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The Components of Effective Predictive Maintenance for Pumps

novity®

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The Criticality of Pumps in Manufacturing

Introduction

Industrial Pumps are widely used in industry for moving fluid and gas. Pumps make up a significant portion of motor driven equipment in industrial production facilities and world-wide energy consumption [1]. According to the U.S. Department of Energy, process pumps account for 25% of total motor system energy use in production. Smooth and reliable operation of pumps lowers energy costs when rotational resisting defects are removed [2]. Monitoring pumps using predictive maintenance technologies saves maintenance time, repair costs, and energy costs.

Without reliable pumps, important and critical manufacturing processes will stop, creating a loss of production and productivity of the plants and the people who work there. Often, without early warning, pumps fail, and you experience unplanned downtime.

Unplanned downtime is one of the most significant pain points for industrial manufacturers today, costing Global 500 Industrials $1.5 Trillion each year as noted in a Siemens 2023 report [3]. The report further notes an average of 11% of revenues is lost to unplanned downtime. The risk is even greater for process manufacturing, where a critical equipment failure could result in the loss of an entire batch, environmental hazards, or safety risks.

The key to preventing unplanned downtime is to detect the presence of defects that cause machinery to fail. This is where Predictive Maintenance steps in, to prevent failure in your plant.

Industry	Application
Refinery	Centrifugal pumps are used to move fluids including water used for steam, cooling water for heat exchangers, raw chemicals as feed stock for refining, and resulting product.
Pipelines	In water and chemical pipelines, pumps keep fluids and gases flowing.
Wastewater	Pumps move incoming water from one process stage to the next.
Power Generation	Pumps provide lubrication to critical assets, provide water circulation from source to steam generation, and move natural gas from storage to gas turbines.
Food and Beverage	Pumps move fluid and gas ingredients into mixers and provide cooling towers with water.
Commercial Buildings	Pumps circulate water to internal facilities and through the cooling towers that are critical for climate control.

Table 1: Industry and Pump Applications

> *"Unplanned downtime costs F500 Industrials $1.5 trillion per year."*

Pumps are important assets for process applications in chemicals, pipelines, water/wastewater, power generation, food and beverage, and commercial buildings, Table 1. Pumps keep the flow in your process.

1. Gould Pumps, "Pumps 101: Operation, Maintenance and Monitoring Basics";
2. IEA Energy Efficiency Series, Paul Waide and Conrad U. Brunner, et al. 2011;
3. Siemens, "The True Cost of Downtime Report", 2022

Failure Modes:

To facilitate detection, we need to understand the failure modes of the equipment, and the sensor technology that allows us to detect defects as early as possible. A pump becomes less reliable when the pump's part(s) develop defects. As the defect progresses, the pump eventually fails to perform its function; it's unable to provide adequate flow and pressure to the process. The result is downtime for the equipment and process until the pump is repaired to its functional capacity.

There are many possible failure modes a pump may encounter. For example, a pump may experience hydraulic failure modes, mechanical failure modes, lubrication failure modes, and electrical motor or electromechanical failure modes, as shown in Table 2. Your pumps may face a wide range of defects that cause failure. A holistic sensor approach gives you the best coverage of possible failure modes.

Failure Mode Category	Failure Mode	Sensor (PLC/SCADA)	Sensor (High Frequency)
Hydraulic	Cavitation	Flow, Pressure	Vibration
	Pressure Pulsation	Flow, Pressure	Vibration
	Recirculation	Flow, Pressure	Vibration
	Radial or Axial Thrust		Vibration
Mechanical	Bearing Defect / Wear	Temperature	Vibration, Ultrasonic
	Seal	Flow, Pressure	Ultrasonic
	Misalignment		Vibration
	Looseness	Vibration (RMS, P-P, etc.)	Vibration
	Imbalance	Vibration (RMS, P-P, etc.)	Vibration
	Bent Shaft		Vibration
Lubrication	Viscosity	Lubrication Sensor	
	Water	Lubrication Sensor	
	Oxidation	Lubrication Sensor	
	Wear Particles	Lubrication Sensor	
Electromechanical	Motor Rotor Bar		Current, Vibration
	Shorted Turns		Current
	Eccentricity		Current, Vibration
	Looseness		Current, Vibration
	Power Quality		Current, Voltage
	Torque		Current
	Insulation	Temperature	Current
	Loss of Efficiency	Current	Current

Table 2: Common Failures and Sensors

The above table is not exhaustive, nor does it include process faults potentially seen by pump sensors. A more complete Failure Modes and Effects Analysis (FMEA) will identify the likely and probable failure modes your pumps will experience.

To begin your Predictive Maintenance journey, focus on the most probable and costly failure modes first. Start with sensors and industry standard alert thresholds as a beginning to your failure mode detection journey.

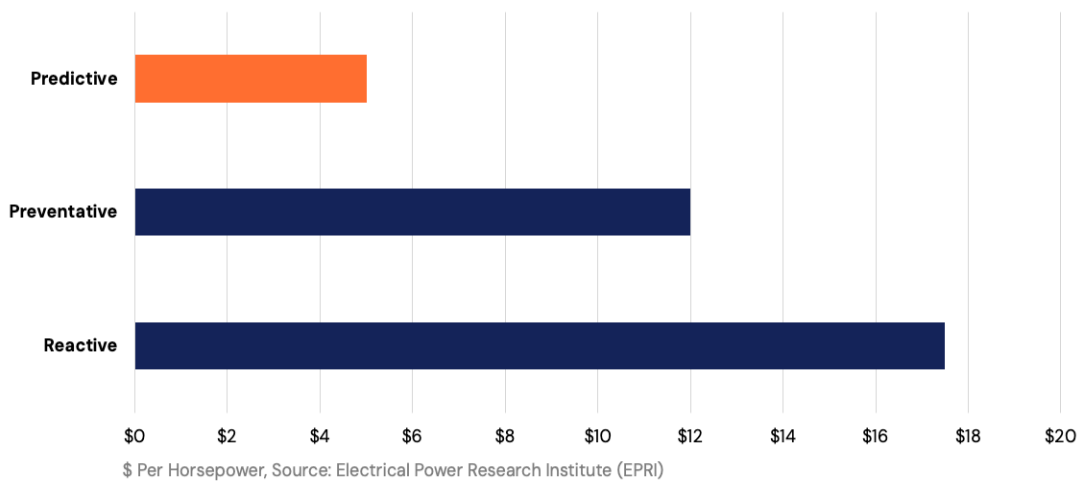
Beginning the Journey from Reactive and Preventive Maintenance to Condition Monitoring and Predictive Maintenance

Vibration sensors are the most used sensors in Predictive Maintenance. Vibration sensors can indicate looseness and imbalance along with the severity of the defect. Using industry standard alerts allows you to move from a preventive (time and usage-based) alignment and balance task to a predictive maintenance-based task where the pump condition, as noted by sensor monitoring, is used to identify a future maintenance need. Lubrication offers a similar example where the presence of contamination or viscosity breakdown moves the task of changing oil from time and usage to an as-needed basis. Changing from a preventive strategy to a predictive maintenance strategy typically extends the time between outages, extending the time equipment produces product. Overall, leveraging sensor data is your place to start, obtaining quantifiable equipment condition data to use in predicting maintenance needs.

Further, the change from your current maintenance posture of Reactive or Preventive to Predictive Maintenance can have a significant impact on your plant's cost of maintenance. Data from the Electrical Power Research Institute illustrates the dramatic change in cost to maintain machinery when moving to an on-condition or predictive posture [4], Figure 1. Figure 1 indicates typical maintenance costs in process industries based on the horsepower of motors driving the machinery, including pumps. The anticipated savings result from a reduction of maintenance costs of 2X or more, plus a reduction in overall downtime.

Further, when taking a predictive maintenance posture, you have more data to infer and investigate root cause. A predictive maintenance posture forms a basis for better root cause analysis and sets up your organization to be more proactive. For example, you can go beyond scheduling a roller bearing change in the future, to understand why the bearing degrades faster than expected. Perhaps you have a lubrication contamination issue. Predictive maintenance practices help you see the trends and help you understand the underlying cause. This allows you to be more proactive and reduce your maintenance costs even further.

Figure 1: Cost of Maintenance Per Horsepower



Predictive Maintenance offers several benefits to your organization. You save maintenance costs by reducing time and usage maintenance, and with early detection of maintenance needs, you can improve your planning and scheduling, optimizing downtime, technician allocation, and parts costs. Further, defects in your pump (and other equipment) create resistance to its function that is often overcome by increased energy consumption. In other words, as your pumps are more reliable, they use less energy.

4. Source: EPRI

The Role of High-Frequency Sensors in Predictive Maintenance

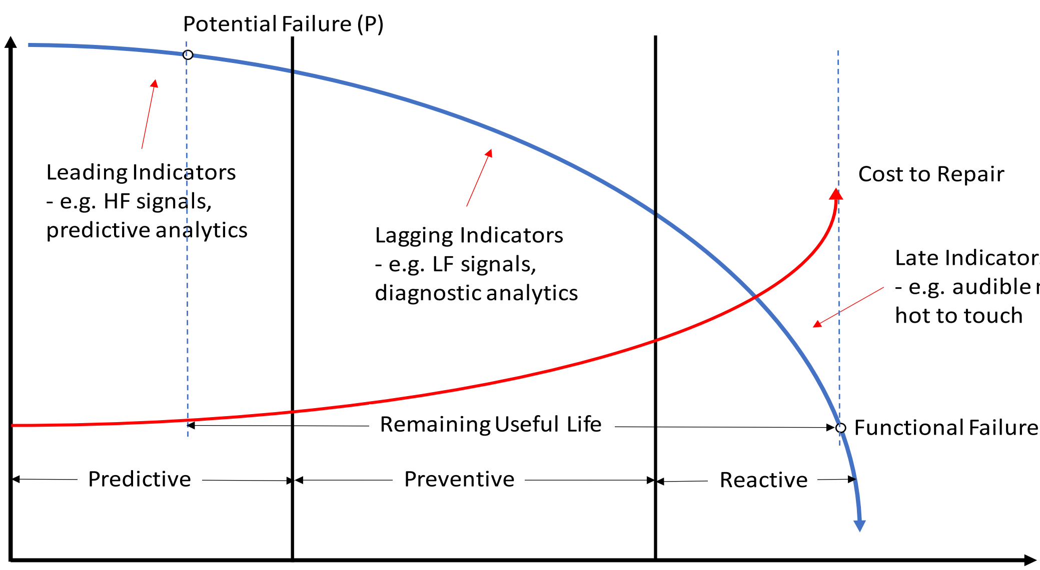
With high frequency sensors, including vibration and current, a likely diagnosis of the acting failure mode can be identified, shortening the time to determine the mitigating action. By obtaining an improved diagnosis, it becomes easier to predict and prescribe specific maintenance mitigating actions. For example, high frequency sensors produce pump defect signals at higher frequency tones. In the case of vibration and motor current, these higher frequency tones help identify early stages of bearing wear, motor rotor bar defects, and pump cavitation events that lead to impeller wear.

High frequency sensors are important in that they enable the ability to specify what action needs to be taken and how soon based on the severity of the defect. In other words, you have an estimate of the Remaining Useful Life (RUL) of the pump's ability to perform its function. This RUL estimate helps you plan an optimal operational window to address the failure mode with a mitigating action. High frequency sensors provide a longer time horizon ahead of functional failure, while offering the opportunity to save energy and repair costs, as shown in Figure 2. The Point of Potential Failure to Failure (P-F) curve gives you a rough idea of the degradation rate. However, it is not linear.

You can use the P-F curve to represent the general degradation curve of an asset. At the upper left of the curve, youfind point "P" representing the first opportunity to detect a defect that leads to functional failure of your pump. There are several opportunities along the P to F curve where you can detect the defect(s) that will lead the asset to failure. This is the role of condition monitoring and predictive maintenance, detecting defects, determining the severity of the defect, and calculating the RUL.

Under the cost to repair curve, the area provides an estimate of risk, cost, and time. This helps you to visualize the benefits of early detection. Without early detection, emergency reaction to failure costs as much as 6 times the cost to prevent the failure by detecting and addressing it early.

Figure 2: Potential Failure Detection to Failure (P-F) Curve



The Physics Behind the Curve

You can get a better understanding of your pump failure modes by using a FMEA or FMECA study. FMECA is an engineering approach that identifies likely and probable failure modes. This effort is based on the physical properties of the pump and its operating environment. Leveraging best practices and OEM suggested normal and alert values for condition monitoring sensor technologies, you can define the expected values in your operational environment. This practice puts the physics of the FMECA into your predictive maintenance program.

To create the prognostics curve, sensor data and data-driven analytics is combined with the FMEA and physics models to improve the ability of predicting the future path of degradation, and the remaining useful life. In other words, the more accurate predictive maintenance and prognostic approaches combine both physics-based models and data driven models to improve the accuracy of the predictions. Ideally, you will want to answer the question: “Can we make it till the next outage?”.

Let’s illustrate the full analytics process. The physics models play an important role in analyzing raw sensor data and in determining the defect and the severity of the defect. Data driven machine learning models then are added to improve anomaly detection and perhaps more importantly to im improve the forecast of the degradation curve, improving the accuracy of the prognosis, Figure 5.

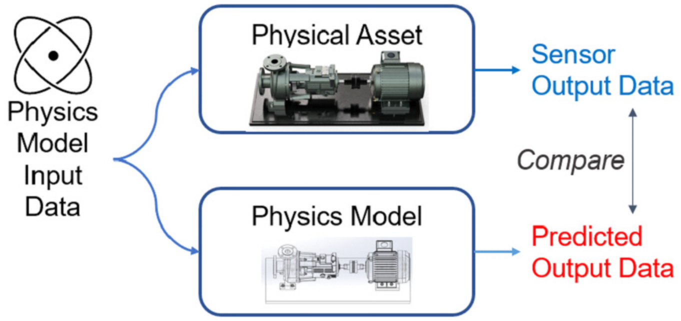


Figure 3: Physics Based Models Identify Expected Sensor Outputs

Industry Example: Starting with Physics Based Models

In the steel industry, hydraulic pressure supply is critical to the hot rolling process. When the hydraulic system was upgraded, condition monitoring and predictive maintenance monitoring was included in scope. The hydraulic system includes six pumps including rotating spares to produce the hydraulic pressure used to control and position the rollers in the hot rolling process. Using five accelerometers and temperature sensors per pump, coupled with physics based specific vibration feature thresholds, defects were detected early enough to plan and schedule corrective action before collateral damage occurred.

Motor mount looseness was detected early, allowing adjustments to prevent damage to the pump. Downstream hydraulic valving problems were detected by vibration at the pump end, allowing a potentially catastrophic production failure to be corrected. And vibration analysis comparisons across pumps showed the balancing controls for the pumps needed adjustment. All three of these “catches” were made within the first three months of operation, resulting in a significant return on investment.

In this industry example, physics-based models using high frequency vibration data played an important role in predicting needed mitigating maintenance actions. Physics based models and high frequency sensors will play a significant role in your predictive maintenance strategy.

Improving the Prediction with Data Driven Intelligence

Let’s take the prediction a step further. You can add predictive, data driven intelligence to trends derived from your high frequency condition monitoring sensors and from your process sensors. This will improve the prediction or RUL estimate of your pump.

As data is collected from your pump, it is compared to the model's expected values and significant differences are reported as an anomaly or diagnosed as a specific defect. Leveraging the physics model, for example for vibration sensors, you can detect the presence of bearing defects. Your future mitigation action is likely to replace the bearing at the drive end of the pump where the vibration sensor is located. With this information, you can plan a specific maintenance task for a convenient operations maintenance window. The remaining question is how long your pump can perform its function before failure occurs. This is the harder part of predictive maintenance, determining the time horizon.

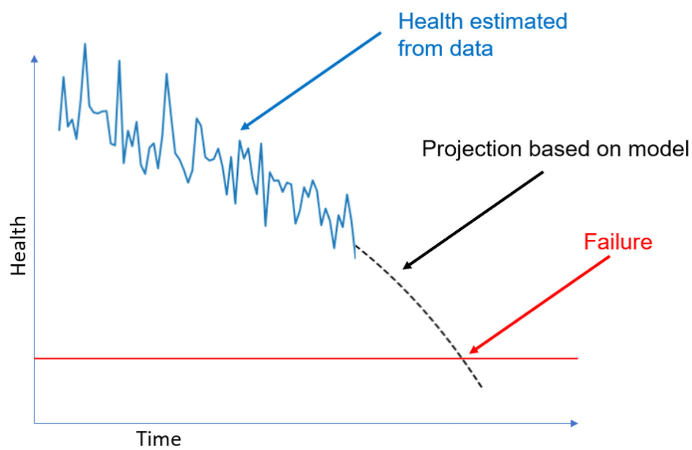


Figure 4: Data and Physics Driven Predictions

> *"The more accurate predictive and prognostic approaches combine both physics-based models and data driven models to improve the accuracy of the predictions."*

When adding data driven intelligence, you have a truer prognostics predictive maintenance solution. You improve the estimate of your RUL. You now have more confidence whether you can or cannot not "make it to the next outage". Do you know whether you can make it to the next outage?

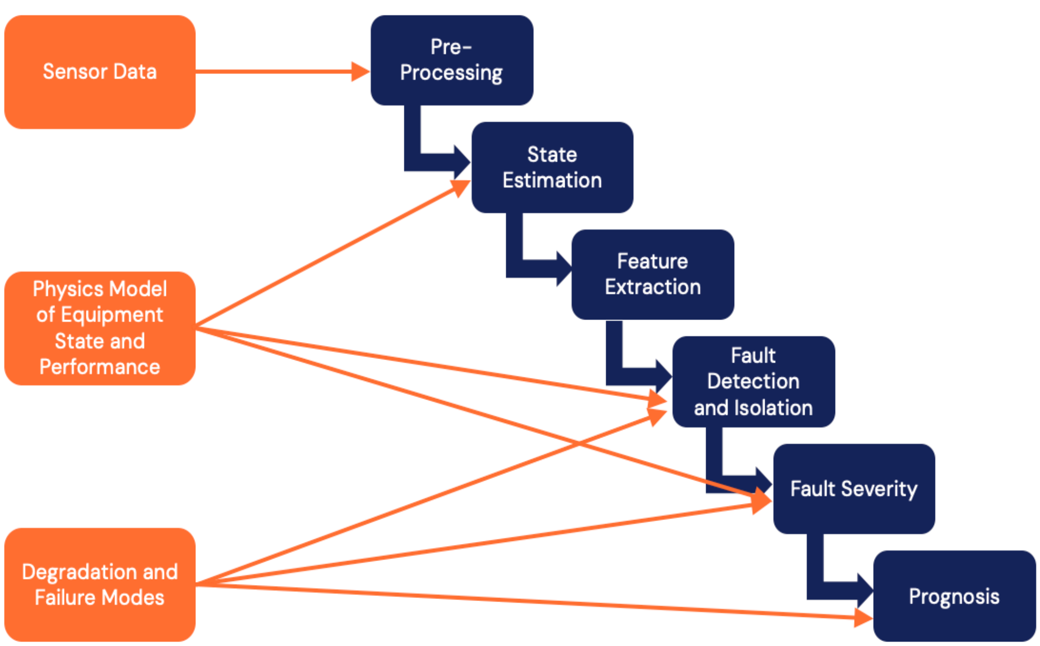


Figure 5: Data, Physics Models, and Data Driven Analysis Improve Prognostics

Summary

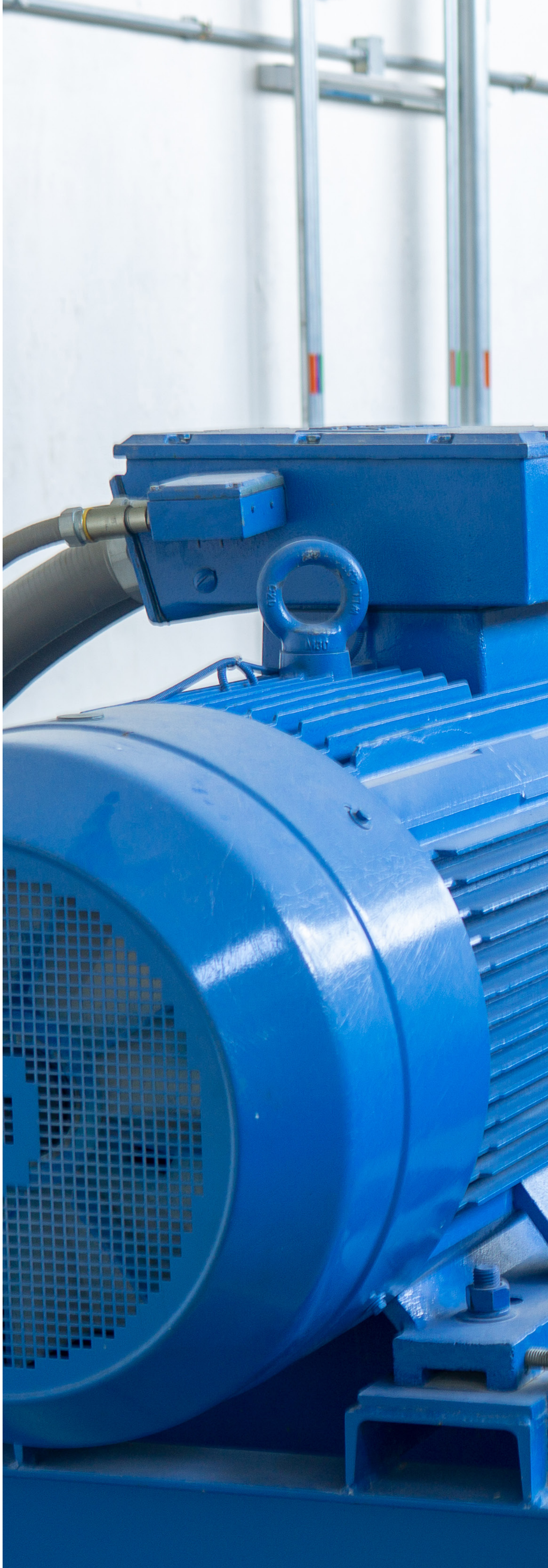
Predictive maintenance provides many benefits to asset intensive industries, particularly those relying on pumps to enable critical manufacturing processes. But to realize these benefits, manufacturers must understand the various possible pump failure modes, deploy a range of sensors to diagnose the appropriate issues, and utilize a combination of physics-based models and data-driven machine learning models for the highest accuracy prognosis of RUL. With these PdM elements in place, manufacturers can lower maintenance costs and improve reliability and safety as their pumps' health is more predictable. With improved reliability, production output increases and energy costs are reduced. Plant personnel are more efficient when more maintenance work is planned and scheduled compared to using emergent and reactive maintenance practices.

At Novity we build on best condition monitoring practices, physics-based models of equipment and processes, and data driven machine learning to provide top performing predictive maintenance and prognostics solutions.

Contact us to learn more about how we can help you detect and predict your equipment maintenance needs. We will also help you determine the positive financial impact your organization will experience from your predictive maintenance efforts.

About Novity

Novity provides truly predictive asset life, leading to the best path to Zero Unplanned Downtime. Using IoT sensors, pre-built physics models of machine faults, and sophisticated machine learning, we provide exceptionally accurate Remaining Useful Life predictions. Because of this unique approach, we can deliver high-performance solutions even in environments with little historical data.



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