White Paper

Pumps 101: Operation, Maintenance and Monitoring Basics

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Executive Summary

Pumps are at the heart of most industrial processes, and the second most common machine in the world. Because they are so common, pumps are often overlooked as a potential source of improved productivity, or a cause of excess costs if not operated properly. Plant managers, maintenance engineers and production supervisors should adhere to best practices and understand the operational do's and don'ts for employing pumps properly in manufacturing and industrial applications. This white paper provides an overview of how to operate pumps properly and the performance parameters that need to be monitored in a preventive or predictive monitoring program. It also describes continuous monitoring systems, with several case studies on how they can be applied to improve system performance and reduce maintenance costs.

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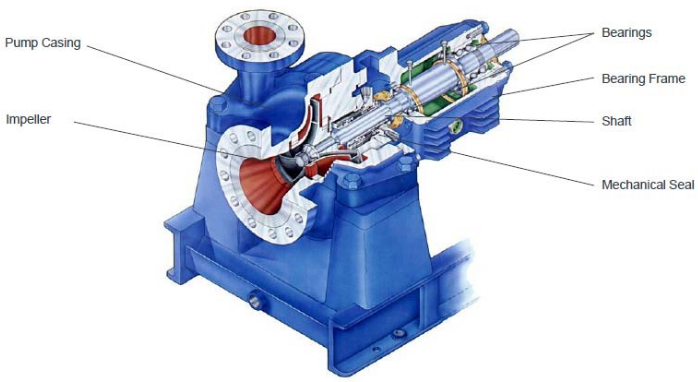
Introduction

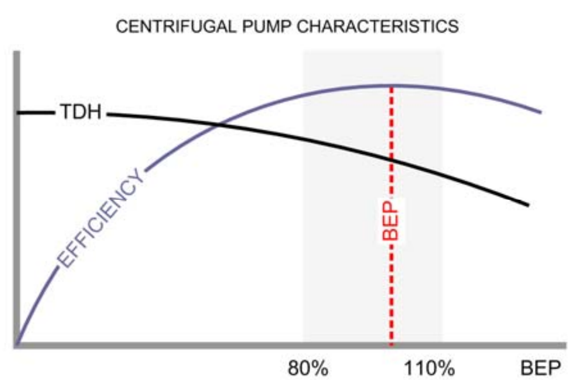
According to the U.S. Department of Energy's 2002 Industrial Electric Motor Systems Market Opportunities Assessment, process pumps account for 25 percent of total motor system energy in manufacturing today. That makes the pump the second most common electronic machine after the motor. Though the performance of process pumps has improved with enhancements to design, materials, and the emerging use of digital technology to monitor performance, the basic structure has changed little in decades.



A centrifugal pump is a rotating machine comprised of six main parts that work together to keep the pump operating properly. They include an impeller, a pump casing, bearings, a bearing frame, a shaft, and a mechanical seal. The operating principle of the pump is to convert mechanical energy to pressure. In operation, a rotating impeller accelerates a liquid and as the area of the pump casing expands the velocity of the fluid is converted to pressure. As a result pressurized fluid exits the pump discharge.

Pump operation basics

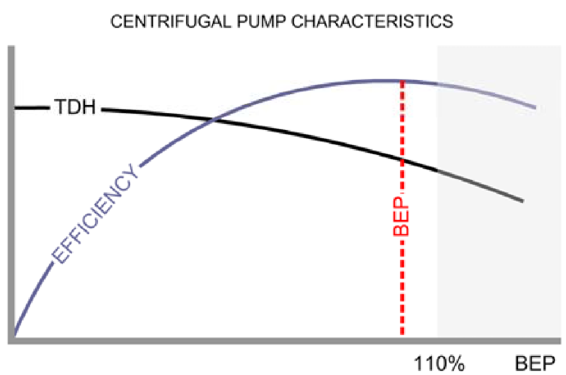
Best Efficiency Point (BEP), the flow rate where a pump has its highest efficiency, is a key factor to assess whether a pump is being operated properly. Few pumps operate at their exact BEP all of the time, because process variables in a production environment are not 100 percent constant. But a pump that is properly sized for its application will maintain a flow near peak efficiency. Maintaining a flow between 80 percent and 110 percent of BEP is a good range to maximize efficiency and minimize the risk of excessive wear or pump failure.



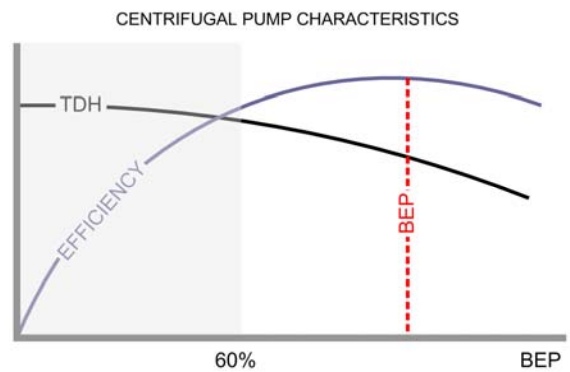
Unfortunately, many pumps do not achieve this level of efficiency. Consider a study by the Finnish Technical Research Center of nearly 1,700 pumps at 20 process plants across multiple industries. The study determined that average pumping efficiency is below 40 percent, and more than 10 percent of pumps were running below 10-percent efficiency.

Problems of inefficient operation

Improperly sized pumps are the major culprit when it comes to pump inefficiency. For a variety of reasons, process pumps frequently are oversized for the needs of the process. One reason is that process parameters are often not fully defined as pumps are being specified—and because “no one was ever fired for having too much horsepower,” engineers tend to err on the side of overestimating pump needs. It’s also possible for a pump that is perfectly suited to its first installation to become oversized or undersized as the demands of the process change.



Operation to the Right of BEP



Operation to the Left of BEP

When a pump operates too far off BEP, forces inside the pump become imbalanced, which can cause parts to deflect and wear excessively. Operating to the right of BEP, a condition known as “runout,” means that the flow rate is higher than the pump was designed to maintain. The high flow increases the exit velocity of fluid leaving the pump, which in turn creates a low pressure area inside the pump. Operating to the left of BEP occurs when the discharge flow is restricted, causing fluid to re-circulate within the pump also creating a low pressure area which can lead to increased radial loading and low flow cavitation.

In either case, the creation of imbalanced pressure increases the radial loads on the impeller, which can cause shaft deflection—the bending of the impeller shaft, which increases vibration of the pump. The vibration and imbalance forces can create stress on the pump’s internal components—most likely to be seen first in the bearings and/or mechanical seals, the two parts of a centrifugal pump that fail most often.

Cavitation is another problem that inefficient pump operation can cause. It happens when Net Positive Suction Head (NPSH)—the pressure provided at the suction of the pump less the fluid’s vapor pressure — is too low. When fluid pressure on the trailing side of the impeller blade (opposite the pump intake) falls below the vaporization point of the fluid, vapor bubbles begin to form. When these vapor bubbles reach an area of high pressure inside the pump, they can collapse violently—causing sudden, uneven axial and radial loading on the impeller. This, in turn, can cause shaft deflection that is random in direction and often severe in magnitude.

Pump monitoring and maintenance

In the ideal world, all pumps would be properly sized to run constantly at their best efficiency points. In the real world of an industrial plant, this is impractical because processes are fluid both literally and figuratively.

Formulations change and production rates vary, but typically the hundreds if not thousands of pumps supporting process do not change with them. The solution to maintaining reliable pump operations is a robust maintenance program that combines monitoring basic machine health data *in addition to* pump operating conditions.

There are four areas that should be incorporated in a pump maintenance program.

- Pump performance monitoring and pump system analysis
- Vibration monitoring
- Bearing temperature
- Visual inspections

Individually, each of these is important indicators; collectively, they provide a complete picture as to the actual condition of the pump.

Pump performance monitoring

Ideally five parameters should be monitored to understand how a pump is performing: suction pressure, discharge pressure, flow, pump speed, and power.

At a minimum, suction and discharge pressure are essential for determining the Total Dynamic Head (TDH) of the pump and the available Net Positive Suction Head (NPSHa). Understanding the pump TDH is critical to estimating where the pump is running with respect to BEP. The suction and discharge pressure are measured by either pressure tranducers that can transmit real-time data or pressure gauges, and the installation of the taps for the gauges is very important. Ideally, they should be located adjacent to the pipe wall and on the horizontal centerline of the pipe. They should also be in a straight section of pipe, ideally a section 10 times the diameter—or a 60-inch straight section for a six-inch diameter pipe. Locating the taps in elbows or reducers will not accurately gauge the true static pressure due to the velocity head component. Also avoid locating taps in the top or bottom of the pipe, where they can become air bound or clogged with solids.

There are limitations using just suction and discharge pressure measurements. If the pump is operated by a variable speed device, pump speed must be factored in using the affinity laws, which state the change in TDH is proportional to Speed^2. It is also difficult to determine pump wear. As the pump wears and internal clearances increase the pump's ability to generate pressure will decrease. Without additional information, this decrease in pressure could be interpreted as a change in the process conditions and not necessarily a worn pump.

An accurate power measurement, in combination with suction and discharge pressure readings, can be a powerful tool in assessing pump performance. While current transducers offer the most basic and cost effective power monitoring solution, apply their readings cautiously. Motor amps are not directly proportion to load. Factors such as input voltage, power factor and motor efficiency should be considered to accurately determine the actual shaft horsepower being transmitted to the pump. Developed for fixed speed pumping applications and a typical investment of less than $1,000 USD, low voltage pump load monitors offer unsurpassed protection for underload and overload conditions that most often result in mechanical seal damage or pump failure. Pump speed also plays a factor in centrifugal pump load monitoring and the change in power is proportional speed^3. Additionally, changes to the fluid properties such as specific gravity and viscosity can have an impact on pump power and should be considered. Combining both suction and discharge pressure with load monitoring can prove very effective to understanding where the pump is operating with respect to BEP.

In the ideal world, flow measurements could be obtained on all pumps. However, this often proves impractical, but vital for understanding overall pump efficiency. In some installations, permanent flow meters are installed to make the job of monitoring easier. Make sure these flow meters are working properly and have been calibrated on a regular schedule. A non-instrusive temporary solution could be the use of clamp-on ultrasonic flow meters. These devices can work on a range of pipe diameters and provide flow accuracy in range of 1 percent. The challenge is finding a straight run on pipe which typically requires 10 x diameters before and 5 x diameters after the flow.

When all of the above parameters are known, it becomes a simple matter of calculating pump performance. There are instances when it is very difficult, if not impossible, to determine all of the above parameters in the field. In these cases, the field engineer must rely on his or her ability to understand where a compromise must be made to get the job done. The basic document the field engineer must have is the pump performance curve.

Pump system analysis

Pump system analysis is often overlooked because it is assumed that the system was constructed with the installed pump in mind, and that operation of the pumps is in accordance with design specifications. This is often not the case. Pumps are often purchased as components to meet an individual process need — or estimated need — not as part of a comprehensive system design.

A typical system analysis will include the following information: NPSHA, NPSHR, static head, friction loss through the system, and a complete review of the piping configuration and valving. The process must also be understood because it ultimately dictates how the pumps are being operated. All indicators may show the pump is in distress when the real problem is it is being run at low or high flows which will generate high hydraulic forces inside the pump.

A pump performance monitoring program that incorporates all of the topics discussed will greatly enhance the effectiveness of the program. The more complete understanding the engineer has of the pumping system, the more effective the maintenance program becomes.

Pump vibration analysis

Vibration analysis is the cornerstone of all pump performance monitoring programs. The vibration level of a pump is directly related to where it is operating and in relation to its BEP. The further away from the BEP, the higher the vibrations will be. There is no absolute vibration amplitude level that is indicative of a pump in distress. However, there are several guidelines that have been developed as target values that enable the analyst to set alarm levels. Users can develop their own site criteria as a guideline, and institutions such as the Hydraulic Institute have developed independent vibration criteria. Caution should be exercised when applying the published values, since each installation is unique. When a machine is initially started, a baseline vibration reading should be taken and trended over time.

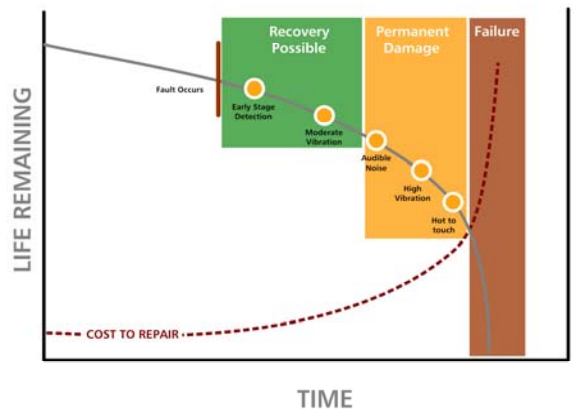
Typically, readings are taken on the motor outboard and inboard bearing housings in the vertical and horizontal directions and on the pump outboard and inboard bearing housings in the vertical and horizontal directions. Additionally, an axial vibration measurement is taken on the pump. The inboard location is defined as the coupling end of the machine. It is critical that when the baseline vibration measurement is taken that the operating point of the pump is also recorded.

The engineer must also look at the frequency where the amplitude is occurring. Frequency identifies what the defect is that is causing the problem, and the amplitude is an indication of the problem's severity. These are general guidelines and do not cover every situation. Bearing defect analysis is another useful tool that can be used in many condition monitoring programs. Each component of a roller bearing has its own unique defect frequency. Vibration equipment available today enables the engineer to isolate the unique bearing defects and determine if the bearing is in distress. This allows the user to shut the machine down prior to a catastrophic failure. There are several methods, but the most practical from a field engineering perspective is called bearing enveloping. In this method, special filters built into the analyzer are used to amplify the repetitive high frequency signals in the high frequency range and amplify them in the low frequency part of the vibration spectrum. Bearing manufacturers publish the bearing defect frequency as a function of running speed which allows the engineer to identify and monitor the defect frequency. Similar to conventional vibration analysis, a baseline must be established and then trended.

It is also good practice to monitor bearing temperature. The most accurate method to monitor the actual bearing temperature is to use a device that will contact the outer race of the bearing. This requires holes to be drilled into the bearing housings, which is not always practical. In most circumstances a temperature sensor mounted to the bearing housing will suffice to alert of possible lubrication breakdown or lack thereof. The other method is the use of an infrared "gun" in which the analyst aims the gun at a point on the bearing housing where the temperature reading is going to be taken. The temperature being measured is the outside surface of the bearing housing, however, not the actual bearing temperature. This must be considered when using monitoring the bearing housing temperature.

Continuous condition monitoring

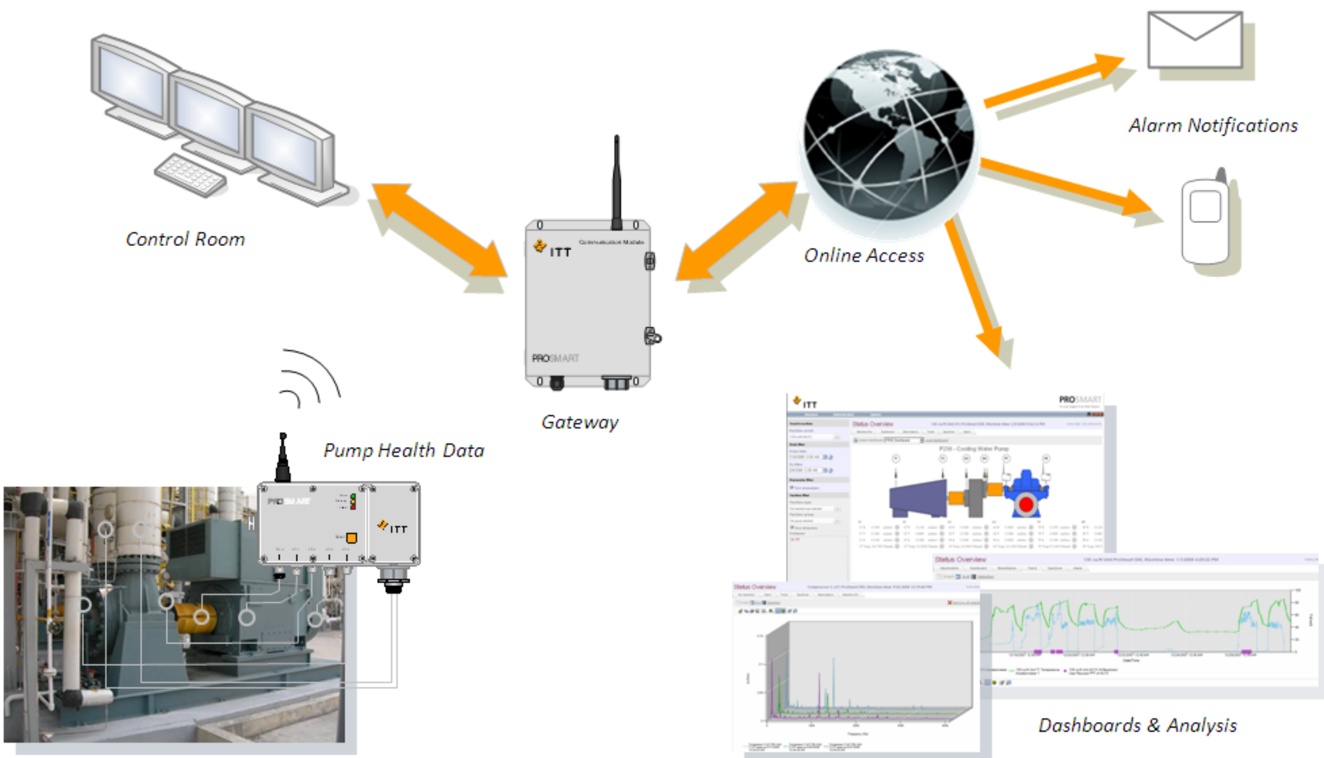
The most rudimentary form of condition monitoring is visual inspection by experienced operators and maintenance engineers. “Walkarounds” are part of any preventive maintenance program, and can detect failure modes such as cracking, leaking, or corrosion before pump failure is likely.



Continuous vibration analysis on rotating equipment is a more certain way to spot problems before they happen, which is the essence of predictive maintenance. One category of solutions is to install a warning signal – a simple mechanical vibration switch or digital warning light that will indicate excessive vibration on individual pumps. To achieve the full benefits of a predictive maintenance program, plants can employ digital monitoring systems that gather more comprehensive data on pump performance. Frost & Sullivan predicts rising adoption of these digital monitoring systems, with growth rates of 5-10 percent per year. Options include:

- Wired systems, where equipment sensors are hard-wired to rack-based computer servers, with data accessed and analyzed over an internal network
- Wireless systems, where sensors transmit data to a central hub, with data accessed and analyzed over secure Internet connections
- Integrated systems, where hard-wired and wireless sensors feed data to an internal server-based network.

All of these systems provide continuous monitoring of key machine health indicators — including performance, including vibration, temperature, flow pressure and power — and provide advance warning of trouble before it occurs. In general, wired systems are more costly to implement and provide more comprehensive process-related information. Wireless systems are simpler to install and provide greater accessibility to information. Data from wireless systems can be fed to automated process control systems to provide a fully integrated solution.



The monitoring data from a digital condition monitoring system can be transferred to both the control room and to a web-based monitoring platform. Simple, easy to understand Key Performance Indicators (KPI) such as NPSHa, BEP percentage and vibration data allow any operator to monitor pump operations without special training. When more advanced diagnostics are necessary such as vibration spectrums and time-wave forms the reliability and maintenance teams can access the system from any web-enabled device. The system integrates maintenance and operational data in a single dashboard, improving operational efficiency and reducing the need for on-site manual monitoring.

Case study 1: Failed pump causes shutdown at refinery

A catastrophic failure occurred at a North American refinery that produces about 70,000 barrels of oil a day. A fire broke out at the bottom of a vacuum tower, forcing a three-day shut down that cost $1.5 million in damages and lost production time. An investigation quickly identified a failed API OH3 pump as the cause.

This is a more common occurrence than one might think, if pumps are not operated and maintained properly. On average, one out of every 1,000 pumps with a failed mechanical seal leads to a fire. A root-cause analysis revealed that the pump's mechanical seal caused the fire — and a review of maintenance records showed numerous repairs and parts replacements consistent with off-BEP pump operation in the weeks and months leading up to the fire. Subsequent to the disaster, the refinery installed a continuous monitoring system in 2009. In nearly two years since the system was installed, the refinery has required no unplanned maintenance on its pumps.

Case study 2: Corn processor picks predictive condition monitoring

The processing and refining of corn into its various mass-market products such as starch, high fructose corn syrup and glucose requires a large investment in plant and equipment. As the largest corn processor in Canada, Casco Inc. has a substantial investment in pumps and other rotating equipment. Since its founding almost 150 years ago, Casco has been consistently looking to improve the effectiveness of plant operations by effectively controlling maintenance costs.

Casco found the answer with a predictive condition monitoring system from ITT, enabling plant officials to identify such problems as a worn bearing that can be picked-up by vibration and temperature sensors to avoid a system shutdown. The repairs could then be scheduled at a convenient time to minimize downtime and lost production.

Casco is presently using the ITT solution in three different areas of the plant, enabling managers to go online at any time to check pump readings, providing a cost-effective solution to maintaining uptime on all of rotating equipment.

Case study 3: Wireless condition monitoring saves boiler feed water pump at paper mill

A North American pulp and paper mill was experiencing failures on a multi-stage boiler feed water pump every six to 12 months. After the third failure within 36 months, ITT PRO Services offered to install the ITT ProSmart Wireless Condition Monitoring system on the pump to provide 24/7 monitoring. Shortly after the installation, ProSmart detected high vibration on the pump and alerted the mill's maintenance staff. After reviewing the operational data it was confirmed that the pump was operating to the left of BEP, near minimum flow, causing the high vibration and eventual failure. It was later discovered that the pump was being improperly used as the trim pump. The pump was originally designed and sized to provide base load to the boiler. At periods of low demand, however, the discharge valve was being heavily throttled to reduce the total load to the boiler causing the pump to run back on its pump performance curve. By combining both machine health data and operational data, the root cause of the failure was identified and corrected. Since the installation of the ProSmart Wireless Condition Monitoring System the pump has not experienced any failures.

Conclusion

While managers, maintenance engineers and production supervisors are continually challenged to maintain production, they can't lose sight of proper pump operation and maintenance that improves efficiency and reduces downtime. They need to ensure that pumps are operating near BEP, and closely monitor pump performance parameters, including suction pressure, discharge pressure, flow, pump speed, and power. In addition to preventive maintenance, it's increasingly essential to make predictive maintenance part of a robust monitoring program. Condition monitoring systems support both machine status and process data to answer why pumps are about to fail, not just when and where. By implementing these best practices, operators can run their pumps like the pros, while boosting efficiency and reducing risk at the same time.

About ITT

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