Whitepaper

3 Innovative Ways to Improve Pump Reliability

EMERSON
Process Management

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Benefits of pump health monitoring

New pump health monitoring solutions combine process and equipment data to drive higher reliability through a more holistic view of pump health.

This paper will focus on basic and advanced monitoring techniques for centrifugal pumps as they are the most prevalent in industrial process applications.

Pumps are essential to the daily operation of industrial processes. They are the workhorses of the plant, and need constant maintenance to ensure the availability of the business. Pumps begin to degrade the day they start up, and the challenge is to know when and how to intervene before they contribute to a critical plant shutdown or slowdown, affecting the company's bottom line.

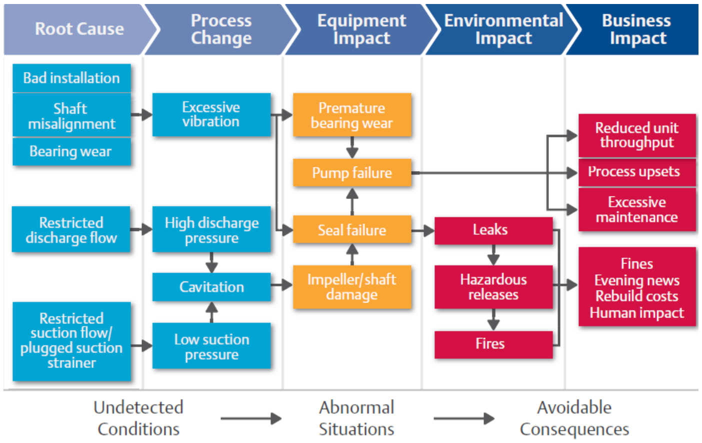
A typical pump failure can cost hundreds of thousands of dollars and the bigger the incident, the more likely it is to draw media attention. This can negatively impact your public image and the value of your stock, as well as increase the possibility of fines and government involvement. Or worse yet, serious problems may affect the safety of plant personnel and nearby communities.

A few pumps deemed as critical to operation may have online condition-based monitoring in place. These systems minimize unnecessary maintenance common with preventive (time-based) maintenance, while avoiding catastrophic failures that can lead to expensive repairs, fires, and plant downtime. In a typical oil refinery, these may account for approximately 10% of pumps. That leaves about 90% of pumps subject to manual rounds of a technician to acquire data and assess pump condition, preventive maintenance tasks, or running-to-failure.

It is estimated that pumps account for 7% of the total maintenance cost of a plant or refinery, and pump failures are responsible for 0.2% of lost production(1). These avoidable costs could be significantly reduced if the unmonitored pumps had online condition monitoring. To decide where to begin applying online condition monitoring, look at those pumps that are at risk to cause process upsets and downtime, often taking hours or days to recover normal operations.

(1) *InTech, 2012. “Improve reliability with essential asset monitoring.”*

Figure 1. Typical root causes of pump failures and resulting impacts



Basic pump maintenance is usually performed either through manual rounds or online condition-based monitoring (CBM). The goal is to prevent failures that require expensive repairs and cause process slowdowns or shutdowns. However, manual monitoring is typically very expensive.

And unfortunately, preventive maintenance and manual rounds are not always enough to identify degrading performance in time to take action. Most pumps do not operate at optimal efficiency, as processes were not designed for the pump to run at its Best Efficiency Point (BEP). Some pumps may be over-sized to accommodate design contingencies and planned increases in throughput capacity, or have been stretched beyond their design and capacity limits due to production demands. This introduces higher stress on pump system components, leading to higher maintenance requirements.

Historically, the expense of installing dedicated online monitoring systems or maintaining wired inputs, as well as overfilled cable trays and highly congested areas, has prevented online condition monitoring from being expanded beyond the most critical pumps. But with the relative ease of adding online pump condition monitoring with today's technology, targeted services now include:

- Pumps with repeat failures
- Pumps without spares
- Pumps that can cause a fire or environmental incident
- Pumps that can lead to a significant process disturbance, process shutdown or slowdown
- In summary, any pumps that previously were not considered critical enough to have wired monitoring systems in place

Plants may not have initially invested in online monitoring for pumps that have an installed spare. But the reason for including an installed spare is because it is expected that the pump will need maintenance before the next overall turnaround maintenance shutdown. If the operating pump is allowed to run-to-failure, it typically makes matters worse by increasing maintenance time and cost to repair the damage. The spare pump may take time to start up, which can prevent an operator from making a "bumpless" transfer to a backup pump. This could create a process upset from which hours or days are required to return to normal operation, in addition to the costs of repairing the pump that was run-to-failure. Furthermore, it is much more difficult to take a failed pump out of service and commission the spare pump if the failed pump is leaking process material or burning.

Many pump failures can be predicted using modern monitoring techniques. New innovative reliability-centered practices for pump monitoring are covered in this paper, specifically: pump seal leaks, cavitation and vibration related failures. By using predictive maintenance techniques, customers can minimize environmental and business impacts.

The following are three innovative methods for increasing pump availability using predictive technologies and reliability-centered maintenance best practices:

Pump seal monitoring

The latest edition of API Standard 682 now shows a preference for level and pressure transmitters instead of level and pressure switches in order to provide the signal to annunciate the level or pressure alarms. The use of transmitters provides an improved view of the pump seal flush reservoirs. A level signal also allows for monitoring the rate of change of a reservoir level for earlier indication of potential seal failure.

Cavitation monitoring

For high head multistage pumps that cannot tolerate cavitation even for a brief time, users monitor discharge flow and pressure, the integrity of the level instrument on the suction vessel, and the differential pressure across the suction strainer to help prevent cavitation from occurring.

Vibration monitoring

Vibration monitoring allows for the detection of the presence of any one of many common causes of pump failure, such as worn bearings, worn shaft coupling, misalignment, impeller damage, cavitation, foundation or frame faults.

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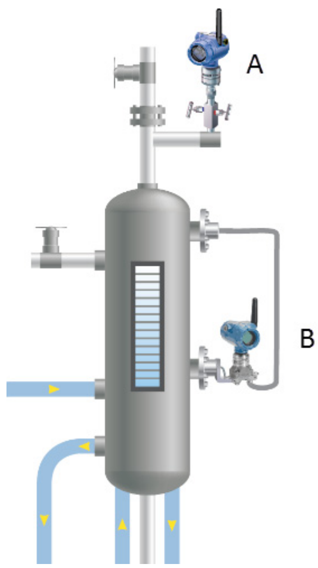
1. Pump seal monitoring/seal fluid reservoirs

Dual mechanical seals are typically used in applications that require a more effective seal than packing or single mechanical seals can provide. These finely machined surfaces have one side affixed to the pump case and one to the shaft. The space between each seal is filled with a seal flush fluid to provide lubrication and remove heat. Contaminants can quickly degrade a seal, but with proper flushing, they can last thousands of hours.

Auxiliary seal flush systems can be pressurized or unpressurized. Unpressurized seal flush systems are designed to leak process fluid into the seal fluid, referred to as a “buffer fluid,” which can then leak to the environment through the outboard seal. Dual mechanical seals with pressurized seal flush systems prevent this potential leakage of process fluid to the environment.

Figure 2. API Piping Plan 52 unpressurized auxiliary seal flush system for online measurements



A. Pressure transmitter
B. Level transmitter

Figure 2 shows a representation consistent with API Piping Plan 52 for an unpressurized seal flush system common with hazardous products, as it provides a clean external buffer fluid to protect the environment. A rising pressure measurement indicates a leak from the process to the buffer fluid when the pumped process fluid vaporizes at atmospheric pressure. Similarly, a rising level indicates a leak from the process to the buffer fluid, if the pumped fluid remains in the liquid phase at atmospheric pressure. A slowly decreasing level is normal, but a sudden increase in the rate of level change indicates that the buffer fluid is leaking across the outboard seal to the environment.

Local pressure gauges are easily replaced with indicating wireless pressure transmitters to provide continuous online monitoring to give early indication of a leak. This can be monitored with the control system or by having an online predictive asset health monitoring system that can interpret rising pressures and provide actionable information.

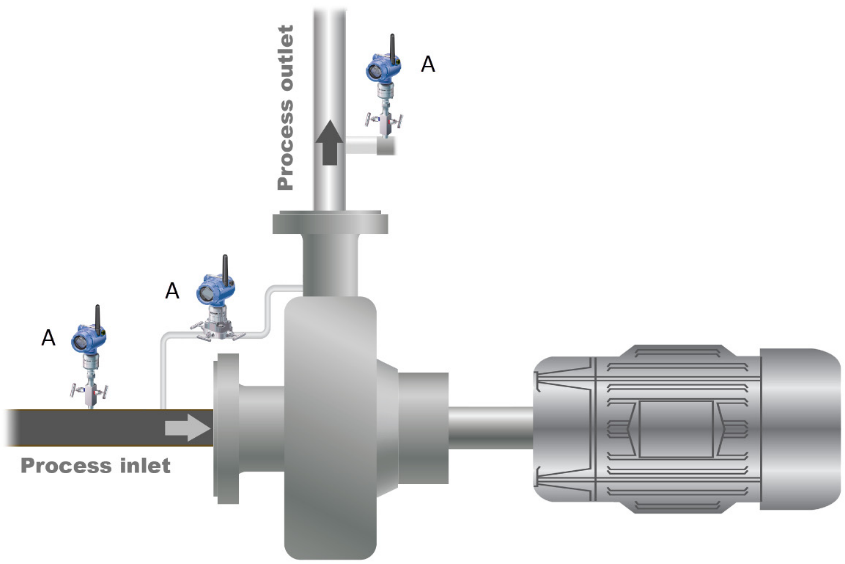
The seal flush reservoirs must be refilled periodically. Manual rounds are often adequate, but if the fluid runs dry, it can cause seal failure with the consequent expensive repairs and a risk of injury and environmental impact, hence the reservoirs have been specified with low level alarms. However, the latest version of API Standard 682 (the fourth edition) indicates the use of hydrostatic level technology for continuous level measurement instead of switches to provide the signal for the low level alarm. Care must be taken to properly install the hydrostatic level technology so that it delivers the expected results. For example, the measurement can be impacted by varying amounts of liquid in the reference leg when wet legs are used. Continuous monitoring of the reservoir level allows the user to identify when and where flush fluid should be replenished. In addition, using the analog level indications from a transmitter, an online monitoring system can monitor the rate of change on the level measurement to alert operations or maintenance when the fluid depletes faster than normal. This enables operations more time to switch to the spare pump and turn the operating pump over to maintenance personnel.

In some cases, the reservoir flush fluid may change density as contaminants or process mix with the seal flush fluid. In this scenario, wireless guided wave radar transmitters may provide a more accurate seal flush reservoir measurement than hydrostatic level. Accuracies of up to +/- 0.2" (5mm) can be achieved over the level span, and guided wave radar is not subject to the errors caused by loss of fluid in the wet reference leg of hydrostatic level installations. Optimally, the guided wave radar level transmitter should be installed on the top centerline of the reservoir, and can extend the entire length of the reservoir giving insight to the actual level over a broader range than what is indicated in the API Standard 682. Alternatively, the instrument can be mounted along the side of the reservoir in an external chamber.

2. Cavitation

Centrifugal pumps accelerate liquids to higher velocities, creating a drop in static pressure at the pump suction. If the liquid pressure falls below its vapor pressure, bubbles form and as the pressure rises, the bubbles implode causing mechanical damage on impellers and interior pump case surfaces. This state, called cavitation, can damage pump components, disrupt flow, accelerate bearing wear and lead to seal failure.

Figure 3. Pump Discharge Pressure Monitoring for Cavitation Alerts



A. Pressure transmitter

Although cavitation often happens when pumps operate outside of their design ranges, it can also be caused by intermittent pump suction or discharge restrictions. Damage can occur before manual rounds discover this problem, but may be detected sooner by monitoring the pump discharge pressure for fluctuations, as shown in Figure 3.

Some advanced pump monitoring solutions monitor discharge pressure fluctuations to give “pre-cavitation” alerts when cavitation is suspected. When these increases in pressure fluctuation are correlated with increasing peak impacting measurements, (discussed in the next section, “Vibration”), it is an indication that the pump is likely experiencing cavitation. Cavitation detection through a combination of pressure and vibration monitoring is an example of a more holistic view of pump health that can be achieved through a combination of process and equipment measurements.

However, for high-head multistage pumps that can be damaged with even brief periods of cavitation, the pump monitoring regimen should also include the robustness of the level measurement in the suction vessel, the differential pressure across the pump suction strainer and the integrity of any automated isolation valves around the pump suction and discharge that may inadvertently move and cause blockage which will lead to cavitation.

3. Vibration

Pumps produce vibrations across a broad spectrum indicating running condition, faults and failures. Vibration transmitters measure this vibration and de-construct the composite signal into a series of frequencies across a broad spectrum that can give particular insight into the nature of what is causing the vibration.

Excessive motor and pump vibration can be caused by failing concrete foundation or metal frame, shaft misalignment, impeller damage, pump or motor bearing wear, coupling wear, and cavitation. Increasing vibration commonly leads to seal failure, and can result in expensive repairs, process upsets, reduced throughput, fines if hazardous material is leaked, and the risk of a fire if the leaked material is flammable.

Online vibration monitoring has been successful in detecting several root causes of pump degradation. However, the traditional overall vibration measurement alone has limitations and may not provide information early enough to avoid failure. For example, bearings with a life of 100% display the same overall vibration as those with 10% of remaining life, and very little change is indicated at even 1% of remaining life.

Figure 4. Traditional Vibration Measurement

Stage	Bearing Life	Vibration (in/sec)	PeakVue (g's)
0	20-100%	0.15	0
1	<20%	0.15	4
2	<10%	0.15	8
3	<5%	0.16	12
4	<1%	0.18	25
Failure	0%	>0.30	>40

A B

A. Traditional vibration measurement shows a minimal change until failure is imminent or has occurred.
B. PeakVue™ vibration measurement shows a significant change in value approaching failure.

Note

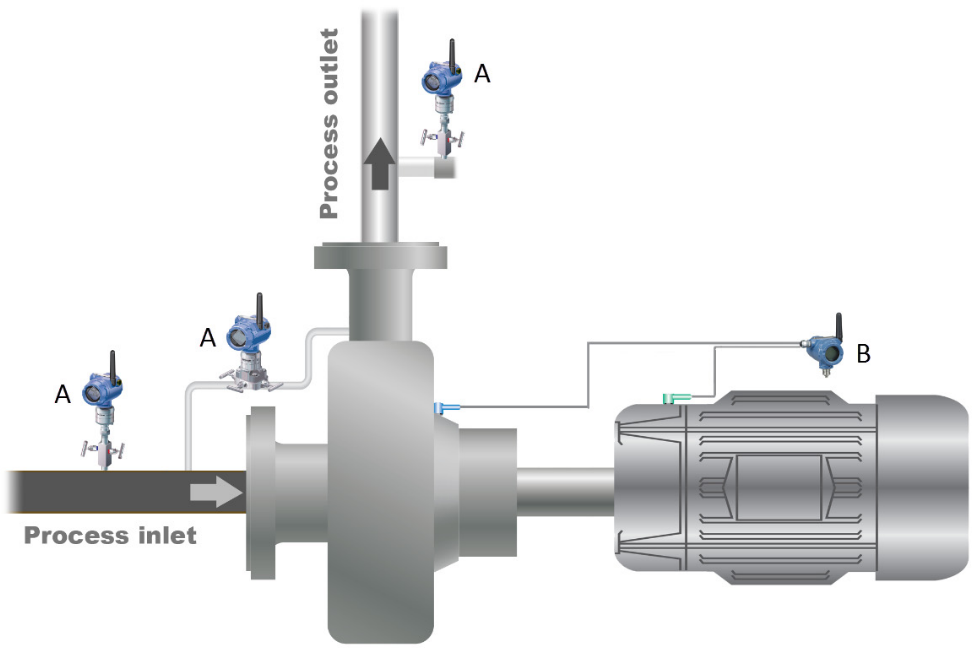
Figure 4 shows a typical application where the pump and shaft vibration are being monitored, showing that vibration can only detect bearing failure, and cannot give early warning.

New technologies are available to measure high frequency impacting faults, such as cases where metal comes into contact with metal, to give early warning of rolling element bearing faults. This peak impacting measurement technology, measured as G's of acceleration, can detect bearing failure with more than 10% life remaining, providing much more time for preventive action.

Note

Figure 5 shows two accelerometers measuring vibration and peak impact on the pump and shaft, transmitted by a single vibration transmitter.

Figure 5. Vibration and Peak Impact Measurement



A. Pressure transmitter
B. Vibration transmitter

Prediction of fault conditions

Table 1 gives a summary of the most frequent fault conditions of pumps and the measurements that can give early warning or indication of failure. Seal fluid level and pressure, pump discharge pressure and peak impacting measurements are the "early warning system." Vibration and temperature indicate failure and are useful for root cause analysis. Modern pump health monitoring solutions are able to observe the overall health of a pump using a combination of both process and machine data, a critical component of a predictive maintenance program.

Table 1. Measurements that should be brought online to detect pump fault conditions

Fault Condition	Vibration	Peak Impacting	Pressure (Discharge, Differential and Seal Fluid)			Seal Fluid Level	Temperature	Leak Detection
High Vibration	☑							
Cavitation		☑	☑					
Bearing Fault		☑						
Pre-cavitation			☑					
Low Head			☑	☑				
Low Discharge			☑					
Seal Pressure				☑				
Low Suction				☑				
Low Flow				☑				
Strainer Fault				☑				
Seal Failure					☑			
Seal Fluid Level						☑		
Bearing temp							☑	
Liquid HC Leak								☑

According to Plant Engineer's Handbook by Keith Mobley, Predictive Maintenance enables:

- Maintenance costs - down 50%
- Unexpected failures - reduced 55%
- Repair and overhaul time - down 60%
- Spare parts inventory - reduced 30%
- 30% increase in machinery (MTBF)
- 30% increase in uptime

Process data like discharge and suction pressure, strainer differential pressure, seal oil pressure and seal oil level, combined with overall vibration data, impacting data, pump bearing temperature, pump speed, and run/stop indication are used to give the earliest warning, like "pre-cavitation" alerts, that can be easily understood by operators and maintenance without the need for machinery experts to interpret the data. Some advanced pump health monitoring solutions on the market today even offer pre-engineered algorithms on a combination of process and equipment data to report asset health.

Pump monitoring solutions can, and should, be customized to a particular process environment and pump design. They are fully scalable, ranging anywhere from simple condition-based monitoring on a single variable to advanced alarming across a range of pump states and operating ranges

The challenge with condition monitoring is providing the diverse needs of both operations and reliability teams with the correct data to enable strategic interpretation and actionable information. Operators may require alarming on serious conditions like seal leaks or cavitation to prevent fast occurring and severe pump damage. Meanwhile, reliability teams often have enough visibility for longer term planning including ordering parts to reduce spare inventory and just-in-time work order management for maintenance. Predictive maintenance is essential to enabling lean reliability programs.

Wireless technologies is a key enabler

Every measurement solution described above can be accomplished with wired or wireless transmitters. The challenges with retrofitting wired 4-20 mA or FOUNDATION™ fieldbus solutions are their complexity, installation difficulty and significant cost.

Many pumps are located in hazardous or difficult to reach areas. In many of these cases, using wired transmitters may be too expensive to be feasible.

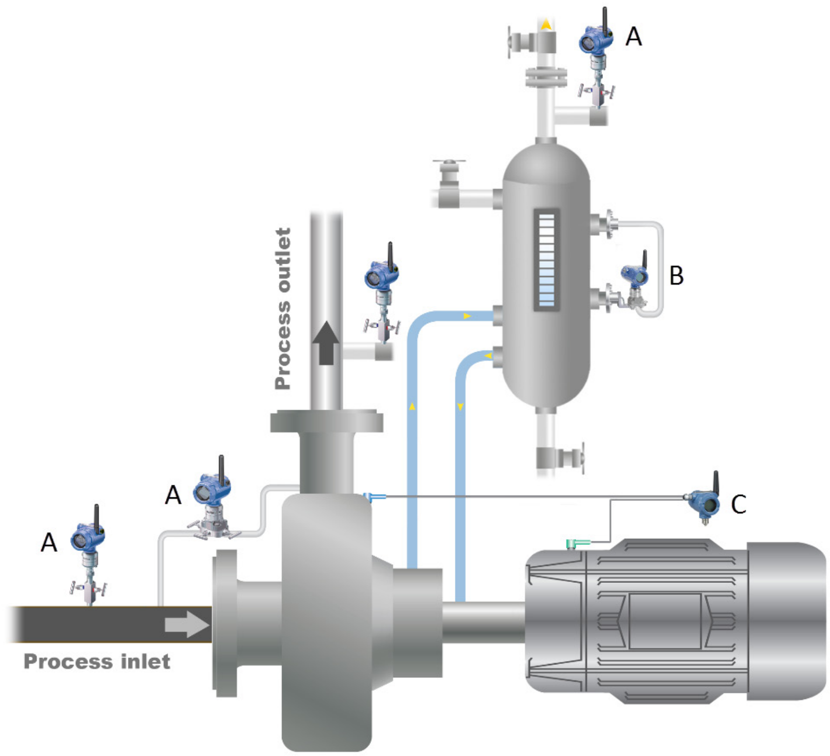
However advances in wireless technologies have led to a growing alternative to wired sensors. Wireless technology has advanced to meet the rigors of the industrial sector, and has enabled plants to greatly expand the number of online measurements economically. The chief advantages of wireless systems are that they are easy to add and install virtually anywhere in an efficient, timely and cost-effective manner.

Battery-powered transmitters require no wired infrastructure, open I/O points or local power supply, so they can be installed in locations far away from a process unit's wired signals. They also do not require the same supporting infrastructure as wired devices, and battery-operated transmitters can operate safely for years in hazardous areas. Installation, therefore, is simple: A typical wireless transmitter can be installed, configured, and commissioned into a control system in a matter of a few hours, as opposed to days or even weeks for its wired equivalent.

Financial benefits of pump health monitoring

A complete pump health monitoring system as depicted in Figure 6 can pay for itself in a matter of months. At one 250,000 bpd refinery, for example, pump monitoring systems were installed on 80 pumps throughout the complex. The annual savings was over $1.2 million after implementing the pump monitoring solution, resulting in a payback period of less than six months. The savings came from decreased maintenance costs of $360,000, and fewer losses from process shutdowns because of failed pumps which were valued at $912,000.

Figure 6. Instrumented Pump Health Monitoring System using Wireless Transmitters



A. Pressure transmitter
B. Hydrostatic level transmitter
C. Vibration transmitter

Conclusion

Serious issues caused by pump failures are costly and avoidable. The challenge is to perform the right maintenance at the right time to prevent hazardous leaks, fires, expensive repairs, process upsets, and downtime, while at the same time preventing any unnecessary repairs. This cannot be done with preventive maintenance and manual rounds alone. Online condition-based monitoring is required, which previously has been limited to critical pumps in most facilities. Predictive maintenance solutions including wireless technologies are changing the landscape of pump health monitoring, making online condition-based monitoring available to virtually any pump in an industrial plant or refinery.

Predictive maintenance using online condition monitoring reduces maintenance costs and catastrophic pump failures associated with infrequent manual rounds by enabling pump repair instead of replacement. It also prevents unnecessary preventive maintenance activities, saving man-hours that can be spent on pumps and other assets that need attention. A critical factor in a highly effective pump monitoring program may hinge on the choice of software application used to analyze pump health from the measured variables and provide timely, meaningful actionable information.

By focusing on automated pump health monitoring, you can get information to the right people at the right time to significantly reduce unplanned production losses and maintenance costs, while improving safety and mitigating recordable incidents.

Emerson Process Management provides pump health monitoring solutions, including Essential Asset Monitoring software, SmartWireless transmitters, and patented PeakVue vibration technology.

For more information visit www.emersonprocess.com/pumps

For more information on improving pump reliability, see www.emersonprocess.com/pumps

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