Cost effective Predictive Maintenance solutions

Abstract

Vibration monitoring is a critical component of any sound Predictive Maintenance strategy. Traditionally, data from the vibration sensors is recorded and analyzed using hand-held, walk-around vibration analyzers or expensive and elaborate online analysis systems. For extremely large operations and/or very expensive equipment, these approaches represent cost effective Predictive Maintenance and have repeatedly shown to save money. In many applications, however, neither of these approaches is cost effective. In recent years we have seen an increase in the use of 4-20 mA loop powered sensors in the market. These sensors have proven extremely valuable, since they can be tied directly into the existing PLC/DCS networks and do not require a skilled analyst or expensive system. However, these sensors only provide trending information to identify that a potential problem exists, and do not provide the detailed information necessary to determine the cause of the problem. A hybrid approach to vibration monitoring provides the best of both worlds to establish a PdM strategy that is not only extremely cost effective but also simple to deploy.

Background

In the early days, equipment maintenance was conducted only when equipment actually failed. The work was more “fix it” than maintenance. Shortly thereafter, came the recognition that performing regular maintenance and refurbishment tasks on equipment could keep equipment operating longer between failures. This became known, variously, as Periodic Maintenance, Calendar Based Maintenance or Preventive Maintenance. The goal was to have most of the equipment able to operate most of the time until the next scheduled maintenance outage. This approach provided more control over the maintenance schedule; however, the system was still susceptible to failure between maintenance cycles.

With the development of the Fast Fourier Transform (FFT) mathematical method in 1964, portable spectrum analysis equipment became available that could be used with special transducers to measure machinery vibration. Early research showed that the mechanical condition of a machine could be deduced while it was still in operation. While this early FFT equipment was called portable, “transportable” might have been a better word to describe it. Early users often installed it in vehicles such as vans or Suburbans to move it and ran long cables to the equipment to make measurements. These efforts laid the groundwork for Predictive Maintenance of machines.

When portable FFT-based data collectors became available in the 1980’s the use of vibration as a tool for diagnosing machinery faults underwent explosive growth. Tens of thousands of data collectors have been sold worldwide for vibration diagnosis. Vibration analysis technology has found its way into a variety of industries including the petrochemical, pulp and paper, machine tool, food processing, pharmaceutical, railway, steel and power generation industries. Instead of waiting for a machine to fail before working on it, or performing maintenance on a machine regardless of its condition, the idea of performing maintenance on equipment only when it indicates impending faults – Predictive Maintenance (PdM) – took hold. The idea of performing maintenance on machines only when they exhibit signs of mechanical failure has become known as Condition Based Maintenance (CBM). This evolutionary process of machinery maintenance has allowed the

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maintenance operation to become more “proactive” than “reactive” in maintenance tasking. The result is that the maintenance department can operate at lower costs because staffing and tasking can be better planned when the process of maintenance is under control.

Current CBM technology

Today there are a variety of technologies for assessing machinery health for a complete CBM strategy. Because of the value of the information provided, vibration analysis is one of the most prevalent methods for a variety of equipment and the primary method for rotational equipment.

One approach to data collection is the off-line walk-around approach. Portable data collection has many advantages and is the most cost effective in some instances, however it has two major drawbacks: it requires a skilled vibration analysts to interpret the data and, without continuous monitoring, problems in between rounds could be costly. In an attempt to overcome the later problem, industry increased the number of points measured and the frequency of the measurements. However, this is a very labor-intensive approach and in recent years, all manufacturing plants have undergone tremendous efforts to reduce staff in cost cutting measures driven by global competition. Hence emerges the on-line vibration analysis system as a second major approach to CBM today.

On-line systems are now widely used for monitoring vibration with piezoelectric accelerometers as the vibration probes and computer-based specialized data acquisition systems for gathering, storing, and archiving FFT data. These FFT-based data systems exist apart from the plant process control computer system because the data files are so massive and specialized. It still requires trained vibration analysts to view, interpret, and analyze the data collected. The system installation costs are high also because of the capital cost of the hardware as well as the installation labor.

The main advantage of an on-line dynamic vibration monitoring system is that is acquires data continuously. Most of the on-line systems use some kind of acquisition system architecture that involves a single input channel that is multiplexed across many vibration sensors. This results in a scan rate that varies according to the system scheduler. However, most systems will acquire a full set of time and spectrum data for each monitored point about once every three to six hours. The result is four to eight sets of data each day, meaning there are 1,500 to 3,000 data sets acquired for each point every year. This is extremely detailed data! However, because of modern computing storage and power, this no longer represents a serious problem.

Another advantage to an on-line dynamic vibration monitoring system is that there is no labor cost to acquiring the data and minimal labor cost for identifying machine faults. The system acquires data 24 hours a day. The resulting data is “sorted” based on algorithms established by the skilled vibration analyst. Problems are “flagged” by the system and identified on the screen of the control computer.

The continuous monitoring advantage of an on-line dynamic vibration monitoring system enables mechanical fault detection at the earliest detectable time. When plants either need or want to be able to detect machinery faults at the earliest possible moment, an on-line dynamic vibration monitoring system is the system of choice.

The disadvantage of on-line dynamic vibration monitoring systems is that they are the most costly CBM systems to implement and maintain. The cost of acquiring an expensive, elaborate online system, maintaining a full time vibration analyst, and installing a wired network to get the signals from the sensor to the analysis system is significant. Furthermore, the software and hardware that make up the system typically require an extensive maintenance contract as well. Many plants are downsizing and aggressively becoming more cost competitive so many plant managers have resisted the move to elaborate on-line vibration monitoring systems or avoided implementing a CBM system altogether.

The critical component: the Vibration Analyst

Whether your CBM operation requires a walk-around analysis system, a dynamic on-line system or both, a dedicated vibration analyst is a critical to the support of the CBM effort.

It takes considerable time to become a skilled vibration analyst. Many years of training and experience are necessary to properly apply the techniques of vibration analysis to the wide variety of machines and equipment installed in plants today. The maintenance department also invests considerable resources in time and training to equip the mechanics and technicians who perform the maintenance on the plant's equipment. In some cases the personnel performing the vibration analysis are the same ones who perform the equipment maintenance. They are not the highly skilled Vibration Analysts, but are able to perform the vibration analysis necessary to maintain their particular machines. Furthermore, well trained, experienced Vibration Analysts are a dying breed.

New age economics

Implementing and maintaining the technologies necessary to have a totally "in-house" PdM program is a very costly investment. As most companies try to improve their cost effectiveness, outsourcing of services has become an attractive way to achieve cost reduction targets in the absence of other alternatives.

Today, the Vibration Analysts can either be on the plant staff or can be an external contracted analyst. Many plants have moderately skilled analysts, but contract the services of vibration consultants when serious problems develop with critical and expensive plant machines. Other plants will contract the entire vibration analysis program to consulting firms and take action based on the report of the consulting analyst.

The size of the plant and the requirement for rapid data analysis will help determine the right mix of in-house versus contracted operations. It will also determine the level of in-house expertise that would be needed to retain some measure of rapid analysis even when most of the data acquisition and analysis is contracted. If there is absolutely no in-house source of independent analysis, the plant is totally reliant on the contractor for equipment condition assessment. The question is what level of internal expertise to maintain to be able to effectively use the contractor personnel and data.

Cost effective options are available for CBM systems

While these CBM systems were driving the evolution of modern plant maintenance programs, real-time plant control computer systems were evolving as well to better monitor and control all plant processes. Over a period of many years, control systems in plants have evolved from the air-powered systems of the past to modern computer control systems.

These systems have evolved from two directions. Older local equipment relay ladder controls were replaced by small Programmable Logic Control (PLC) systems. Meanwhile, the total plant air operated system was being replaced by an integrated, computerized Distributed Control System (DCS) to maintain the operation of the plant equipment and coordinate the flow of the production process. Over time, with increases in computing power, these two on-line control techniques have gradually merged into a variable-scale Process Control System (PCS).

Although only a small percentage of plants have an installed cabled network for on-line vibration analysis system, most plants have an existing PCS network. Being able to access these existing networks would produce a cost-effective alternative to dynamic on-line vibration analysis systems.

4-20 mA vibration data

To interface to existing PCS networks, the vibration data must be converted to a standard PCS format. One of the most common formats employed today is a 4-20 mA current loop signal. The current loop signal standard was established due to its noise immunity performance and the fact that it can be transmitted over very long distances without loosing its integrity. The lowest signal level was standardized at 4 mA to ensure that non-operating conditions were differentiated at lower current levels below 4 mA. The top end of the scale was standardized on 20 mA to provide enough range to address almost any process.

The 4-20 mA current loop is a low bandwidth system that can not support the transfer of the dynamic vibration data necessary for FFT Analysis. Therefore, the PCS network can never be employed as a direct replacement to the dynamic on-line vibration analysis system. Alternatively, many maintenance engineers have recognized that using a 4-20 mA network to transfer less dynamic information about equipment vibration is a very low cost way to trend the system's general condition. This results in a more cost-effective approach to equipment maintenance than traditional PdM.

Today, vibration transducers can incorporate the signal processing to produce a conditioned vibration signal that can be transferred on a standard 4-20mA PCS network. These devices can be directly powered from the plant DCS or PLC system and yield an overall 4-20 mA signal proportional to the machine vibration level.

Vibration transmitters are also available that utilize the dynamic accelerometers traditionally used by portable data collectors and on-line FFT-based vibration systems. These modules are DIN-rail mounted and convert the dynamic signal to a 4-20 mA loop-powered signal.

Modern plant DCS/PLC systems can accept the 4-20 mA signal as input; then interpreting the overall vibration signal is simple. The signal is a calculation related to the overall energy of the vibration, and ISO 10816 is an industry standard that provides guidelines to determining the machine condition based on the overall vibration level[1]. If the user knows the manufacturers recommended maximum vibration level, that can be used to establish limits to the allowable vibration. Otherwise, ISO 10816 can be used for guidance.

<table>
<tr><th>Vibration Velocity in/sec. peak (mm/sec. r.m.s.)</th><th>Class I < 20 HP</th><th>Class II 20 to 100 HP</th><th>Class III > 100 HP typ. rigid rotor</th><th>Class IV > 100 HP typ. flexible rotor</th></tr>
<tr><td>2.5 (45)</td><td rowspan="5">D</td><td rowspan="4">D</td><td rowspan="3">D</td><td rowspan="2">D</td></tr>
<tr><td>1.6 (28)</td></tr>
<tr><td>1.0 (18)</td><td rowspan="2">C</td></tr>
<tr><td>0.63 (11.2)</td><td rowspan="2">C</td></tr>
<tr><td>0.4 (7.1)</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>0.25 (4.5)</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>0.16 (2.8)</td><td rowspan="2">B</td><td rowspan="6">A</td></tr>
<tr><td>0.1 (1.8)</td><td rowspan="2">B</td><td rowspan="5">A</td></tr>
<tr><td>0.063 (1.12)</td><td rowspan="4">A</td></tr>
<tr><td>0.04 (0.71)</td><td rowspan="3">A</td></tr>
<tr><td>0.025 (0.45)</td></tr>
<tr><td>0.006 (0.112)</td></tr>
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[1] For additional assistance see the "Application Guide for PC420-series LPS® Transducers", Wilcoxon Research, Inc.

The advantage of using 4-20 mA based vibration data is that there is no complex analysis to perform. The data is the overall vibration of the machinery. While the overall vibration level does not change significantly in the early stages of machinery mechanical fault development, it will change significantly for most machine faults during the last three months prior to failure. The overall vibration level does not contain sufficient information to determine the specific machine fault, but it can serve well as a "pointer" to problem machines. The long-term trend data will confirm that a problem is developing as it will show that a true increase in the vibration occurring. An astute mechanical maintenance department can generally find the specific machine fault once alerted to a change in the overall vibration level.

The main disadvantage of 4-20 mA vibration data is that it contains no specific pointers to problems. The overall vibration can usually only point to the machine. Multiple sensors on machinery "sets" such as a motor-pump or motor-fan set can aid in focusing on the component of a machine set. With sufficient sensors or with band-limited signal processing, certain types of problems can be diagnosed. However, these implementations will also increase the monitoring system cost.

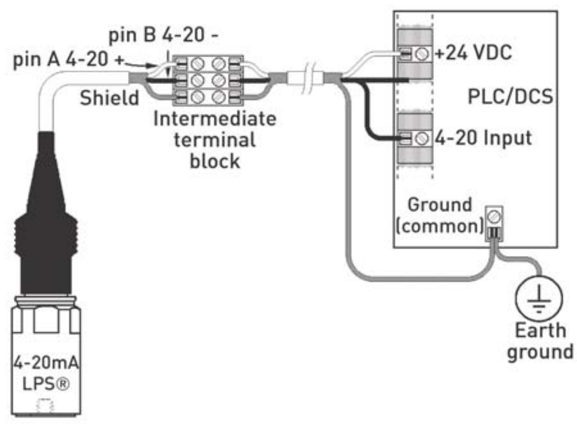
Sensors for 4-20 mA process loops

The transducers that are available for vibration sensing offer a wide range of monitoring options. They can output 4-20 mA loop current as a velocity of vibration signal, or as an acceleration signal. The transducers use a piezoelectric acceleration sensing element as the heart of the sensor and include electronic circuitry, powered from the 24 Volt DC power of the process system.

The internal circuitry allows these sensor to be configured in a variety of ways. They usually offer the output calibrated in true root-mean-square (r.m.s.) amplitude or in peak output. The peak output is usually just a derivative of the processed r.m.s. signal, equal to 1.414 times the calculated r.m.s. as this is the ratio of peak to r.m.s. for a sinusoidal waveform. Wilcoxon also offers a 4-20 mA output that is "true peak" and it actually captures the real peak amplitude of the signal being measured. The sensors can be customized with built-in high-pass and low-pass filters to focus on just the range of frequencies of interest to the user, offering trending of specific types of vibration problems.

As the use of these loop-powered sensors has become popular the demand to be able to install and operate them in hazardous classified areas has also increased. 4-20 mA sensors are available as Intrinsically Safe certified units as well as in Explosion-Proof housings. This allows their use in those areas classified under NEC® section 500 as classified hazardous areas.

The real advantage of using the 4-20 mA loop-powered sensors is that they are simple to install and wire, as illustrated to the right. Using shielded, twisted pair wires one conductor brings the 24-Volt power to the sensor, the other carries the 4-20 mA signal back to the DCS/PLC analog 4-20 mA input.

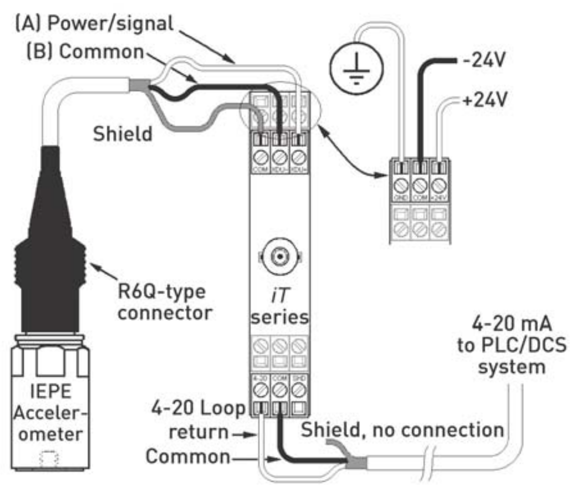


Transmitter modules for 4-20 mA process loops

In some plants, accelerometers have already been installed permanently on machines to aid the vibration data collection process. These are often located on equipment in hard-to-reach areas or for safety reasons. These already existing sensors can also be used for gathering 4-20 mA vibration signals. The transmitters are powered from 24-Volt DC supplies and output a processed signal quite similar to that produced by the 4-20 mA sensors.

These modules offer more power and space for signal processing than the sensor version. The transmitters can also implement stronger filtering with more filter options than the sensor. Whether the user wants to trend the entire vibration spectrum of signals or focus on a small range within the possible spectrum, the transmitter modules give more options for the user.

In addition to the advantage of being able to use existing installed dynamic accelerometers, the transmitter modules can be tailored for the frequency range of interest to alert specific machine faults. Multiple modules can easily use the same accelerometer to process different frequency bands for comprehensive fault identification. Using multiple modules also allows developing both acceleration and velocity 4-20 mA loop signals.



The input, power, and output wiring connections for vibration transmitters are illustrated to the right. The accelerometer connects directly to the vibration transmitter. The 4-20 mA output of the vibration transmitter wires directly to the PLCor DCS system input.

One disadvantage of transmitter modules is that they require power to operate. Either AC or DC power must be available. Depending on where they are mounted, this may not be an issue.

A hybrid monitoring system

Using vibration trending data from 4-20mA sensors and vibration transmitters is a cost effective alternative to traditional PdM programs. In some applications, i.e., spared equipment and non-essential equipment, 4-20mA trending provides an excellent total cost effective solution. However, in more critical applications where an effective CBM system is required, analysis of the dynamic vibration data is essential.

An ideal alternative would be a hybrid approach that leverages the best of both options, the cost-effective approach of vibration trending and the more complete FFT dynamic analysis approach. This is now possible through a hybrid approach that employs dual output devices, either a sensor or vibration transmitter. The 4-20 mA vibration sensors and the vibration transmitters are now available with the 4-20 mA processed output for the PCS, as well as a “buffered” dynamic signal output available for the Vibration Analyst’s portable data collector.

The dynamic buffered output signal allows traditional vibration analyses to be performed. This means only one sensor can perform two monitoring functions. It can trend the overall equipment condition through the PCS and the dynamic data is available for use by the Vibration Analysts as a permanently mounted sensor for the further analysis. Besides the buffered dynamic output, some models also have a third option for temperature measurement as well. In those cases the user can have both the buffered dynamic signal and the temperature signal. Wilcoxon offers the triple output option (4-20, dynamic, temperature) sensor in a low-profile side-exit connector case style. With the addition of the temperature signal, the sensor now can implement temperature trending with vibration. This is a powerful complementary tool for confirming a developing mechanical fault.

The hybrid implementation presents a win-win opportunity for plants. Essentially this provides continuous monitoring of equipment with early warning of pending trouble in sufficient time to employ a contract Vibration Analyst to collect and analyze buffered dynamic data on an ‘as needed’ basis. This truly cost-effective system will allow CBM to expand its market into new industries and equipment for much more cost-effective plant operation.

Using 4-20 mA vibration sensors or transmitters with a DCS or PLC system allows plants the ability to have overall vibration data on a very frequent basis. The data can then be trended to allow the system to alarm when trends indicate a problem developing. Wilcoxon Research, Inc. also has an application guide available to assist in interpreting the meaning of the overall levels and setting alarms and automatically editing data to eliminate “wild points” in the data that can cause false alarms.

Having vibration data available on-line for critical machines can allow the maintenance management staff to always be aware of the general vibration condition of those critical machines. As the machines that need to be monitored change, the system can be adapted readily to account for more machines. The data is straightforward and easy to interpret. The flexibility of 4-20 mA loop signals allows the sensors to be re-positioned where necessary or the system to be expanded. The result is a flexible system that can be used to manage risk regarding machinery health condition monitoring. The primary objective for modern plant monitoring systems is to manage the risk while minimizing the associated cost of data.

Summary

4-20 mA transducers and transmitter offer plants the ability to monitor vibration on a continuous basis. The 4-20 mA loop signal is the de facto standard for plant process control signals. Where plants already have existing process control systems (PLC or DCS) vibration can be added without the need for resident technical staff to assist in data interpretation. While on-line dynamic systems offer the advantage of detailed diagnostic ability, they come with the added cost of requiring an analyst to interpret the data. Off-line dynamic signal monitoring (walk-around data collector) systems also offer detailed diagnostic ability with a low entry cost, but with a very high continuing annual cost.

Modern lean management can take advantage of a hybrid monitoring technique to implement on-line 4-20 mA vibration monitoring of plant machines and employ the services of an experienced Vibration Analyst only when a pending problem is identified. This is an ideal approach for an extremely cost-effective Predictive Maintenance system.