Vibration Of Cooling Tower Fans

Barry T. Cease
Cease Industrial Consulting
Vibration Institute 2015
ceasevibration@icloud.com
(843) 200-9705

WHAT IS A COOLING TOWER AND WHAT DOES IT DO?

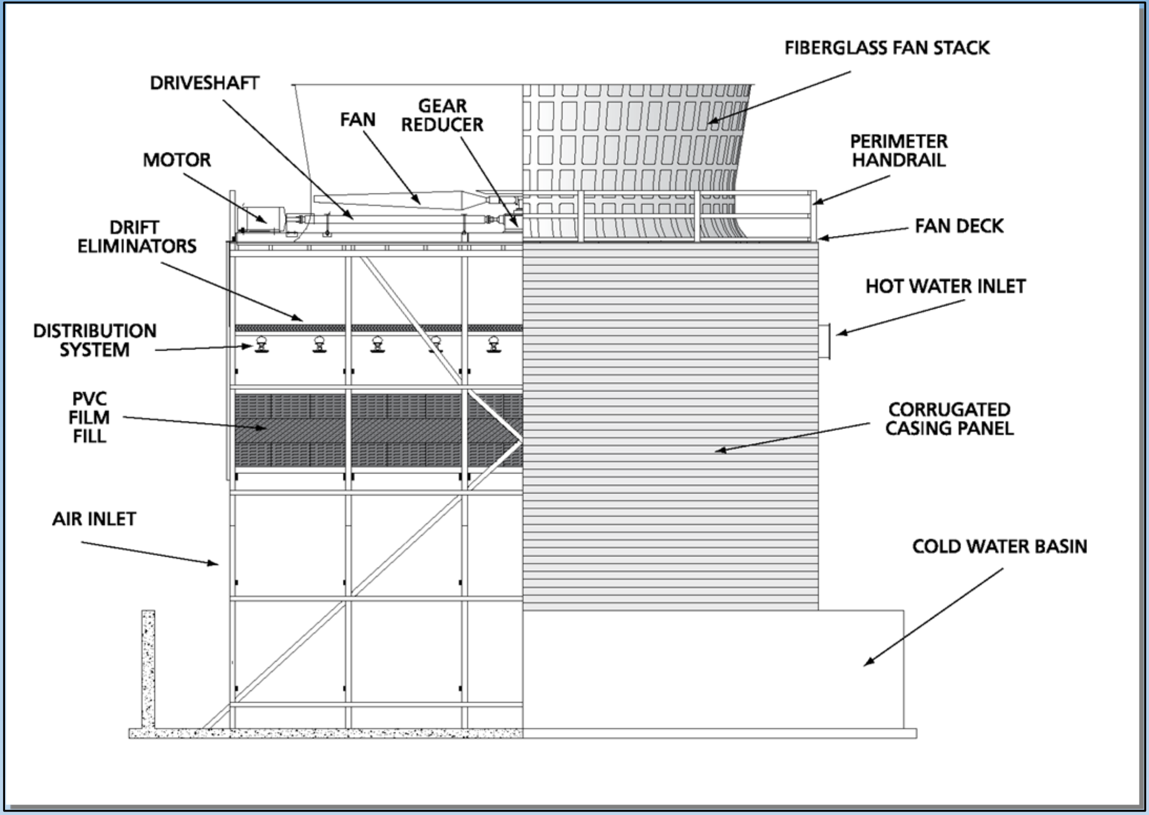
- All cooling towers are used for **heat rejection** within an industrial plant, hospital, or other large building, facility.
- Heat is rejected from a working fluid (water) into the atmosphere (air) by means of **evaporation** (wet) & convection (dry).
- Two primary types of cooling towers: natural draft & induced draft.
- Natural draft – No fans needed. Air flow occurs due to design of tower and temperature/air density differences.
- Induced/forced draft – Fan needed to cause air flow within tower.
- This presentation will focus on vibration analysis of induced draft wet cooling towers.

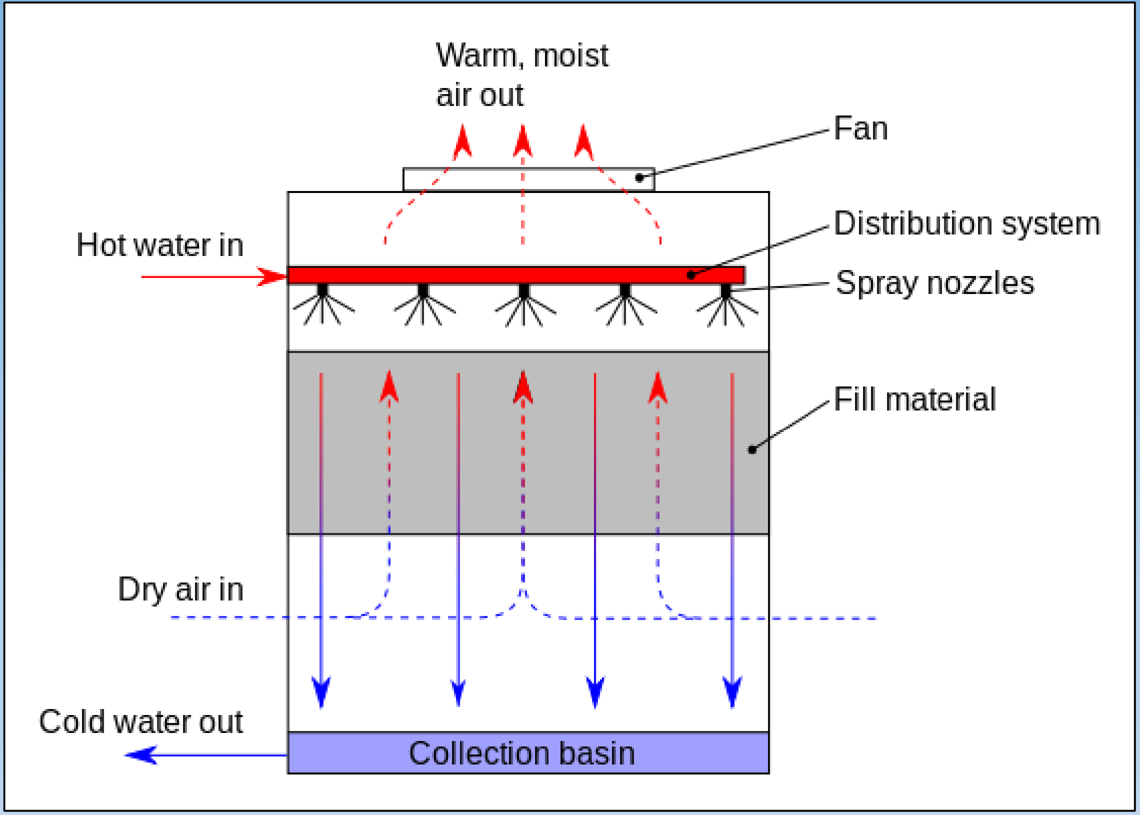
TYPES OF COOLING TOWERS: NATURAL DRAFT

TYPES OF COOLING TOWERS – INDUCED DRAFT

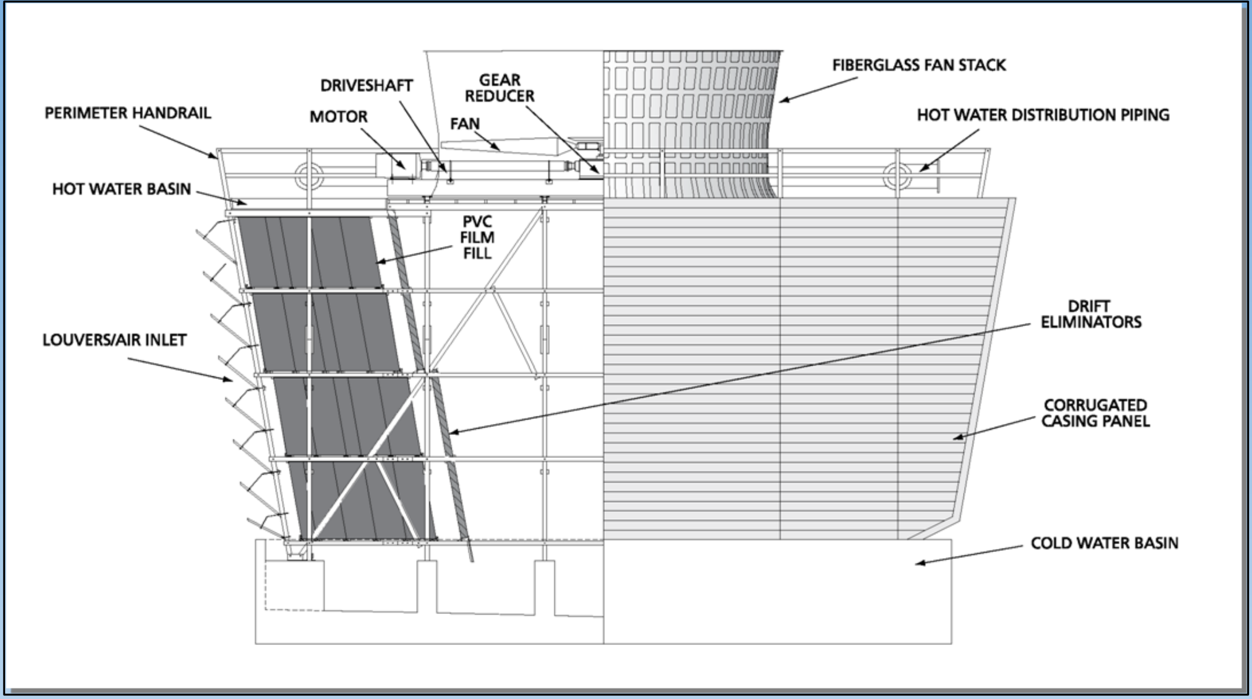
<u>OPERATION OF COOLING TOWER - COUNTERFLOW DESIGN</u>

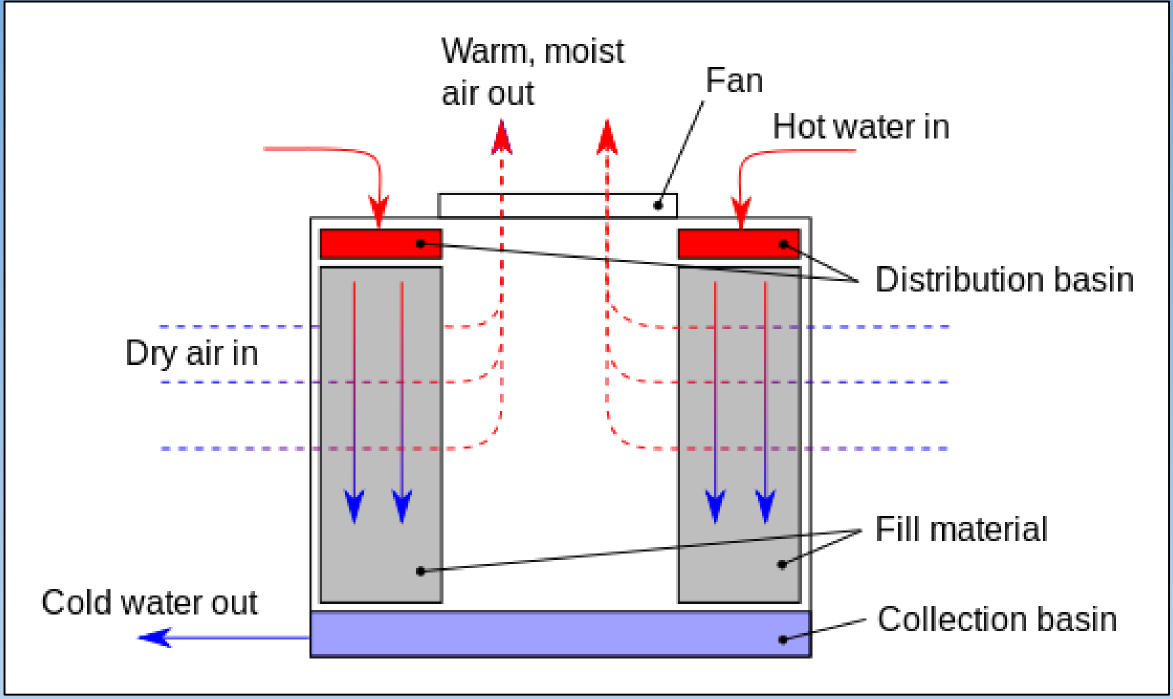
- <u>Counterflow Design</u>: Air & water are moving in opposite directions.
- *Dry cool air* enters the bottom of tower, moves thru fill where it accepts heat (energy) from the hot water and moves out the top of the stack as warm, moist air.
- *Hot water* is sprayed into the tower thru nozzles near the top, moves down thru the fill where it transfers some of its heat (energy) to the cool, dry air and finally falls into the basin below where it is pumped back into the process.



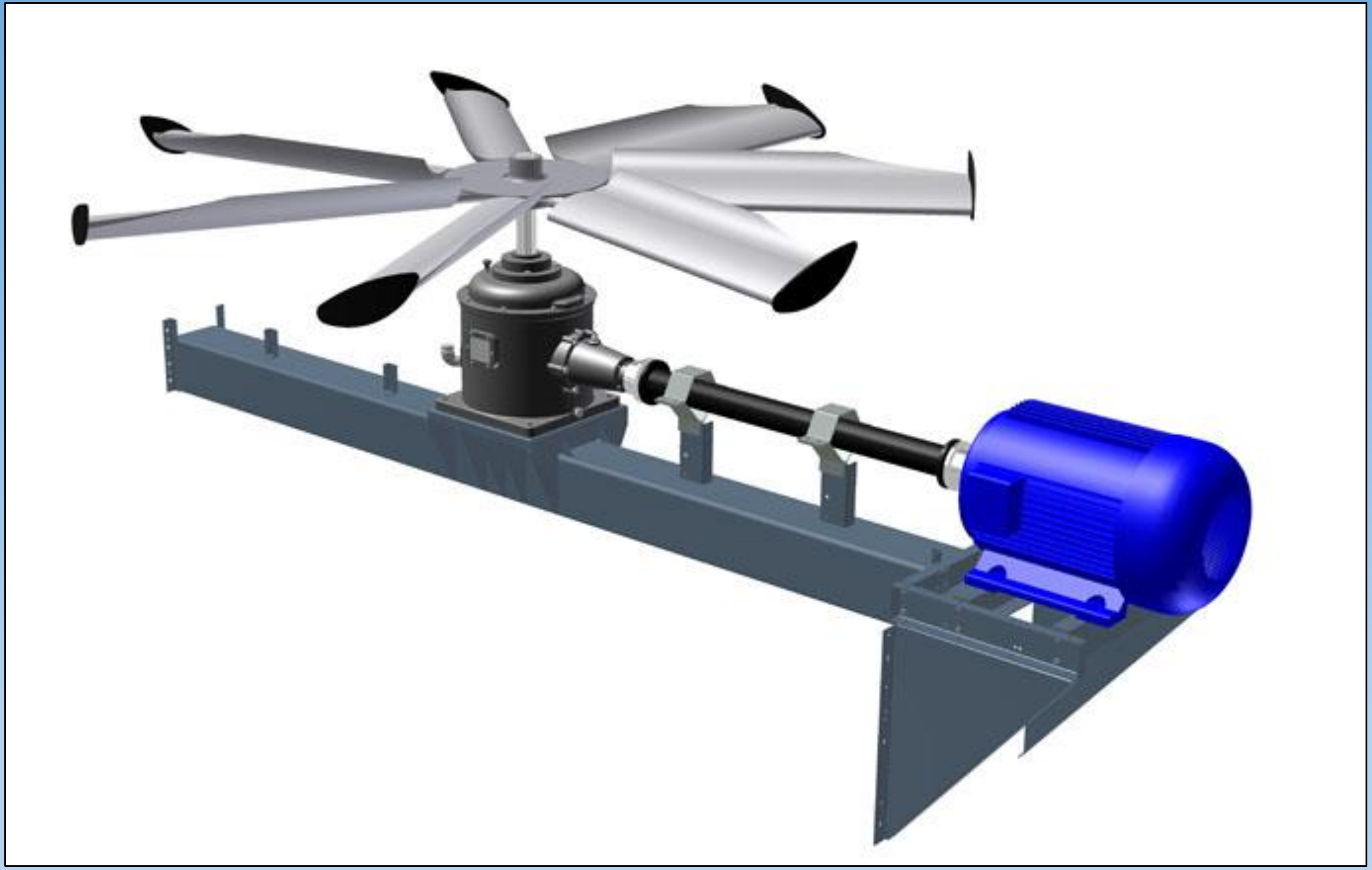


OPERATION OF COOLING TOWER – CROSSFLOW DESIGN





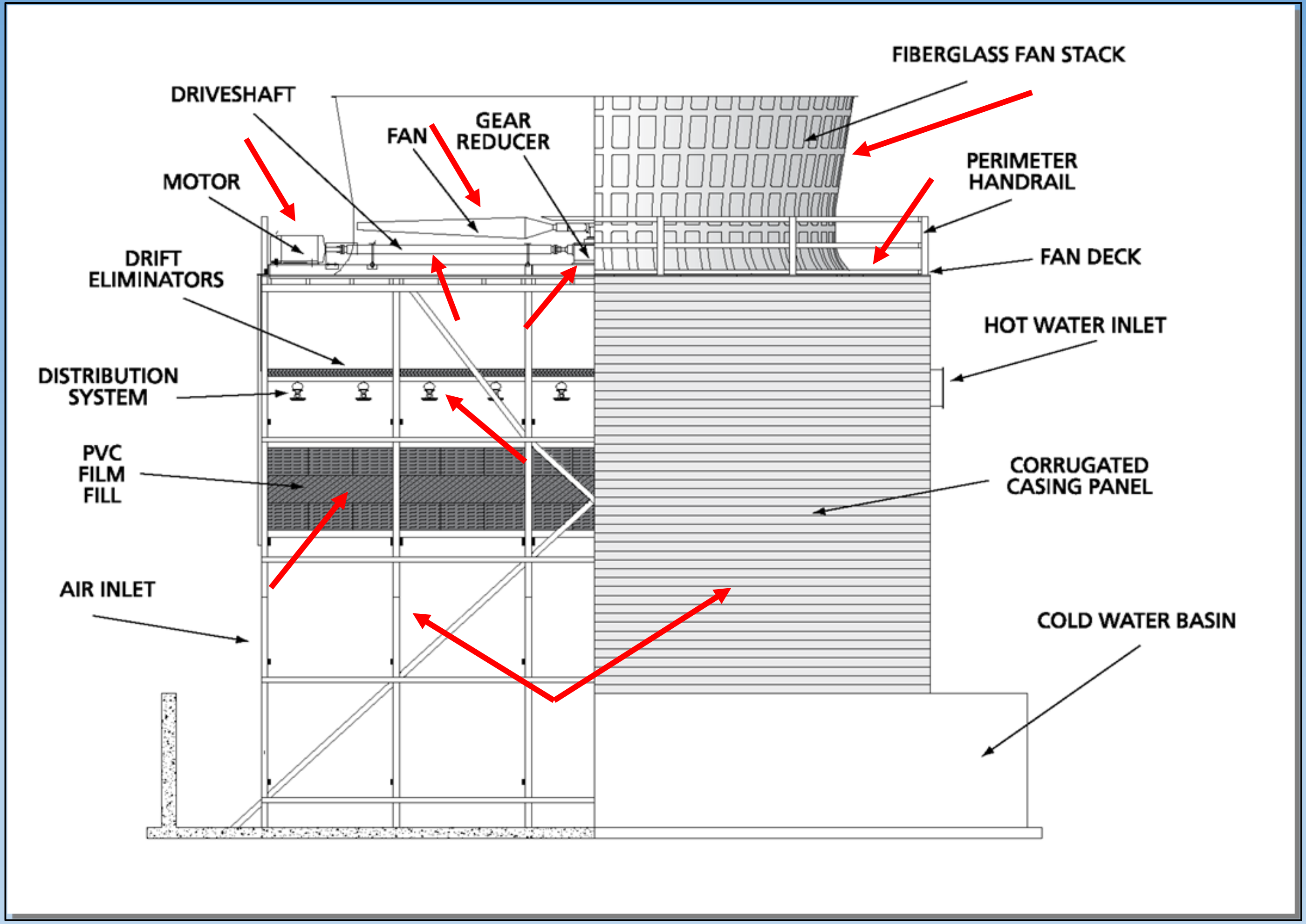
COOLING TOWER FAN DRIVE DESIGN - GEARBOX



COOLING TOWER FAN DRIVE DESIGN - BELTS

PRIMARY MECHANICAL COMPONENTS OF COOLING TOWERS

1) Tower structure & panels
2) Decking
3) Fan shroud/stack
4) Motor
5) Drive (shaft or sheaves/belts)
6) Gearbox
7) Fan wheel & blades
8) Fill material
9) Water piping & distribution



COMMON COOLING TOWER PROBLEMS BY MECHANICAL COMPONENT

COMMON CT PROBLEMS BY COMPONENT

1) Tower Structure
   a) Loose, damaged or missing beams
   b) Loose or missing bolts
   c) Loose, damaged or missing panels, partitions
2) Decking – Loose or damaged decking
3) Fan Shroud/Stack/Cylinder
   a) Loose or damaged shroud.
   b) Loose or missing bolts (connecting bolts & base bolts)
   c) Rubbing between fan & shroud (VERY BAD)
4) Motor – Typical, common mechanical & electrical problems as well as possible *interaction (beating)* between motor speed & fan blade-pass.

COMMON CT PROBLEMS BY COMPONENT

5) Fan drive problems (shaft or sheaves)
    a) Shaft misalignment, coupling problems, shaft unbalance, shaft resonance, etc.
    b) Sheave alignment, sheave run-out (eccentricity), belt wear, belt resonance, etc.
6) Gearbox
    a) Bearing or gear wear/faults.
    b) Lubrication problems including loss of oil due to fill line failure.
7) Fan wheel, hub & blades
    a) Fan unbalance
    b) Blade pitch problems (improper pitch or inconsistent pitch)
    c) Blade elevation differences (drooping blade)
    d) Blade cracking (usually at or near hub fit – point of maximum stress)
    e) Blade weep holes clogged or open?
    f) Balance weights in place?

COMMON CT PROBLEMS BY COMPONENT

8) Fill Material
   a) Purpose of fill material is to increase the time the hot water is exposed to the air thus increasing the transfer of heat from the water to the air.
   b) The presence of fill material in good working order directly improves the cooling tower's efficiency.
   c) Missing, damaged or clogged fill material will degrade the cooling tower's efficiency and potentially disrupt the air flow.
   d) Buildup of algae and other organic matter (biofilm) will both hurt the cooling tower's efficiency, potentially increase vibration levels due to disrupted air flow (blade-pass), and increase safety concerns (lung infections due to excessive bacteria in air flow.

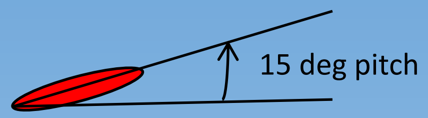
COMMON CT PROBLEMS BY COMPONENT

9) Water piping & drainage
   a) Water leaks from piping or reservoirs
   b) Buildup causing improper water flow (reducing efficiency)
   c) Distribution nozzles clogged or not working properly

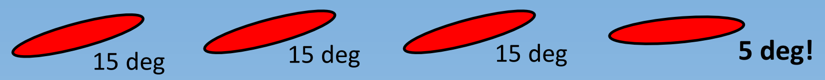
SUGGESTED COOLING TOWER FAN INSPECTIONS

SUGGESTED CT FAN INSPECTIONS

1) Blade Checks
   a) Pitch angle actual versus OEM recommendations?



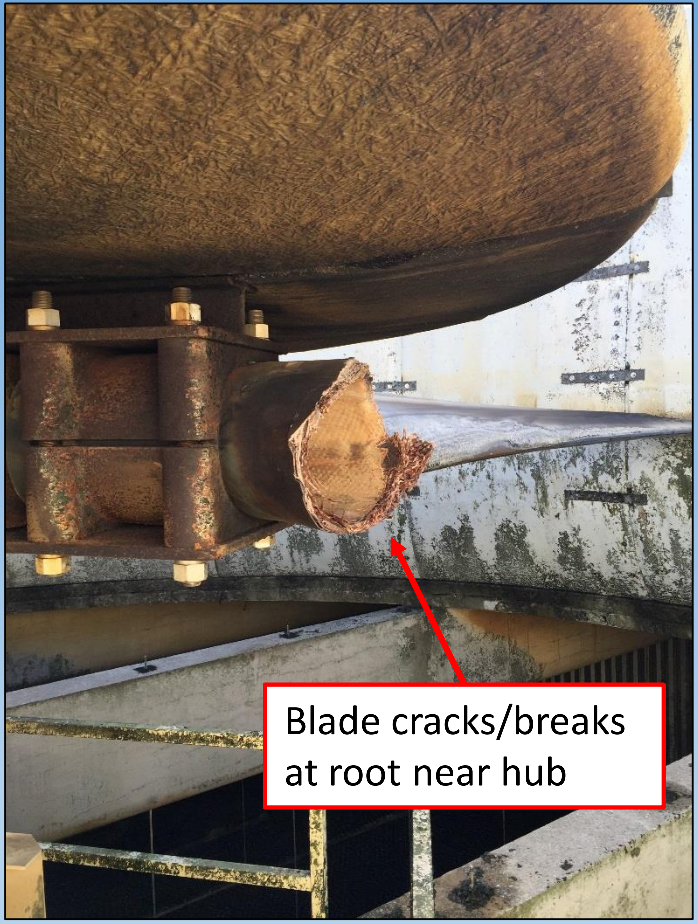
   b) Pitch angles consistent between blades?



   c) Visual inspection of blades (cracked at roots or rubbing at shroud).
   d) Blade weep hole checks (are they open?).
   e) Blade bolts tight at hub?
   f) Balance weights in place or missing.
   g) Vibration impact testing on blades (why not? You're already in the fan).

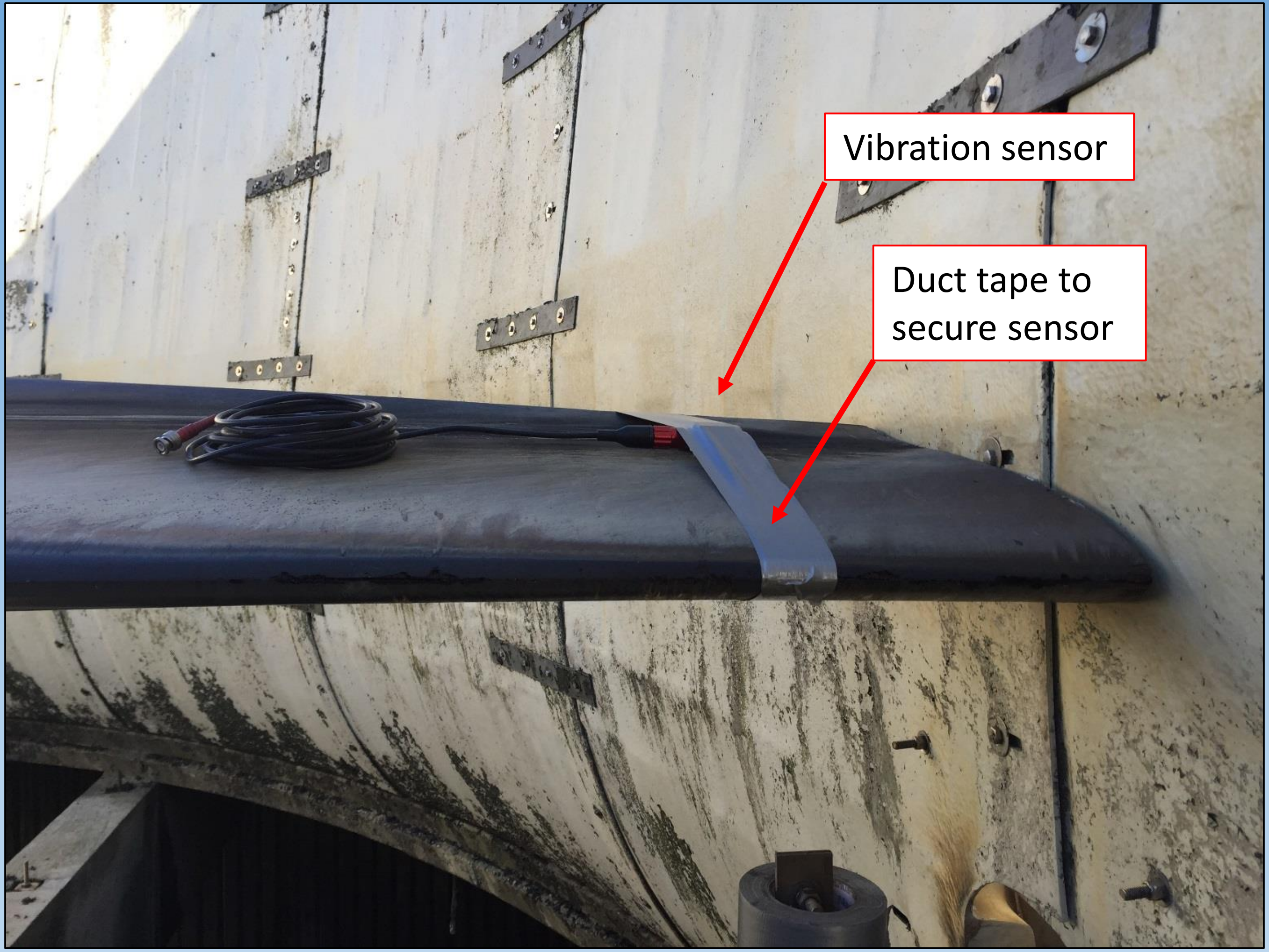
2) Shroud Checks
   a) Signs of rubbing inside shroud?
   b) All shroud bolts tight? Check bolts holding shroud together and those that secure it to the decking. Observe the shroud during operation.

CT FAN BLADE FAILURE:
DON'T LET THIS HAPPEN TO YOU



- This CT fan blade failure was thought to be caused by contact between the shroud & blade.
- If true, looseness and excessive vibration of the shroud could have played a role in this failure.

PHOTO – BLADE IMPACT TESTING SETUP

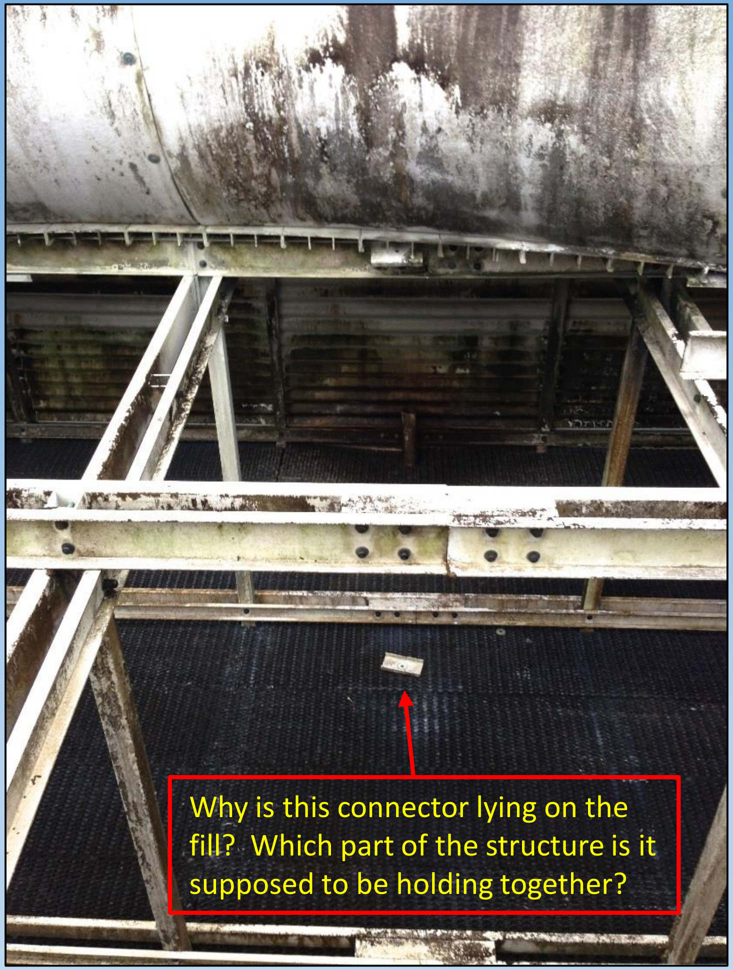


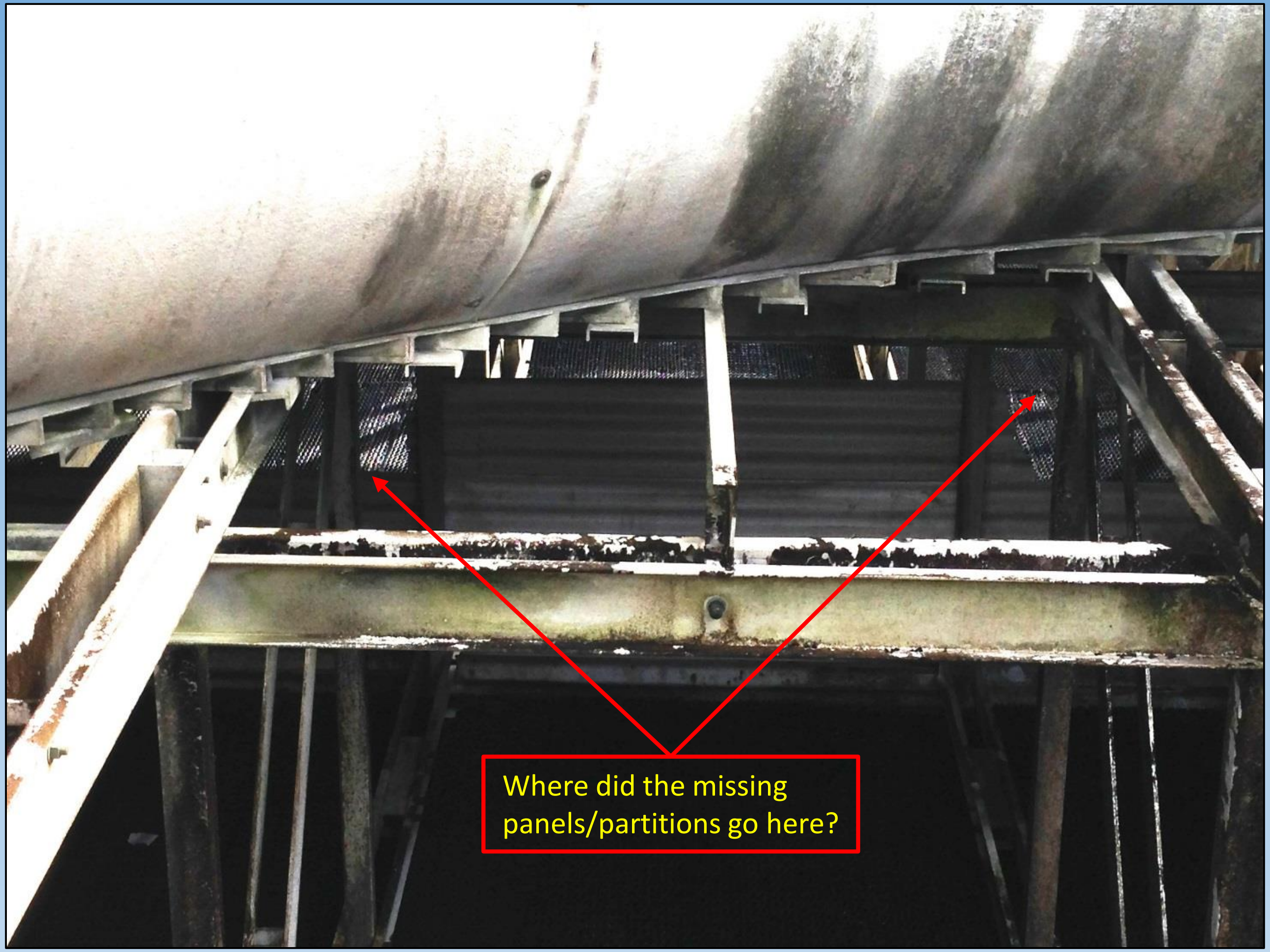
- The photo at left shows the simple setup used to accurately measure a cooling tower fan blade's 1st bending mode (natural frequency).
- A vibration sensor is attached near the blade end using duct tape and the blade is "plucked" by hand for the impact.
- The vibration analyzer is setup to collect a time waveform in velocity or better yet displacement (low frequency) using a level trigger with 10% pre-trigger setting (this way you can see before, during and after the "impact").
- To measure higher bending modes of the blades (2nd, 3rd, etc), the sensor will need to be repositioned at the quarter points or other locations along the blade.

RECOMMENDED CT FAN INSPECTIONS

3) Structure & Fill Material Checks
   a) Excessive buildup in fan?
   b) Is plant using biocide or a similar cleaning agent regularly to control bacteria (safety)?
   c) Uneven buildup in fill material. One side has more buildup than another?
   d) Damaged or missing fill material?
   e) Loose or missing bolts at structure & beams?
   f) Missing or broken beams or supports?
   g) Missing partitions or sheet metal on sides of fan?

EXAMPLES OF STRUCTURE DAMAGE & MISSING PANELS/PARTITIONS





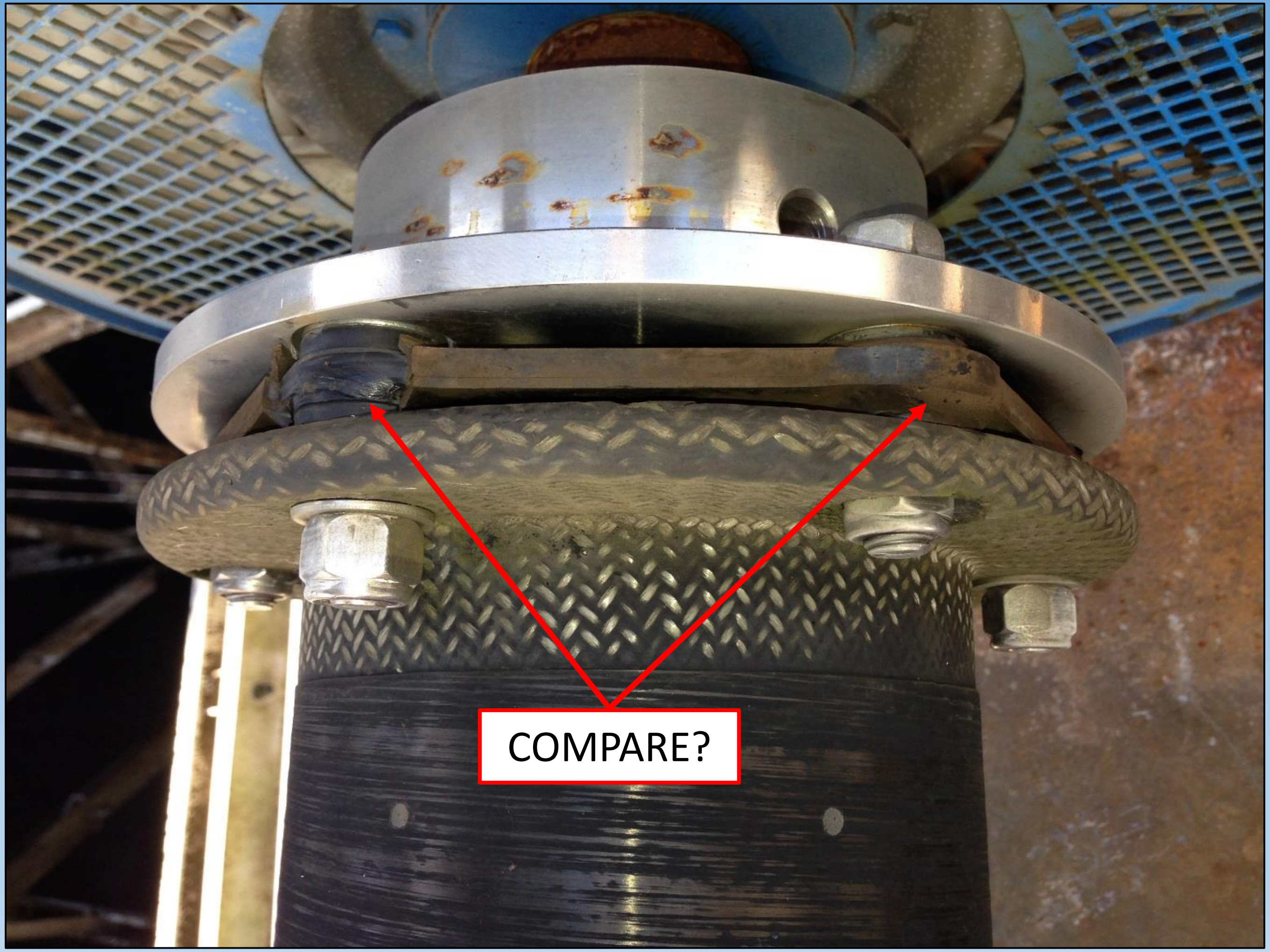
RECOMMENDED CT FAN INSPECTIONS

4) Gearbox Checks
   a) Is the oil level correct? Any oil leaks present?
   b) Perform a simple blade lift check with a dial indicator mounted on the fan output shaft. This check can identify excessive clearance or wear at the gearbox output bearing. Compare findings to OEM recommendations & versus similar fans (if possible).
   c) Oil fill line in good condition? Any cracking or leaking seen? *Seriously consider using SS materials and a SS flex line to connect this oil fill line to the gearbox.* Failure or leaking at this line or its connections can cause catastrophic failure of the gearbox (complete loss of lubrication). Due to the real risk of future catastrophic loss of oil and thus gearbox failure, some plants have opted to remove this oil fill line entirely and just check the oil level using the dipstick at the gearbox on a periodic basis (takes very little time during an outage and also presents an opportunity to collect an oil sample for analysis).
   d) Rotate input shaft by hand feeling for any resistance or catches during rotation. Excessive backlash present?
   e) Vibration sensor(s) present on gearbox?
   f) Document or take photo of gearbox nameplate while on-site.

RECOMMENDED CT FAN INSPECTIONS

5) General Drive Checks
   a) Coupling inspection. Worn or cracked components? Loose or missing bolts?
   b) Does the drive-shaft rotate easily by hand?
   c) Condition of drive-shaft itself. Is the shaft bowed, distorted or damaged in anyway? Observe shaft during operation (if possible) or use dial indicator at or near center to check for run-out.
   d) Was the drive-shaft balanced? Were the balance weights welded to the shaft itself or were additional washers or other weights used at coupling bolt locations to accomplish the balance? Were these weights put back in their exact locations after a coupling or shaft change?
   e) Shaft alignment good?
   f) Belt sheaves aligned?
   g) Belt tension set properly? Observe belts during operation. Are they worn or loose? Prefer use of matched sets.
   h) Excessive run-out of belt sheaves? Use a dial indicator to check for this.
   i) Perform a simple impact test on the drive-shaft. Perform this test at the shaft center and at a quarter points to find both the 1^{st} & 2^{nd} bending modes.

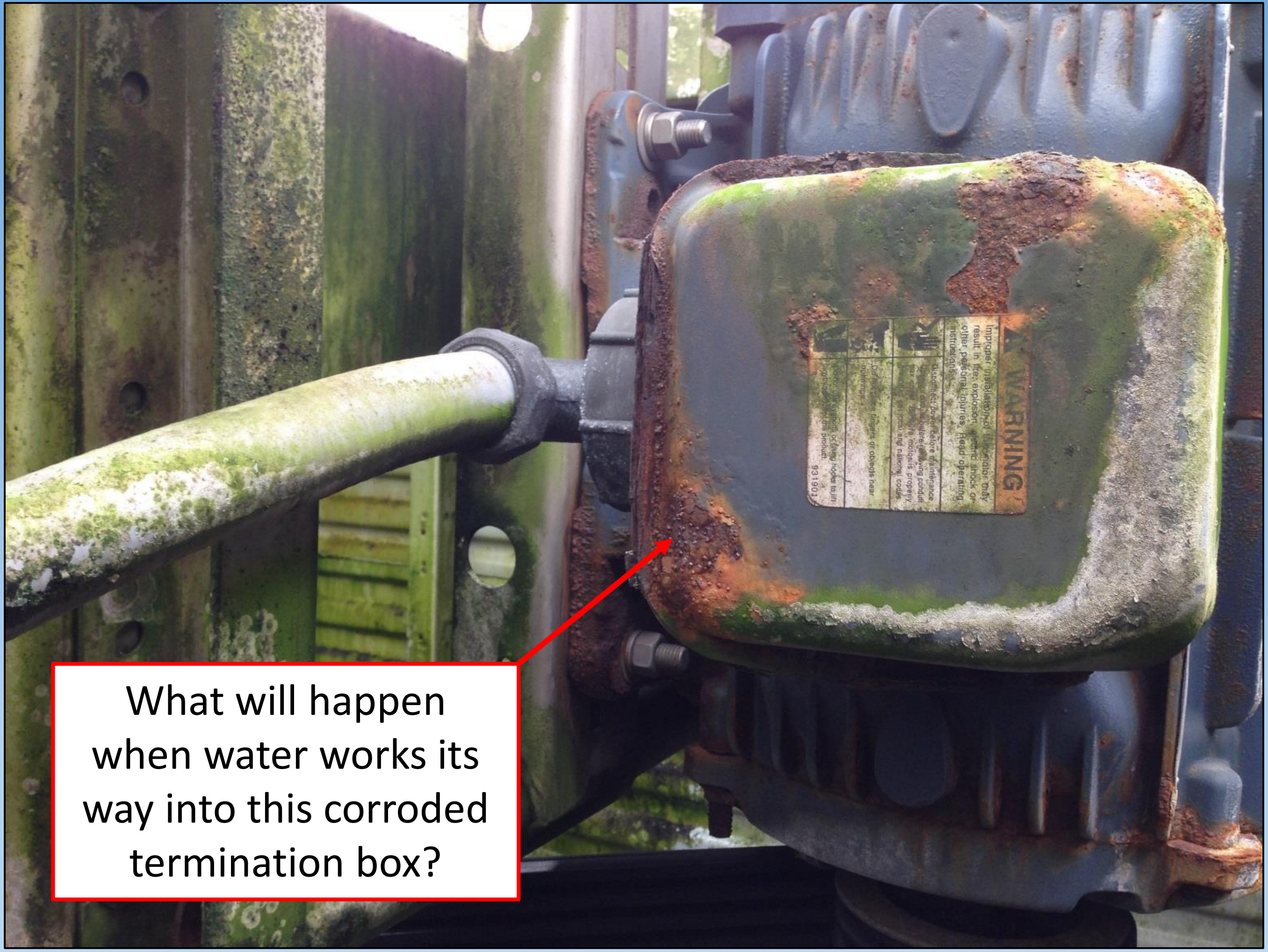
WHAT IS WRONG WITH THIS COUPLING?



RECOMMENDED CT FAN INSPECTIONS

6) Motor Checks
   a) All bolts tight?
   b) Motor base in good condition?
   c) If motor operates inside shroud, how is the motor and its components standing up to corrosion? Motor materials should be selected accordingly.
   d) Shaft alignment & soft foot checks?
   e) Does motor shaft rotate easily by hand?
   f) Any electrical checks? Condition of motor termination box? How is this termination box standing up to corrosion? Is the seal on the box still good?

CORRODED MOTOR & WIRING TERMINATION BOX



SUGGESTED PDM & PM'S ON COOLING TOWER FANS

RECOMMENDED PDM & PM INSPECTIONS ON CT FANS

1) Install vibration sensor(s) on gearbox and/or fan bearings. At least one sensor on the gearbox is recommended (more on a 2-stage gearbox). Follow OEM recommendations on sensor locations (where available), but in general favor flat surfaces at or near the input shaft. Attach sensors via stud mounting (if possible).
2) Monitor vibration periodically (quarterly recommended).
3) Perform analysis of the gearbox oil annually. Follow OEM recommendations on oil changes.
4) Perform visual inspections of the fan during operation at least quarterly.
5) Use biocide or similar anti-bacterial agent to keep tower clean & safe.

RECOMMENDED VIBRATION LEVELS ON COOLING TOWER FANS

RECOMMENDED VIBRATION LEVELS ON CT FANS

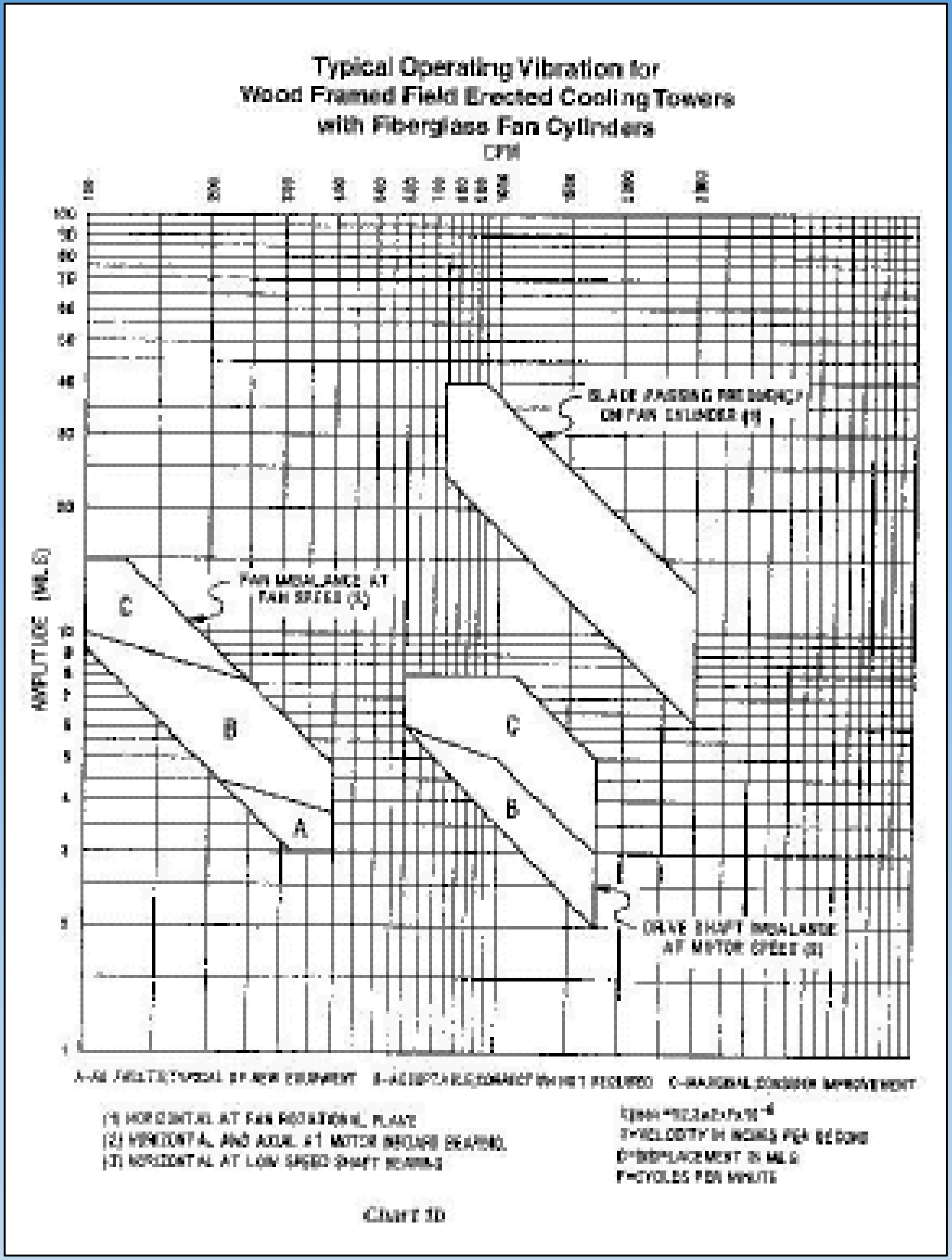
- Nearly all cooling tower fans operate within structures that are quite flexible (wood, fiberglass or metal structures). As a result, we expect our normal vibration levels to be higher than those seen from a similar machine operating on a rigid base.
- Two vibration standards for cooling tower fans are presented as follows:
  1) Cooling Technology Institute (CTI) Vibration Standards.
  2) Technical Associates (TA) Machine Specific Standards.
- The CTI Vibration Standards are presented in units of displacement (mills-pk-pk) and are dependent on both construction type (steel, fiberglass, wood, or concrete) and frequency. No overall vibration standards are given by CTI.
- The TA vibration standards concern overall vibration levels and are dependent only on the drive type (close coupled direct drive, close coupled belt drive, or long hollow drive shaft). The TA standards are presented in units of velocity (ips-pk).
- The TA "proven method" can be used to derive vibration tolerances at specific frequencies similar to those given by CTI for cooling towers.

RECOMMENDED VIBRATION LEVELS ON CT FANS COOLING TECHNOLOGY INSTITUTE (CTI)

- The Cooling Technology Institute (CTI) offers vibration standards for use on cooling tower fans.
- Copies of these vibration standards can be obtained by contacting the Cooling Technology Institute at 281-583-4087 or on the web at www.cti.org
- These CTI vibration standards are given only for the three primary vibration frequencies present at cooling towers: *fan speed, motor speed & blade-pass frequency*. No overall vibration level standards are offered by CTI.
- The vibration levels at both motor & fan speed are to be measured at the motor while the vibration levels at the blade-pass frequency is to be measured at the fan shroud or stack.
- These CTI vibration standards are given for each major type of tower construction: *concrete, metal, wood & fiberglass*.
- All CTI standards are expressed in units of displacement (mills-pk-pk).

EXAMPLE - CTI VIBRATION STANDARD (Wood Towers with Fiberglass Shrouds)

- Recommended levels are frequency dependent and are given for the following conditions:
  A. Region “A” – Acceptance, New Equipment
  B. Region “B” – Acceptable, In-Service Equipment
  C. Region “C” – Unacceptable, In-Service Equipment
- Example - For a motor operating at 1,800 rpm driving a fan operating at 300 rpm with a blade-pass frequency of 1,500 cpm (5-blades) we arrive at the following acceptable “B” levels:
  1) Motor 1X RPM – Up to 3 Mills or 0.28 ips-pk
  2) Fan 1X RPM – Up to 7 Mills or 0.11 ips-pk
  3) Blade-pass – Up to 25 Mills or 1.96 ips-pk (measured at fan cylinder/shroud)



EXAMPLE – TECHNICAL ASSOCIATES (TA) VIBRATION STANDARDS

MACHINE TYPE	NEW - ACCEPTANCE	GOOD	FAIR	ALARM 1 – WARNING	ALARM 2 - FAULT
Long Hollow Drive Shaft	0.20	0 – 0.38	0.38 – 0.60	0.60	0.90
Close Coupled Belt Drive	0.14	0 – 0.28	0.28 – 0.43	0.43	0.65
Close Coupled Direct Drive	0.10	0 – 0.20	0.20 – 0.30	0.30	0.45

- The Technical Associates vibration standards for cooling tower fans are given in terms of overall vibration levels.
- Units are in velocity (ips-pk).
- These standards do not account for different construction types (concrete, steel, wood, etc) but do account for different drive types.
- The TA Proven Method can be used to determine recommended levels at motor speed, fan speed & blade-pass frequency.

TABLE II
TECHNICAL ASSOCIATES OF CHARLOTTE, P.C.
CRITERIA FOR OVERALL CONDITION RATING (PEAK OVERALL VELOCITY, IN/SEC)*

1. Assuming Machine Speed = 600 to 60,000 RPM.
2. Assuming Measurements by Accelerometer or Velocity Pickup securely mounted as Close as Possible to Bearing Housing.
3. Assuming Machine Is Not Mounted on Vibration Isolators (for Isolated Machinery - Set Alarm 30% to 50% Higher).
4. Set Motor Alarms the Same as that for the Particular Machine Type unless Otherwise Noted.
5. Consider Setting Alarms on Individual External Gearbox Position about 25% Higher than that for a particular Machine Type.

MACHINE TYPE	GOOD	FAIR	(WARNING) ALARM 1	(FAULT) ALARM 2
COOLING TOWER DRIVES				
Long, Hollow Drive Shaft	0 - .375	.375 - .600	.600	.900
Close Coupled Belt Drive	0 - .275	.275 - .425	.425	.650
Close Coupled Direct Drive	0 - .200	.200 - .300	.300	.450
COMPRESSORS				
Reciprocating	0 - .325	.325 - .500	.500	.750
Rotary Screw	0 - .300	.300 - .450	.450	.650
Centrifugal With or W/O External Gearbox	0 - .200	.200 - .300	.300	.450
Centrifugal - Integral Gear (Axial Meas.)	0 - .200	.200 - .300	.300	.450
Centrifugal - Integral Gear (Radial Meas.)	0 - .150	.150 - .250	.250	.375
BLOWERS (FANS)				
Lobe-Type Rotary	0 - .300	.300 - .450	.450	.675
Belt-Driven Blowers	0 - .275	.275 - .425	.425	.650
General Direct Drive Fans (with Coupling)	0 - .250	.250 - .375	.375	.550
Primary Air Fans	0 - .250	.250 - .375	.375	.550
Vacuum Blowers	0 - .200	.200 - .300	.300	.450
Large Forced Draft Fans	0 - .200	.200 - .300	.300	.450
Large Induced Draft Fans	0 - .175	.175 - .275	.275	.400
Shaft-Mounted Integral Fan (Extended Motor Shaft)	0 - .175	.175 - .275	.275	.400
Vane-Axial Fans	0 - .150	.150 - .250	.250	.375
MOTOR/GENERATOR SETS				
Belt-Driven	0 - .275	.275 - .425	.425	.675
Direct Coupled	0 - .200	.200 - .300	.300	.450
CHILLERS				
Reciprocating	0 - .250	.250 - .400	.400	.600
Centrifugal (Open-Air) - Motor & Compressor Separate	0 - .200	.200 - .300	.300	.450
Centrifugal (Hermetic) - Motor & Impellers Inside	0 - .150	.150 - .225	.225	.350
LARGE TURBINE/GENERATORS				
3600 RPM Turbine/Generators	0 - .175	.175 - .275	.275	.400
1800 RPM Turbine/Generators	0 - .150	.150 - .225	.225	.350
CENTRIFUGAL PUMPS				
Vertical Pumps (12' - 20' Height) } Height from Grade to Top Motor Bearing.	0 - .325	.325 - .500	.500	.750
Vertical Pumps (8' - 12' Height) } May be Necessary to Spec. Lower Alarm	0 - .275	.275 - .425	.425	.650
Vertical Pumps (5' - 8' Height) } for Lower Motor Bearing & for Upper	0 - .225	.225 - .350	.350	.525
Vertical Pumps (0' - 5' Height) } Pump Bearing (depending on height)	0 - .200	.200 - .300	.300	.450
General Purpose Horizontal Pump - Direct Coupled	0 - .200	.200 - .300	.300	.450
Boiler Feed Pumps - Horizontal Orientation	0 - .200	.200 - .300	.300	.450
Piston Type Hydraulic Pumps - Horizontal Orientation (under load)	0 - .150	.150 - .250	.250	.375
MACHINE TOOLS				
Motor	0 - .100	.100 - .175	.175	.250
Gearbox Input	0 - .150	.150 - .225	.225	.350
Gearbox Output	0 - .090	.090 - .150	.150	.225
Spindles:				
a. Roughing Operations	0 - .065	.065 - .100	.100	.150
b. Machine Finishing	0 - .040	.040 - .060	.060	.090
c. Critical Finishing	0 - .025	.025 - .040	.040	.060

*NOTE: The "ALARM 1" and "ALARM 2" overall levels given above apply only to in-service machinery which has been operating for some time after initial installation and/or overhaul. They do not apply (and are not meant to serve as) Acceptance Criteria for either new or rebuilt machinery.

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FIGURE 24
CRITERIA FOR OVERALL CONDITION RATING
(PEAK OVERALL VELOCITY, IN/SEC)

VIBRATION FORCING FREQUENCIES EXPECTED AT COOLING TOWERS

VIBRATION FREQUENCIES EXPECTED AT CT FANS AND COMMON CAUSES

1) Fan speed (1x fan rpm)
   a) Fan unbalance
   b) Weep hole plugged at one or more blades
   c) Drooping blade(s)
   d) Rubbing of one fan blade on shroud
2) Motor speed (1x motor rpm)
   a) Alignment or coupling problems
   b) Shaft unbalance (source of unbalance can be at the shaft itself or at one or both of the coupling hubs)
   c) Bent or damaged shaft
   d) Resonance of shaft
   e) Beating between motor speed & blade-pass amplifying vibration

VIBRATION FREQUENCIES EXPECTED AT CT FANS

3) Fan blade-pass & harmonics (number of blades x fan speed)

a) Just like all other centrifugal machinery (fans, pumps, compressors, etc) cooling tower fans naturally & normally produce vibration at their blade-pass frequency = number of blades x fan speed.

b) The blade-pass vibration frequency is essentially a pressure pulsation or pressure force. It is analogous to the rate at which an amount of air is moved by the fan.

c) Some amount of vibration at blade-pass is expected and normal at all cooling tower fans. It is only when the level of vibration at this frequency is excessive that we suspect problems.

d) Problems that can increase blade-pass vibration in cooling tower fans include the following:

I. Blade pitch problems (pitch of one or more blades different from the others, or all blades at the improper pitch).

II. Blade elevation differences (one or more blades drooping relative to others).

III. Shroud problems (shroud loose, weak or damaged).

IV. Improper, uneven or inconsistent air flow around circumference of fan (damaged fill, buildup in fill, missing or damaged partitions, missing or damaged sheet metal, etc).

V. Structural weakness or resonance of another component of the tower.

VI. Poor system design resulting in beating between blade-pass & motor speed (For the life of me I don’t know why this is done).

EXAMPLE OF POOR CT DRIVE DESIGN

- As an example of poor CT drive design, take a CT fan driven by a 4-pole motor operating at 1,800 rpm.
- The fan has 6-ea blades and operates at 290 rpm (gearbox ratio of 6.2:1).
- The blade-pass frequency for this fan will occur at 1,740 cpm.
- A beat frequency will be present at this fan as only 60 cpm separates the motor speed & blade-pass frequency (3 to 4% separation).
- My question is why would the OEM design a CT fan on purpose with two dynamic forces so close to one another?
- Wouldn't it be possible to have for instance 5-ea blades instead of six or to have a gearbox with a ratio > 6.67:1 or < 5.45:1 (≥ 10% differences from motor speed)?

EXAMPLE COOLING TOWER FAN VIBRATION SPECTRA