Machinery Vibration Analysis – Fact v.s. Speculation

By William Watts, P.E.

Machinery vibration analysis is a very important and powerful component of a Predictive Maintenance (PdM) program. While it involves a great deal of exact, detailed scientific data, things are not always black and white. The following paper discusses how proper analysis includes the ability to address the various shades of gray to provide good information from which repair planners can perform their jobs most efficiently and effectively.

A successful predictive maintenance program for most rotating machinery uses vibration spectral data analysis as a primary tool for assessing machine condition. In preparing a report for an individual machine, a basic scientific approach is used. The analyst gathers data and other information with respect to operation and history. Vibration spectral amplitudes are examined along with their deviations from appropriate baseline values. Waveform and demodulated vibration data also may be examined. The analyst evaluates all data in terms of test locations, axes, and how they have trended over time. Test operating conditions may be a factor. Observations on site and history of problems and repairs are considered. After digesting all data and information, the analyst uses a combination of logical and empirical thinking to arrive at one or more diagnoses (or a lack thereof) and an appropriate repair recommendation. Both the analyst and the customer (recipient of the report) must keep in mind a very important point: The data and information used as input to the analysis are facts. The resulting diagnosis and repair recommendation may be speculation.

Some diagnoses are clear and unambiguous. For example, in a simple direct drive motor driven pump, one test location at the motor with an 8-ball bearing shows a very strong and extensive series of 3.1 times motor rotational harmonics (multiples of 3.1xM frequency) with 1xM sidebands and abnormal high frequency random noise. They are prominent only at this location. In such a case the diagnosis of motor bearing wear (bearing outer race damage) is virtually unimpeachable. In other cases, however, abnormal vibration can be evidence of different faults and lead to an erroneous diagnosis and conclusion. The danger arises when the analyst does not differentiate between the facts of the case and diagnostic opinion. The latter may be treated as a fact, then lead to credibility issues for the analyst as the customer discovers that the machine problem is actually quite different. The general solution is for the analyst to make clear in the report that which "is fact" and that which "is speculation". Certain customers do not like vague results. They want clear and simple answers. That is not always possible. It is permissible to recommend two or more specific actions (inspections, for example) in some sort of order which reflects convenience for the mechanic.

Example of the Same Evidence for Two Different Problems:

In 1995 I was doing a survey on a very large ship which included a very large main condenser circulating pump. The pump end included a 4-blade propeller and journal bearing, which are very difficult and expensive to repair. Vibration test data from the pump end showed an extremely strong series of lower order pump shaft rotational rate harmonics (multiples of 1xP frequency) accompanied by elevated random noise. This is classic evidence of impacting or looseness. The logical diagnosis was pump journal bearing wear or excessive clearances. This diagnosis was supported on site by observation and recent history. Pump packing had to be replaced every two weeks and water was leaking from the pump gland in significant quantity. The diagnosis proved to be correct and the journal bearing was replaced at great effort. Let us fast-forward to 2002. I was on a similar ship and tested a similar machine. Pump end vibration signatures looked very similar to those recorded in 1995. Being supremely confident at the time, I diagnosed pump journal bearing wear and recommended the same costly repair. The ship was pier-side and there had recently been a typhoon at the site. Apparently the typhoon had stirred up debris from the sea floor and the debris became lodged in the pump. Included was a plastic 2-liter Pepsi bottle. The impacting of this debris resulted in the abnormal vibration data. Subsequent testing of the unit following removal of the debris showed a smooth running pump. The pump journal bearing was in good condition. Fact – Data showed strong 1xP harmonics. Fact – Such harmonics generally indicate impacting or looseness. Speculation – The data may indicate a pump journal bearing problem or there may be a different cause.

Example of Overlapping Evidence:

This case also illustrates how to assess an automatic diagnostic system result. At a nuclear plant, there was a vertical main feed booster pump consisting of a motor, flexible coupling and centrifugal pump. There was one test location (incorporating a tri-axial sensor) each on the motor and pump. The vibration test data were processed through an automatic diagnostic system. The expert system result included two diagnoses, serious pump internal looseness and serious indication of coupling wear or looseness. The automated recommendations were to inspect both the coupling and pump. Spectral data showed a strong series of shaft rate harmonics. As noted above, such harmonics are a general indication of impacting or looseness. The cited amplitudes and exceedances of average baseline values were quite strong and abnormal at both the motor and pump, thus the diagnosis of a coupling problem. They were somewhat stronger at the pump, thus the diagnosis of pump internal looseness. Certainly that was a reasonable diagnosis considering that source vibration tends to magnify upward in a vertical machine. The mechanics on site took a common sense approach. It was much easier to inspect the coupling than to open and inspect the pump. So they first disconnected the coupling and inspected it. The coupling grease had turned solid. They refurbished the coupling, reassembled the unit and tested it again. Vibration data reflected a smooth running unit. No pump end inspection was made. Was the automatic diagnostic system successful here? The mechanics were provided with two different diagnoses and recommendations based on the same evidence. They took a common sense approach and performed the easy initial task of inspecting the coupling. Having found and corrected a problem, it was reasonable to retest the unit before opening and inspecting the pump. Since the second test was satisfactory, there was no need to inspect the pump. The problem was solved quickly and cheaply. That seems successful. However, one program overseer considered the automatic diagnostic results to be bad. He determined that since there was not in fact pump internal looseness, the program failed. The overseer should not have been so narrow-minded in his judgment. Even a manual analyst in this case would question the specific vibration source. While vibration analysis does involve a great deal of science and logic, there are many factors which introduce uncertainty and present multiple possibilities. The mechanics performed the proper response to the results and therefore were successful.

Example of the Same Evidence for Two Different Problems - Again:

On another very large ship there were 150-HP seawater fire and flushing pumps. For one of them, the automatic diagnostic system kept producing a test result of "serious angular misalignment" despite the fact that the chief mechanic repeatedly performed shaft alignment readings and found them to be nearly perfect. The diagnosis was based on high level motor rotational rate (1xM) vibration in the axial and transverse directions at both the motor and pump. The problem turned out to be a foundation soft. That is a reasonable alternative, since a foundation soft foot warps the alignment and makes the machine act misaligned even though shaft alignment readings at the coupling are good. Both conditions produce the same vibratory forces. In presenting a report, the analyst should comment that the abnormal 1xM vibration is classic evidence of angular shaft misalignment. However, if shaft alignment readings are good, then there may be foundations soft foot or a warped shaft. The customer needs to understand that sometimes there is more than one answer to the question of what is wrong with the machine.

Conclusion:

Machinery vibration analysis is a very important and powerful component of a predictive maintenance program. It involves a great deal of exact, detailed scientific data. There is abundant proven theory regarding the correlation between data and actual condition as found. Despite all of these advantages, the analyst at times needs to consider multiple possibilities regarding the source and root cause, and to provide a common sense repair recommendation which may involve multiple steps. The customer must keep an open mind and accept the concept that not all results are neat and precise. Instead of all black and white, there may be various shades of gray. The object is to provide good information from which repair planners and personnel can perform their jobs more efficiently and effectively.

The Ultimate question

Troubleshooting instruments and methods and traditional PdM instruments/software have similarities, but their effectiveness as maintenance tools are vastly different. Ultimately you must ask: Do you want to test a few suspect machines and identify a limited set of problems with pretty good accuracy, or do you want to survey a large number of machines for the maximum set of faults with highest achievable accuracy to optimize the maintenance in your plant?

About the author:

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William (Bill) Watts graduated from Webb Institute of Naval Architecture (Glen Cove, NY) in 1976 with a dual B.S. degree in naval architecture and marine engineering. After nine years in that profession, he joined DLI Engineering (now Azima DLI). The subsequent 26 years at Azima DLI have been spent involved directly with vibration analysis, including co-development of an expert system (automatic diagnostics) software. He has a state professional engineer's license in California (mechanical engineering) and Washington (NA & ME).