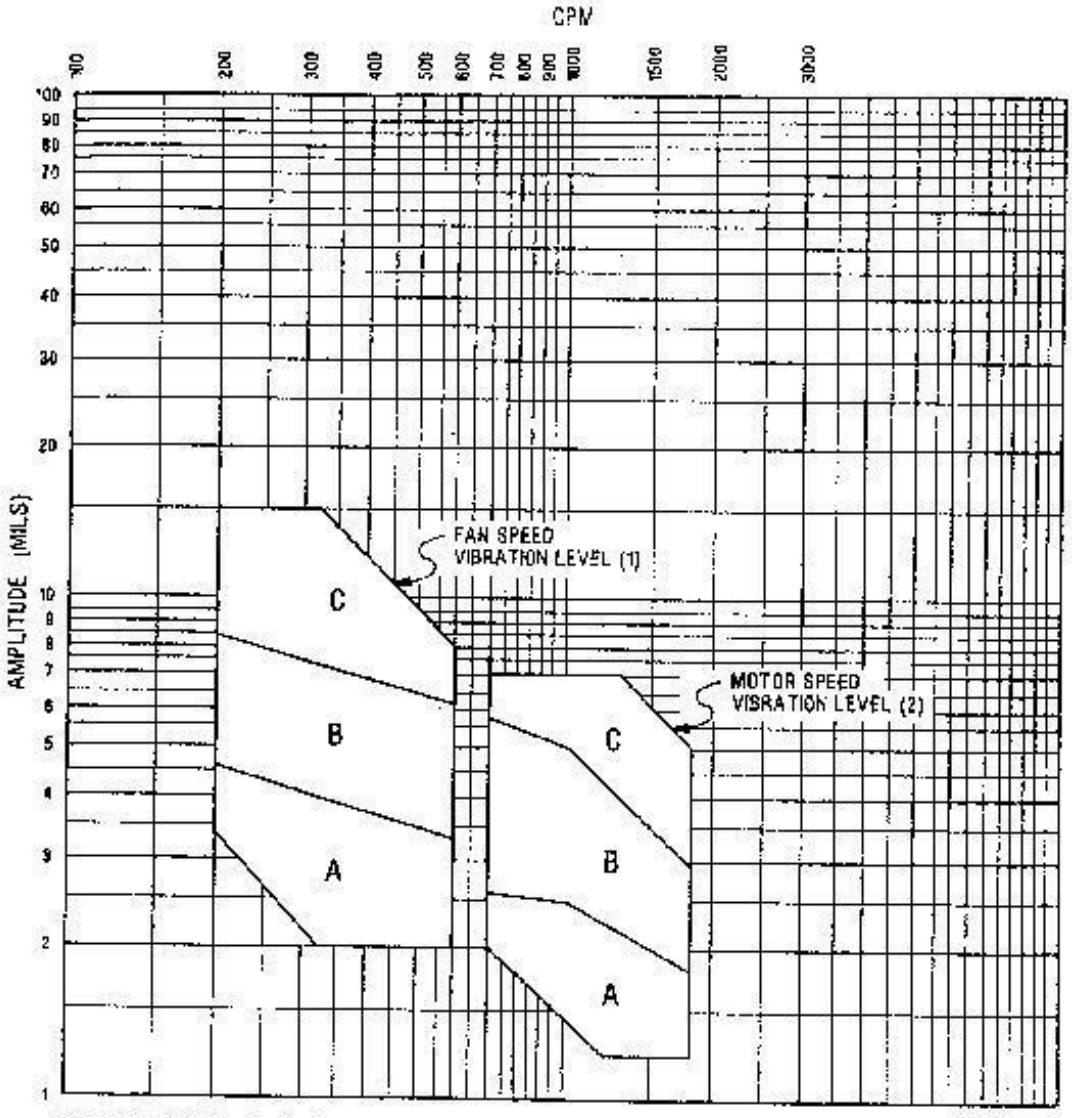
Typical Operating Vibration for Steel Factory Assembled Cooling Towers



A–NO FAULTS;TYPICAL OF NEW EQUIPMENT B–ACCEPTABLE;CORRECTION NOT REQUIRED C–MARGINAL;CONSIDER IMPROVEMENT

(1) HORIZONTAL AT LOW SPEED SHAFT BEARING
(2) HORIZONTAL AND AXIAL AT MOTOR INBOARD BEARING.

$V_{peak} = 52.3kDxFx10^{-6}$
V=VELOCITY IN INCHES PER SECOND
D=DISPLACEMENT IN MILS
F=CYCLES PER MINUTE

Chart 1a

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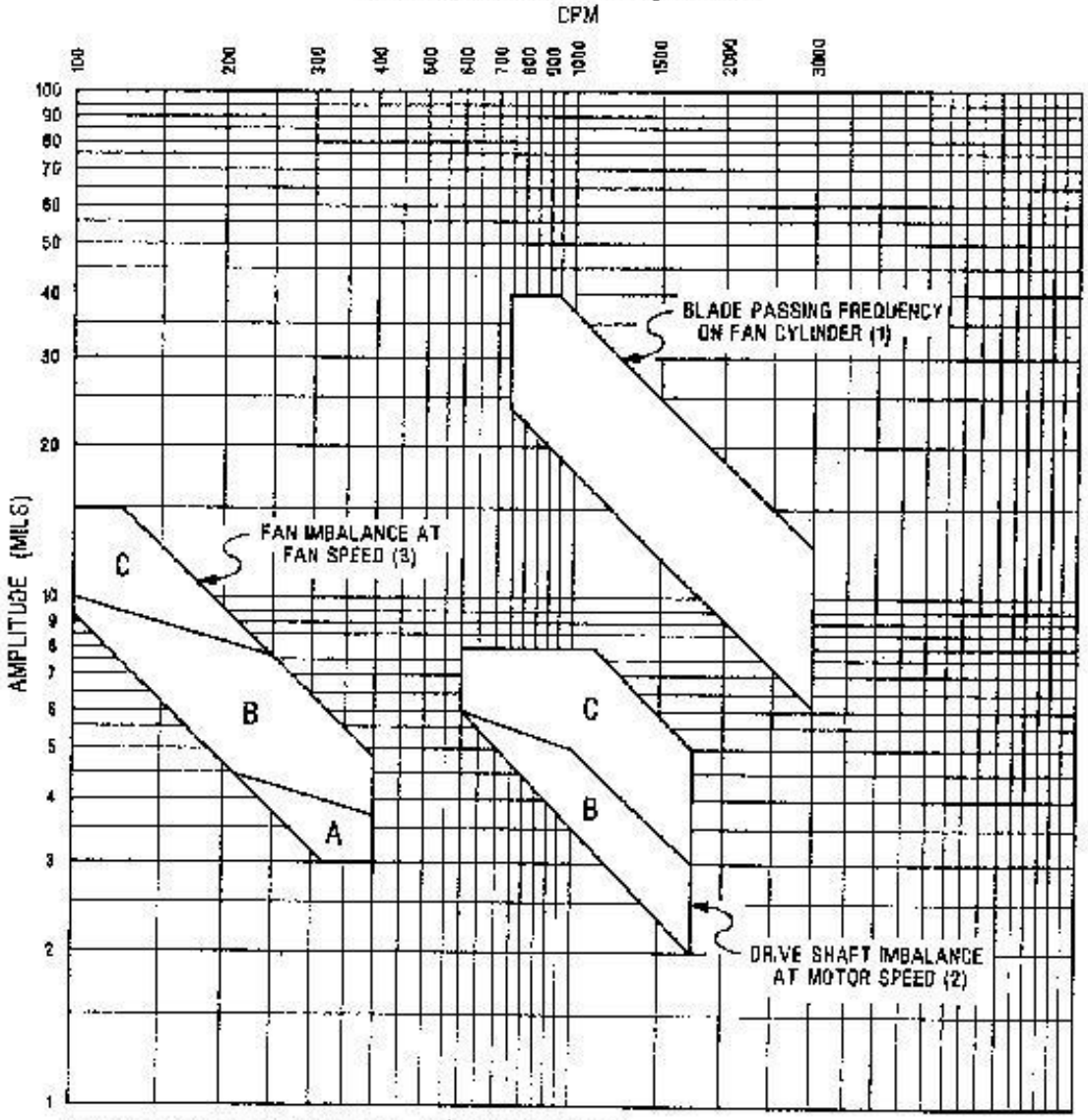
Typical Operating Vibration for Wood Framed Field Erected Cooling Towers with Fiberglass Fan Cylinders



(1) HORIZONTAL AT FAN ROTATIONAL PLANE
(2) HORIZONTAL AND AXIAL AT MOTOR INBOARD BEARING.
(3) HORIZONTAL AT LOW SPEED SHAFT BEARING

$V_{peak}=52.3xDxFx10^{-6}$
V=VELOCITY IN INCHES PER SECOND
D=DISPLACEMENT IN MILS
F=CYCLES PER MINUTE

Chart 1b

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