

The Practical Side of Vibration Testing and Analysis

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This article was written to enlighten designers, contractors, commissioning agents, and building owners to the practicality of performing vibration testing on their mechanical equipment. For a “little” money up front, a lot of money can be saved in damages and repairs. In addition, the full potential of the capital life of the mechanical equipment can be achieved.

Vibration testing and analysis. This has been referred to in a number of different ways, most of which are not meant to be complimentary. Voodoo box, black magic, rocket-scientist stuff, etc. It is an unknown for most people, and if something is unknown, people either run from it or attack it. Customers come in many forms and with many types of needs. Our (my) job is to provide a service to a customer that solves his or her vibration problem. Keep in mind that when vibration becomes an issue, it's a bad thing. Vibration has always existed in mechanical equipment, it just becomes bad when it impacts people, money, and equipment life. Otherwise it goes unnoticed.

The most common reason that I have found in my industry (mechanical contracting and service) for needing vibration correction is basic fan balancing. A lot of specifications in new equipment call out a maximum allowable vibration, usually at fan speed, to determine whether correction needs to be taken before allowing the equipment to be turned over to an owner. The intent is to turn equipment over so that the owner gets a fully functional piece of equipment that should operate for at least its expected life. This is also one of the basic tenets for the use of baseline vibration testing when commissioning buildings and equipment. I used to work with a franchise of a major HVAC manufacturer, and I had the opportunity to balance hundreds of fans in the field. Most of these were very easy to balance, and then you would come out as the hero, and your reputation grows, whether it is deserved or not.

The next step seemed to be vibration analysis of larger rotating equipment. When the company I first worked for with vibration as a service started down this path, it was to perform analysis on large centrifugal chillers. Pulling large AC units down to inspect bearings on a periodic basis was the norm in the early 1980s. Recovering large quantities of refrigerant and pulling machines apart was very expensive to do, and is even more so now. If it could be determined what problems existed in a unit (usually bearing problems), or whether a problem actually did exist, then documented justification for pulling a unit apart for repairs or allowing a unit to operate for an extended period before a unit needed maintenance repair saved a customer money over the periodic teardown of equipment.

When I first started into analysis of this type in the early '80s, it required eight to 16 hours of hard copy print outs of each point of vibration. This was then followed up with 16 to 32 hours of calculations to determine where the vibration problems existed to couple with determining what was critical to machine operation to prevent catastrophic failure.

Remember earlier what I said about those rocket scientists (or engineers, the people we love to throw under the bus when things don't work the way we expect or want them to) doing the things we do not understand and run away from? Well, those people have made our lives better, especially in my world of vibration. Their math skills have allowed equipment and vibration analysis tools to come down to those of us who are willing to read beyond the Sunday comics and appear to be smarter and faster than we really are. I do not subscribe to the idea that “just anyone” can or should get into vibration work, just that if one is willing to apply themselves and be detailed in their work, observations, and analysis, the mechanical world will be better off, as would be your customers.

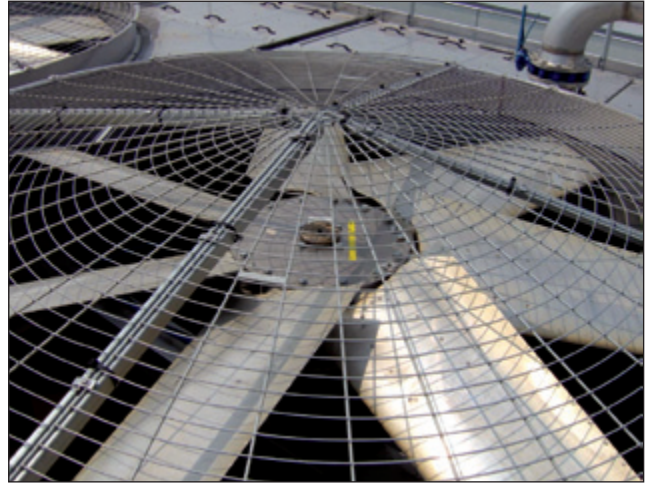


Figure 1. Cooling tower fan before failure on different tower.



Figure 2. Cooling tower fan after failure from tower sump.

Vibration equipment manufacturers offer many types of great equipment that can perform many different functions, provided you are willing to purchase all of the functions. This is capable of making all of us appear much smarter than we actually are. (I say this from experience, since I have been given credit where none is due). Many manufacturers sell software that will self-perform analysis for you and assist in report writing.

About 90-95% of the time, the vibration issues will fall into the “canned” analysis. I have always been a firm believer that you should always know the proper mechanical operation of the equipment being analyzed. I base this on the 10% of the time when the canned software report can give you an incorrect analysis of the problem in a unit.

Knowing the equipment you are working on allows you to expand the interpretation of the analysis to include the parts of the analysis that are not a part of the canned program. Keep in mind that you can do great things all of the time that no one will hear about, but make a mistake one time and see how far that will get and the damage it can do to your reputation.

Vibration testing and analysis is here to stay in whatever form people will use. It will make all of our mechanical equipment run

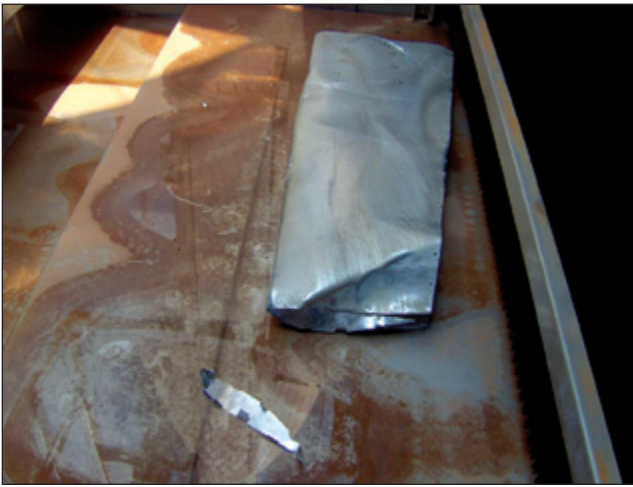


Figure 3. Cooling tower fan blade in sump after failure.

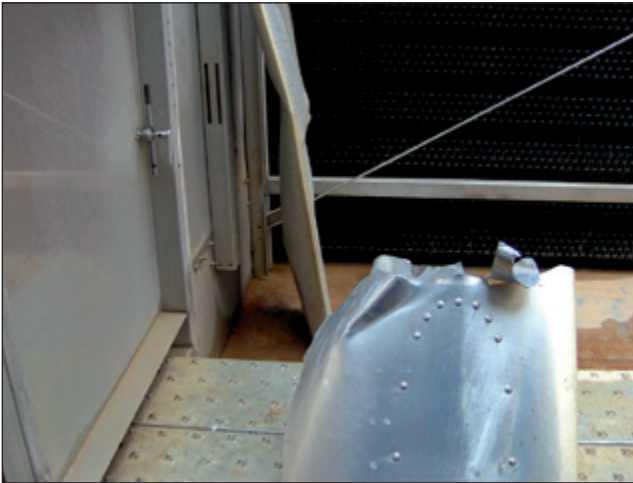


Figure 4. Failed tower fan blade showing destructive "ripping" of blade from fan hub.



Figure 5. Close up of stress fracture separation from fan hub.

better. Balancing, analysis, predictive maintenance, or for commissioning, vibration is of important to all of us, even if we do not see it.

Case Study – Cooling Tower Fan

I was called to perform vibration analysis on 12 large cooling towers. The specifications on the job called for vibration testing to be performed before the equipment was turned over to the owner. This was basically written to determine whether there were any unit problems before the owner took control of them and would allow the manufacturer to correct any issues at the manufacturer's expense. The owner would then take over the predictive maintenance

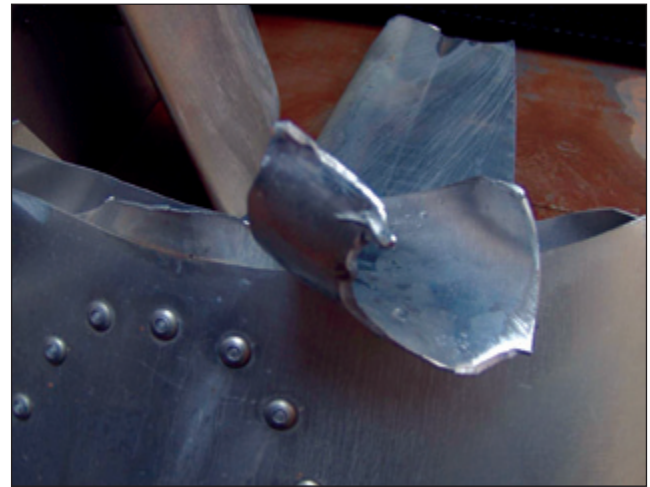


Figure 6. Close up of "ripped" fan hub.

and trend analysis because they had the skills in house. I was not called in until two of the cooling towers had run to catastrophic failure by having the induced tower fan blades break apart and do much damage to the tower. See Figures 2 through 6.

Any of the towers could be configured to operate with any of the 12 chillers operating in the plant, but in this case, the towers were designated to operate with a particular chiller. Inadvertently, this rigidity in the control helped to allow the equipment to reach catastrophic failure (Figures 2 and 3). As happens too frequently, the contractor did not perform a baseline vibration commissioning reading as was required by the contract.

Not until the failure occurred was vibration testing considered to actually be required. In many cases, the specs call for testing to be performed, but are not actually enforced. Many times the contractor pockets the money budgeted to perform the testing, and walks away and hopes the equipment makes it through warranty. In addition, the owner of this facility (a data center) had specified the installation of vibration switches on the cooling tower fan assemblies, but instead of shutting down the tower, they only wanted an alarm sent to the energy management computer. In this case, instead of shutting down the tower and switching to another tower, because of the rigidity of the control sequence, this allowed the towers to continue to catastrophic failure (Figures 4, 5, and 6). All of these "little issues" combined led to repairs that eventually totaled over \$500,000, most of it borne by the manufacturer of the cooling tower.

Testing

Upon arriving at the job, the mechanical contractor's project manager explained to me that two of the tower fans had failed with one of the fans "helicoptering" (which to this day I do not understand, because an induced tower fan should want to "fly" down into the sump due to the pull of air across the blades) out of the tower and landing in the paved open service area behind the towers. My guess is that the helicopter phrase was an exaggeration, but the blades, the fan hub, and the blade screen was piled together on the ground. The second fan had failed by having the blades (four of seven) break into the sump and into the tower fill.

I performed vibration readings on the remaining ten towers by using 10 points – five on the motor and five on the fan gears (Figure 7), as well as performing hammer resonance tests on the blades.

Of the remaining 10, only two of the towers met specification for allowable vibration. The other eight (and eventually the two that were rebuilt) had problems that were consistent – misalignment and blade pass vibration. The natural fan blade resonance happened to be at the same frequency of the blade pass when operated at 55 Hz on the frequency drive. It was determined that on the worst vibrating fan blades that the blade pass vibration was moving the fan blade tips 3 to 4 inches vertically (peak to peak) near the shroud. (See Figures 8 and 9).

After presenting the results to the mechanical contractor, the tower manufacturer performed its own readings, which confirmed the findings. They also performed dye tests on the fan blades near

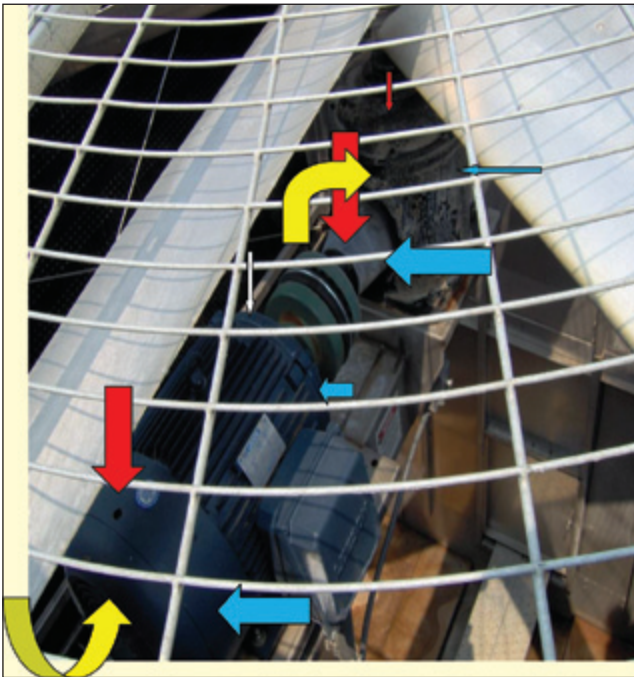


Figure 7. Transducer locations on cooling tower motor and fan gearbox.

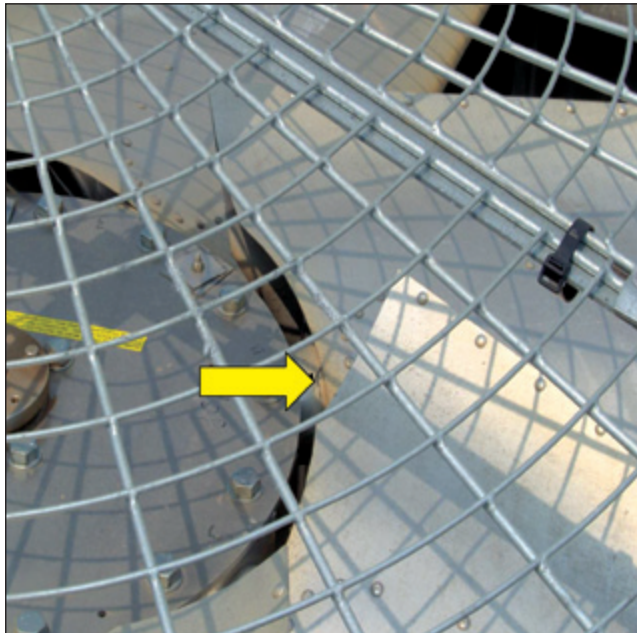


Figure 8. Arrow points to break of a fan blade hub going to failure.

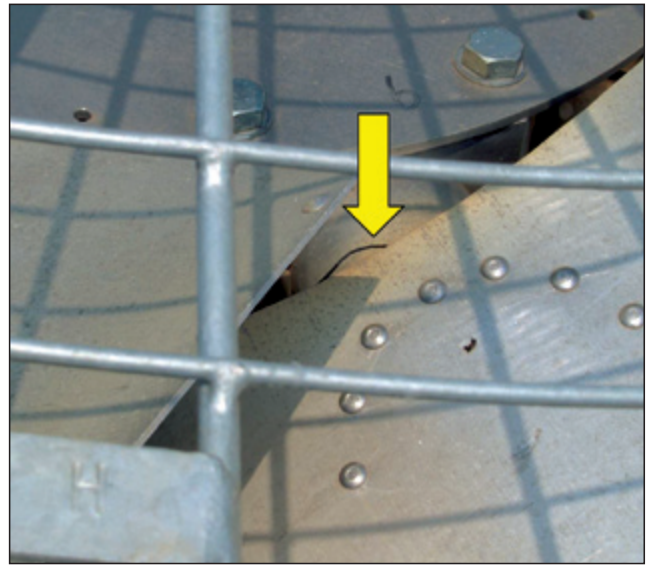


Figure 9. Close up of a break of a fan blade hub going to failure.

the hub where the previous blades had failed on the first two towers. Over 75 % of the blades had hairline cracks from vibration fatigue. Some of these towers had less than 10 hours run time. The tower manufacturer then rebuilt all 12 towers with new fans with different blades tested to ensure that the blade resonance did not impact tower operation and vibration.

The mechanical contractor then requested a remeasurement of the towers after the manufacturer had rebuilt and balanced the fans. The remeasurement yielded four of the towers still out of specification for vibration due to motor/gear misalignment. Once again, the manufacturer was called in to make corrections, and the final remeasurement demonstrated that the towers were now within specification.

This particular job was an extreme case, and it's doubtful as to whether this would ever be repeated. But it is a *great* story! A lot of the damage and repairs could have been prevented with early baseline vibration measurements and proper commissioning. Fortunately for the owner, this occurred under warranty (actually before, because the equipment had not been turned over to the owner, and fortunately for the contractor, while still under manufacturer warranty) and was a "minor" irritation. Handled properly, this problem was preventable and could have been corrected at a minimal cost.

Vibration measurement and analysis should be used much more frequently than the industry currently requires. For maximum benefit, it must be performed on a periodic basis starting with initial baseline readings to determine when equipment needs maintenance, repair, or overhaul. In this manner, repairs and maintenance can be scheduled in the most cost-effective manner and at a time when it creates the least impact on building operation. **SV**

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