Instrumentation – It's Not Just for Process Control Anymore

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Abstract

One significant resource for asset health information that often goes untapped in many plants is the process control system. Many potential failure modes can be discovered in their early stages using instrumentation that was installed primarily for process monitoring and control. For example, if we are already measuring flows and temperatures across a heat exchanger, we can trend this information to determine if fouling is beginning to occur and calculate the optimum time to take the exchanger offline for cleaning. This paper will explore some of the more common ways that process instruments can provide asset health indication and discuss how some advances in wireless technology can open the door to expanding this condition monitoring technique.

Condition-Based Maintenance

Since the landmark study report entitled "Reliability Centered Maintenance" was published in 1978 by F. Stanley Nowlan and Howard F. Heap, the "state of the art" for effective maintenance strategies has included condition-based maintenance. Per the SMRP Body of Knowledge Glossary, condition-based maintenance is defined as "an equipment maintenance strategy based on measuring the condition of equipment against known standards in order to assess whether it will fail during some future period, and then taking appropriate action to avoid the consequences of that failure. The condition of the equipment could be measured using condition monitoring, statistical process control, equipment performance, or through the use of human senses." The Nowlan and Heap study indicated that a calendar- or usage-based maintenance strategy was inappropriate for most assets because the dominant failure modes were not wear-out, especially as the assets increased in complexity.

Most maintenance and reliability professionals understand the concept of using condition monitoring to avoid the consequences of failure. The concept of the "P-F Curve," made popular by John Moubray, the author of RCM II – Reliability-centered Maintenance, shows that as an asset begins to degrade toward failure, it usually provides some indication of degradation (see Figure 1 below). If we are able to detect these indications, we can take the necessary action to avoid the consequences of failure. We can schedule the equipment down for repair at a time most convenient to the business instead of allowing the equipment to control the time of failure. The result is a much more proactive response to the problem, a lower scope of repair due to reduced collateral damage, an overall reduction in costs, and (hopefully) a shorter downtime per incident.

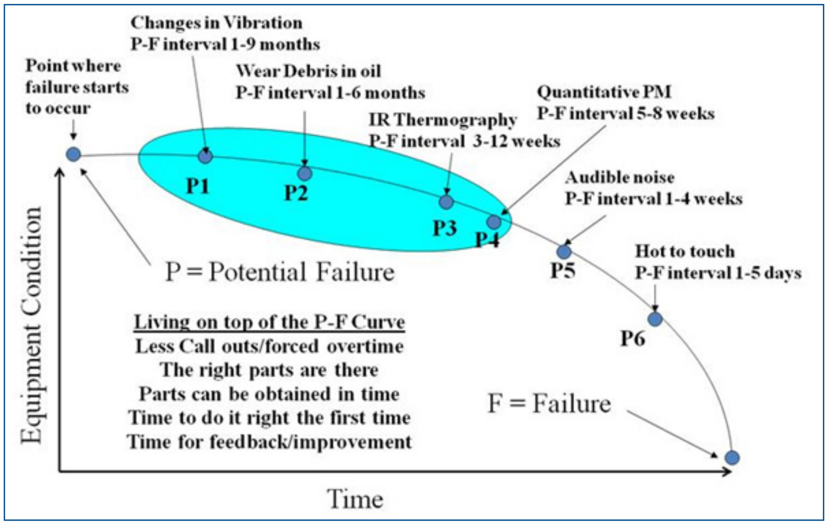

Figure 1 — *P-F Curve.*

Although the P-F Curve is great for illustrating the concept of consequence avoidance, there is one very significant issue. The interval between the potential failure point—where degradation begins to occur—and the point of functional failure is entirely dependent on the failure mode and will vary according to equipment service. In a centrifugal pump for example, the P-F interval for worn wear rings will likely be extremely high for a pump in clean water service, but it may be much lower for a pump that is moving abrasive slurry. Bearing failure in a screw conveyor may exhibit a long P-F interval in lightly loaded and slow-speed service, but it would be much shorter under high loads and speeds. Per Moubray, the checking interval to detect the onset of failure needs to be no less than ½ of the P-F interval, or the potential exists to completely miss the warning signals. With such high variability in the interval, how does one determine the appropriate checking frequency? We will explore this point later.

There is another very significant reason to use condition-based maintenance instead of a time-based approach, and that is to identify the root causes of potential failures. For example, vibration due to misalignment between the motor and driven equipment due to poor installation techniques can be detected by vibration analysis, and corrective action can be taken before significant damage occurs. Similarly, cavitation in a pump caused by low level in the suction tank can be detected in time to rectify the problem before impeller wear causes a loss of capacity. The use of condition monitoring for this purpose actually improves reliability because it offers the opportunity to remove the root causes of failure before equipment damage has occurred.

Failure Mode Detection

Several technologies can be used to detect problems in machinery well in advance of a functional failure. As noted in Figure 1 above, vibration analysis, oil analysis, and infrared thermography are some of the most common. Others common technologies include ultrasonic leak detection, contact ultrasonics, ultrasonic thickness testing, and motor circuit analysis. Less common technologies are remote visual inspection, eddy current testing, radiography, magnetic particle, and liquid dye penetrant testing. However, many equipment failure modes can be detected in their early stages through the use of common process measurements such as flow, pressure, temperature, level, and position. Many process plants already have the capability of using these techniques for condition monitoring but fail to do so, primarily because instrumentation is perceived to be only for process control.

Although the processes in use and the products produced by manufacturing plants around the world vary widely, most have similar types of equipment. For this discussion, we will focus on some of those common assets:

- Centrifugal pumps
- Shell and tube heat exchangers
- Centrifugal compressors
- Blowers and fans
- Cooling towers

Figure 2 below indicates some of the typical failure modes of centrifugal pumps and the process parameters that can be used to detect them. As with the other rotating machinery in these examples, failure modes will require the traditional condition monitoring technologies such as vibration analysis, oil analysis, and infrared thermography.

Failure Mode	Detected By
Worn wear rings	Changes in flow
Worn impeller	Changes in flow
Worn pump casing	Changes in flow
Plugged impeller	Changes in flow
Loose impeller	Changes in flow
Seal leak	Seal pot level
Bearing problems	Changes in temperature

Figure 2 — *Centrifugal Pumps.*

Figure 3 below indicates some of the typical failure modes of shell and tube heat exchangers and the process parameters that can be used to detect them.

Failure Mode	Detected By
End cap baffle failure	Changes in temperature
Internal end cap gasket leak	Changes in temperature
Tube fouling	Changes in temperature
Plugged tubes	Changes in temperature or flow
Air trapped in heat exchanger	Changes in temperature
Tube to tubesheet seal failure	Changes in temperature or flow
Tube rupture	Changes in temperature or flow
External leak	Changes in flow

Figure 3 — *Shell and Tube Heat Exchangers.*

Figure 4 below indicates some of the typical failure modes of centrifugal compressors and the process parameters that can be used to detect them.

Failure Mode	Detected By
Bypass valve failed open	Changes in flow
Discharge check or block valve partially closed	Changes in flow or pressure
Inlet guide vanes partially closed	Changes in flow
Intercooler failure	Changes in flow or temperature
Worn impeller	Changes in flow
Plugged inlet filter	High differential pressure or changes in flow
Aftercooler failure	Changes in temperature
Bearing problems	Changes in temperature

Figure 4 — *Centrifugal Compressors.*

Figure 5 below indicates some of the typical failure modes of centrifugal blowers and fans along with the process parameters that can be used to detect them.

Failure Mode	Detected By
Worn fan wheel	Changes in flow
Inlet control vanes partially closed	Changes in flow
Drive belts slip	Changes in flow or pressure
Inlet screen obstructed	Changes in flow or pressure
Expansion joint failure	Changes in flow or pressure
Inlet filter plugged	Changes in flow or pressure

Figure 5 — *Blowers and Fans.*

Figure 6 below indicates some of the typical failure modes of cooling towers and the process parameters that can be used to detect them.

Failure Mode	Detected By
Degraded internals	Changes in temperature
Fan bearing failure	Changes in temperature
Fan gearbox failure	Changes in temperature
Fan motor failure	Changes in temperature
Plugged media	Changes in temperature
Plugged discharge screen	Changes in basin level
Basin cracked	Changes in basin level
Plugged holes in the distribution box	Changes in temperature
Drift eliminator failure	Changes in makeup water flow

Figure 6 — *Cooling Towers.*

The Total Condition Monitoring Solution

As seen in the examples listed above, process parameter data should be used with the traditional condition monitoring technologies to gain insight into equipment health. However, with some additional instrumentation, we can get an even more comprehensive picture of asset health and root cause determination. For example, on all rotating machinery, vibration transmitters can be added to the driver and driven machines, and temperature transmitters can be placed in the lubricant system and bearing caps.

On centrifugal pumps, pressure transmitters on both the suction and discharge piping can help detect (along with vibration) incipient cavitation. This data, along with flow measurement, can provide operators with sufficient information to enable them to keep the pump operating at its best efficiency point for maximum reliability. Addition of a pressure transmitter on the seal pot can give indication of a seal leak.

On shell and tube heat exchangers, measuring the flow through both the hot side and cold side along with the temperature differential can enable calculation of actual heat duties on both sides and the actual heat transfer coefficients. Trending this information can help the site determine the rate of fouling and determine the optimum time for cleaning or tube bundle replacement. If corrosion is an issue, corrosion transmitters can be added to detect this.

Centrifugal machines, such as blowers, fans, and compressors can benefit from the addition of position transmitters on any inlet or discharge vanes to provide feedback to the flow control loop. If the unit is variable speed, a speed transmitter can provide the necessary feedback and ensure that the unit is not operated near a critical speed. Differential pressure transmitters across the inlet filters can facilitate determination of the optimum filter change interval. Electrical current measurement can determine the actual loads on the system and help identify system-related problems such as baghouse filter blinding.

A forced-draft cooling tower presents several opportunities for the addition of instrumentation for condition monitoring. Temperature measurement across the tower can provide indication of the actual approach temperature and can help determine efficiencies. The potential for scaling, corrosion, and biological growth can be determined by installation of pH, ORP, and conductivity sensors. Flowmeters can be added to the blowdown and makeup systems to help control the cycles of concentration in the basin and minimize makeup water consumption.

Expanding Condition Monitoring

The effort that most organizations place in condition monitoring is usually determined by asset criticality—if the asset is highly critical, more in-depth monitoring is justified. This is why large, valuable rotating equipment, like turbines and compressors, are usually equipped with expensive continuous monitoring systems. However, as can be seen from the above examples, even less critical assets can benefit from extensive condition monitoring. In fact, benchmark data indicates that the deeper throughout the asset base that condition monitoring is employed, the lower the operating costs and the higher reliability the site will enjoy. In addition, knowledge of asset condition can help reduce the likelihood of those unexpected equipment failures that invariably happen on nights or weekends.

Using a route-based strategy to access additional condition monitoring points is labor intensive because valuable technician time must be spent on non-productive travel time to get to the field. This is even more of a drawback when the conditions in the field warrant additional preparation time such as getting permits or wearing special clothing. Additionally, many plants are experiencing shortages of skilled labor due to an aging workforce. Rather than consuming technician time making trips to the field, time is better served in analyzing the information derived from condition monitoring sources. Therefore, permanently installed instrumentation should be considered any time a condition monitoring strategy is defined for an asset.

In addition to the labor savings to access information, permanently installed sensors offer a number of advantages. Technicians don't have to be sent out to hazardous areas where their safety could be at risk. If an asset is not required to operate continuously, scheduling a condition monitoring route can be challenging because the technician's schedule must be aligned with the operating schedule. Although this is not an insurmountable barrier in plants with their own predictive maintenance staff, it is frequently an issue in plants that use contract predictive maintenance services. Readings can be taken from permanently installed sensors at any time, and the results can be saved for later analysis. And finally, permanently installed instruments solve the problem discussed earlier—the high variability in the P-F interval for different assets and different failure modes. Permanently installed sensors make the checking frequency infinitely adjustable.

In the past, the high installation cost of permanently mounted sensors has limited the number of instruments that can be used for remote condition monitoring. However, relatively recent advances in wireless technology have dramatically reduced the per-point installation cost (up to 50%), enabling a wider deployment of devices whose purpose is primarily condition monitoring. A wireless network also presents a number of additional advantages:

- It is easily expandable to accommodate additional instruments; a single gateway can support up to 100 measurement points
- The network is "self-healing" because each wireless instrument functions as a repeater for other instruments, providing many paths from one instrument back to the gateway
- It can help eliminate "blind spots" where it was previously too expensive or difficult to install wired instruments
- Battery life on most wireless instruments is extensive; it can be up to five years depending on the sampling rate
- Wireless makes scope changes relatively inexpensive because additional instruments or gateways can be added very easily

If an organization wants to expand its condition monitoring footprint, a wireless network would likely be the most cost-effective solution.

As condition monitoring points are added, the organization should resist the temptation to bring all the data back to the operator's control station. This can quickly result in information overload, and some of the subtle changes in equipment condition can be missed. The condition monitoring information should be reviewed by reliability technicians who are familiar with the purpose of the measurement, understand what to look for, and can investigate potential problems to verify that they are indeed due to a developing problem.

Summary

Organizations that experience top quartile performance in maintenance costs and reliability share a common trait—they have a deep desire to understand the operating condition of their assets to ensure that their business goals are achieved and that they do not suffer unexpected failures and downtime. Much of this operating condition information can come from process instrumentation already being used for process control purposes, and wireless technology can offer a cost-effective means to expand the number of monitoring points. Expanding the use of condition monitoring will help the organization take a more proactive approach to managing their assets and will result in improved cost and reliability performance.

Keywords

Instrumentation, Condition monitoring, Wireless, P-F interval, Predictive maintenance, Failure modes, Process control, Process monitoring, Root cause

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