Machinery Health Monitoring

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MACHINERY ANALYSIS - YESTERDAY, TODAY AND TOMORROW

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Most everyone is aware of technology which, when finally developed into a mature state had departed far from the original objective. Using the current and highly visible controversy over urban transportation as an example, the question of how to create the most efficient and enjoyable integrated system for moving people and things from place to place was never addressed until the chosen course of action, building more roads and facilities to encourage vehicular transportation began to create more problems than it was solving. The same pitfalls are present in any technological endeavor— in order to avoid a costly diversion, perhaps an unforseen insurmountable problem, or an undesirable final result, it is imperative to develop a set of long range objectives, work toward those objectives, view each development with skepticism and continually subject the effort and its progress to penetrating evaluation.

THE OBJECTIVES OF MACHINERY MONITORING AND ANALYSIS

The principal objective in any program of machinery monitoring and analysis, whether continuous or periodic can be stated as follows: To provide a means by which mechanical equipment can be operated safely and with confidence for longer periods of time. Naturally such a program has numerous side benefits such as improving maintenance efficiency through a reduction in the effort, time and cost of inspecting equipment known to be in satisfactory condition, as well as providing the forward vision necessary to take equipment out of service in time to avoid a catastrophic failure which is likely to produce costly secondary damage. In short, machinery monitoring and analysis is a tool or means to an end rather than an end in itself.

CHOICE OF MEASURED VARIABLES

There are many parameters to choose from in machinery monitoring; temperature, pressure, dynamic vibration over a wide frequency range, sound, strain and position just to name a few general categories. Within each category a specific characteristic can be isolated and correlated to a mechanical component such as metal temperature close to the surface of a thrust bearing. Despite statements such as "its always been done this way" or "everyone knows (blank) is the best way to monitor condition", it pays to be skeptical and always ask the following questions:

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- Is the chosen variable the most responsive indicator of changing mechanical condition?
- Is the variable being sensed at an optimum location?
- Is the resulting information being properly presented and effectively utilized?
- Do the individuals gathering and using the information understand its meaning, importance and function?

THE HISTORY OF MACHINERY ANALYSIS AND MONITORING

In order to assess where we are today and visualize where we are going, it is important to examine where we have been. For the first hundred years or so of the industrial revolution, the condition of operating machinery was judged by assessing characteristics, vibration, temperature, sound and smell which could be sensed by our own senses. Next, the introduction of various types of instrumentation provided a means to quantify and record machinery characteristics. Of course, this gain had some disadvantages as well for a measurement is a discrete quantity at one particular point rather than an overall evaluation. As a result, many measurements are often necessary to develop an assessment of overall condition equivalent to that rendered by an experienced professional, often without tools other than basic physical senses. Measurement technology is a little like visual magnification; to greatly increase detail one must sacrifice field of vision.

The introduction of instrumentation to measure vibration had precisely this effect; suddenly characteristics such as high frequency buzzing, knocks, rattles and squeaks which could be felt and heard were removed from the field of view in order to focus on the area of the spectrum around running frequency. The establishment of periodic monitoring programs for equipment surveillance quickly extended the use of vibration measurement from a diagnostic tool (implying the problem had been discovered by some other means) to a tool for assessing condition and thereby predicting the remaining lifetime of operating machinery.

From this beginning it was quite a logical step to permanently install vibration measuring equipment for continuous monitoring. For the first time operators were provided a continuous, consistent means to recognize machines in difficulty as well as trends which might lead to difficulty. Even though the mechanism producing a change might not be totally understood, early recognition provided time to call for assistance and the opinion of a skilled machinery analyst.

Although this type of continuous and periodic monitoring probably provided some type of warning for 80% to 90% of all machinery problems, uncovering the cause of the problem was often quite difficult. As a result, more advanced analytical instrumentation such as the real time spectrum analyzer were introduced. The speed and accuracy of the real time analyzer represented a significant step forward for it provided a highly discrete focus on individual characteristics while simultaneously expanding the field of vision by orders of magnitude.

CURRENT STRENGTHS AND WEAKNESSES

With this brief history of machinery analysis and monitoring one needs to examine today's strengths as well as the areas where improvement is needed. On the positive side:

- A great deal more is known now than ever before about machinery condition and normal as well as abnormal characteristics.
- Differences in machine type, operating speed, design and construction vastly affect its external characteristics.
- A large percentage of developing problems can be recognized early enough to avoid outright failure and accompanying secondary damage.
- The use of modern monitoring and analysis instrumentation and techniques has allowed operating larger higher speed machines for extended intervals with a degree of safety and confidence which would not be possible if sole reliance were placed on physical senses for warning and protection.
- Overhaul routines based on a comprehensive program of machinery analysis are much more focused and problem oriented than those based solely on operating time.

On the opposite side of the ledger, an occasional unexpected catastrophic failure still occurs. Although this type of failure is fortunately rare, its real cost in terms of repairs and lost production may well exceed the savings accrued by anticipating the remaining 90% of all machinery problems. Additionally, many promising programs of machinery analysis fail because they are overly time consuming and the instruments and procedures involved are too complex and require advanced analytical skills which are generally in short supply.

AREAS WHERE IMPROVEMENTS CAN BE REALIZED

The next question, and one which will be addressed in the remaining paragraphs, is how can the ability to analyze operating machinery and assess its condition be improved.

Based on current levels of knowledge, skill and experience, improvements are needed in the following areas:

- Develop interpretative skills, e.g. advance the ability to understand the mechanical phenomena or interaction producing currently measured external characteristics such as vibration.
- Optimize the use of parameters such as dynamic vibration and temperature as indication of machinery health through better sensor selection, location of sensing points and information presentation.

- Simplify instrumentation and develop a device which will enable a person totally unfamiliar with machinery, machinery analysis and analysis instrumentation to quickly and efficiently distinguish between machines in good condition and those in poor condition.
- Subject currently available dynamic characteristics such as vibration to different types of processing and analysis, e.g., demodulation, envelope detection, and cepstum to ascertain the best indicator of condition and developing flaws.
- Search for additional flaw or defect oriented variables or combinations of variables.

DEVELOP INTERPRETATIVE SKILLS

Although a typical mechanical vibration signature is filled with harmonic multiples of rotating frequency and events such as blade and vane passing and gear mesh, there is little general knowledge of their formation, behavior and meaning except what has been observed empirically. Within a machinery vibration signature containing a harmonic series, it is not unusual to observe components with higher amplitudes than the fundamental. Added knowledge is required in the area of how and by what mechanism harmonics are produced in a mechanical system, what do they mean and can a single harmonic component created by two separate phenomena be reduced to its parts? All these questions are vital in machinery analysis and need answers.

OPTIMIZE THE USE OF EXISTING PARAMETERS

Temperature

For maximum effectiveness, temperature sensors, thermocouples or RTD's must be placed as close as possible to the point at which the temperature change originates. For example, a temperature sensor located in the metal and close to the surface of a thrust or journal bearing is a rapid, responsive indicator of bearing load and probably the best anticipatory indicator of a potential thrust overload. In contrast, the same sensor, placed a few centimeters away in the oil drain line will be totally ineffective.

Vibration

For optimum results, the choice and location of vibration sensors as well as the method of monitoring the resulting signal should be based on machine type, characteristics and response. Diverse machinery such as pumps fitted with anti friction bearings, large centrifugal compressors, gears and gas turbines all have their own unique characteristics requiring a slightly different approach to analysis and monitoring.

Conventionally, everyone is accustomed to measuring unidirectional vibration, yet perhaps measuring total motion in all planes might be a faster, better and more responsive indication of mechanical condition. For example, in shaft vibration analysis, the pitfalls of single plane measurement are readily apparent by the existence of highly elliptical orbits.

The choice of instrumentation, in itself, can make significant differences in the measured value. A comparison of the measurements made by two different vibration instruments, one with an average or RMS detector calibrated to read peak with a sine wave input and the other having a true peak detector can be quite revealing. If the input to both instruments is an equal amplitude sine wave, both will read the same value. If, however, the input signal to the two instruments becomes highly complex and contains numerous individual components, the two readings will vary significantly with the amount of variation dependent on the type and complexity of the input waveform. The peak to RMS ratio has been used effectively to detect flaws in anti friction bearings (crest factor analysis) and should be explored for other types of problems.

Another simple, but neglected, method to determine the harmonic content of a complex signal is to take two measurements at the same point, one in displacement and the other in velocity units. Next the value of one variable is calculated from the other using the machines rotating speed. If the calculated and measured values are equal, then the predominent vibration is occurring at rotational frequency; if they are different there is a significant contribution from a component either above or below running speed.

SIMPLIFY INSTRUMENTATION

At the present time instruments called vibration analyzers are not really analyzers at all but simply tools for presenting information. The actual interpretation or analysis task has to be accomplished by an experienced person capable of translating vibration levels and patterns into machine condition. There is a clear need to mechanize as much of the analysis procedure as possible within a simple to operate, virtually foolproof, instrument so that a less experienced person can separate machinery in marginal or poor condition from that in good condition quickly and with a high degree of accuracy.

How might such an instrument be implemented: First, it must have only those controls which are absolutely necessary such as an on off switch. An unambiguous digital readout with sufficient dynamic range to accommodate all machinery without necessitating a range change would be highly advantageous. Second, small size, light weight and battery power are necessities to encourage its use by operators. Third, the ability to perform rudimentary analysis; compare a vibration level against some severity criteria, assess harmonic content and present condition as an easily interpreted numerical value or color code would remove most of the training and experience now required to accurately assess machinery condition.

It should be emphasized that the device described in the previous paragraph, an engineered analyzer, is not designed to replace advanced analysis instrumentation or skilled analysts. Rather, it will directly increase the number of people able to assess machine condition, allow more machines to be placed under close surveillance at an attractive cost and will permit skilled analysts to use their time and instrumentation much more effectively analyzing complex problems and developing the technology necessary to advance interpretative skills.

Monitoring systems likewise require simplification. It appears unfortunately true that recent trends have evolved gadgets and seldom used controls which, although providing flexibility, frighten people away. Again more time must be devoted to human engineering without forgetting the purpose of a continuous machinery monitoring system which is to apprise an operator of the condition of the machinery entrusted to his care. A better display such as a CRT showing the measured value, its proximity to warning setpoints and trends during the last 24 hours would, at a glance, tell an operator all he needed to know. Complex, perhaps, but infinitely better than requiring a person to read and log measurements from a string of meters which may or may not be representative of actual machinery condition.

Next, is it really necessary to express monitored values in engineering units? In most every case where this is done there is some confusion concerning limits, why they are set and possibly differences in limits from similar measurements taken on machines which outwardly appear quite similar. Perhaps consideration should be given to displaying measurements on an arbitrary scale of 10 with approximately 6-7 being a first level warning point. For added capability, a combination of weighted variables might be presented as a single value to lessen the amount of interpretation required by an operator.

SUBJECT KNOWN DYNAMIC CHARACTERISTICS TO DIFFERENT TYPES OF ANALYSIS

In many cases analytical procedures themselves become suspect when they do not clearly differentiate between normal and abnormal mechanical condition. Often the failures can be traced to differences in the test procedure such as not duplicating exact operating conditions, however, there are times when machines known to be in satisfactory condition appear abnormal and vice versa. Studies with anti friction bearings have shown that with a given piece of information, the method of analysis itself may be key to locating a flaw. For example, it is often quite difficult to pick out the direct components generated by anti friction bearing flaws among numerous other spectral lines generated by the machine itself. If however, another section of the spectrum is selected, envelope detected and the resulting signal spectrum analyzed, bearing related frequencies are much more pronounced and experience larger changes from normal to abnormal mechanical condition thereby facilitating evaluation.

Time averaging, de modulation and cepstum are other types of analysis which have been reported as having significant advantages in spotlighting flaws and anomalies.

SEARCH FOR ADDITIONAL FLAW OR DEFECT ORIENTED VARIABLES

Most chronic machinery problems are characterized by symptoms which slowly increase in severity. In this world of small slow changes, it is difficult to convince others of a problems severity, and there is a strong temptation to watch and continue operation. Depending on the strengths of the individuals involved, this can have disasterous consequences. What is needed here are variables and methods of processing which are more flaw oriented and exhibit large unmistakable changes to a developing abnormality. As cited earlier, the location at which the measurement is taken is often of prime importance and should be examined closely. A second possibility is to combine two or more variables such that a change in one confirmed by a change in the other is weighted to produce a larger change in displayed condition than would be produced by a change in a single variable. The display might be a meter reading, colored light display or a bar graph.

Finally, there are undoubtedly variables capable of being measured which in themselves are highly flaw oriented. The high frequencies, to 100 kHz and higher have been used with a high degree of success in locating flawed gears and anti friction bearings. Typically this area of the vibration spectrum, properly processed, will produce changes of several hundred percent between normal and abnormal conditions.

A discussion on machinery monitoring would not be complete without mentioning computer monitoring systems. Thus far, computer monitoring has been limited to comparison, trending, data logging and reporting with on line diagnostics an unfulfilled dream. Although the results certainly aren't in yet, it is the author's opinion that on line spectrum analysis will prove too complicated for cost effective implementation on the majority of mechanical equipment. The problem is that the spectrum generated by typical machinery is extremely complex, amplitudes, particularly at the higher frequencies, vary widely in response to changes in operating conditions, and it will be extremely difficult to take all this into account and still produce meaningful results. Perhaps we will see a technological breakthrough which will make it all possible, but for the time being observing variables in a broad or lumped sense and thereby examining complex characteristics through windows rather than pinholes seems to offer much greater chances for immediate success.

In conclusion, keeping sight of long range objectives, being skeptical, asking questions, and never being satisfied with the current way of doing things, provides the discipline to control and direct technology to our advantage. Only in this fashion will we achieve an optimum, satisfying end result.