OPTIMIZING THE ASSET MANAGEMENT OF PUMPS THROUGH INTEGRATED ONLINE MONITORING

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ABSTRACT

Effective asset management strives to maximize reliability and performance while minimizing maintenance and operation costs. Asset management improvement is possible by integrating new advances in smart online pump monitoring and flexible plant communication technologies. This results in the automated delivery of relevant real-time information to people who operate and maintain the plant.

In reality, we do not have enough time and personnel to manually monitor equipment, analyze data, and then effectively communicate the results. As a result we react to surprise incidents/shutdowns or spend effort on what should have been unnecessary maintenance. Based on two applications, this paper discusses the type of information we should react to. It also discusses methods and available technologies to automate the process of equipment monitoring and the presentation of performance and condition information. Through integration, information can be targeted to the right system and end user.

INTRODUCTION

In this paper, asset management is defined as the work processes used to operate and maintain production equipment within the plant. Effective asset management strives to maximum reliability and performance while minimizing maintenance and operational costs. Effective asset management contributes to improved business performance in terms of availability, throughput, quality, and cost. Effective asset management also contributes to overall customer satisfaction in terms of on-time delivery, quality, and cost. With the opportunity to improve business performance and customer satisfaction, businesses are motivated to implement new asset management processes.

This paper will present the concept and benefits of integrated online monitoring along with discussing its application and benefits for two companies. For both companies, the pumps are expensive critical production equipment. Both companies required improved pump reliability but were limited by a shrinking workforce.

INTEGATED ONLINE MONITORING

Overview

Integrated online monitoring for critical pumps provides relevant real-time performance and equipment health information to the people who operate and maintain the equipment. Integrated online monitoring goes beyond vibration shutdown protection to include predictive machinery health monitoring that is integrated to the process control system and other plant decision support systems. Figure 1 shows a simplified integrated online monitoring schematic.

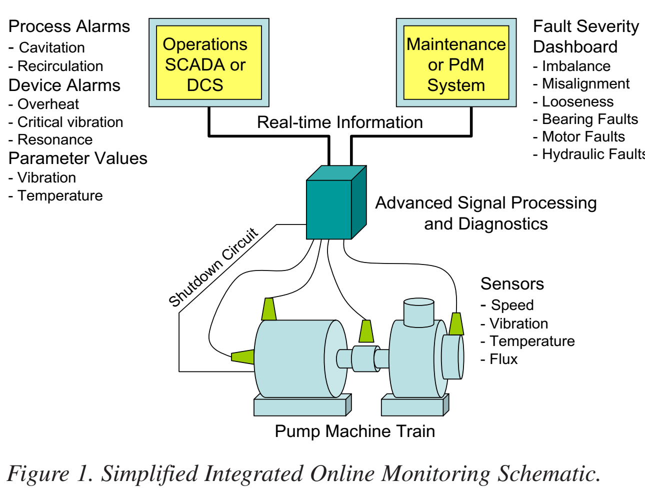

Figure 1. Simplified Integrated Online Monitoring Schematic.

Sensors mounted to the pump machine train provide raw signals to a processing unit. This unit analyzes the signals using techniques such as waveform and spectral analysis and then applies diagnostic rules to determine the root cause and severity of abnormal situations. This information is integrated into plant systems in the form of alarms with recommended corrective actions and fault status or dashboard screens. The advanced diagnostics can detect the early stages of most faults to allow for optimum maintenance planning and minimized component damage. For critical faults that develop quickly, the monitoring system is equipped with shutdown protection.

Benefit

Integrated online monitoring provides benefit to both the equipment operators and to the staff that maintains the equipment. Operators are immediately notified or alerted to problems such as cavitation or urgent vibration. Without notification these may remain hidden and cause process inefficiency and equipment damage. Some problems may be eliminated or minimized by the operator adjusting the process. With access to monitoring parameters such as vibration, the operator may be able to tune the process for maximum performance, efficiency, and asset life. Integrated online monitoring also enhances the operators' ability to manage problems. With automated problem notification, problems can be assessed to minimize secondary component damage and production losses.

For maintenance staff, specific preventive and predictive work processes can be minimized or performed on an extended interval. The online monitoring system automates most predictive maintenance processes. The authors' company customer case studies have shown that troubleshooting machine faults can be reduced by 90 percent with online monitoring. It also provides the specific condition information to allow a shift from time-based maintenance to condition-based maintenance. With this, many typical maintenance tasks such as pump overhauls need to be performed only when necessary. It is estimated 68 percent of machine failures follow an outage or machine commissioning. Also with online monitoring, problems are identified when they first appear. These problems can be monitored continuously for failure progression. Most importantly, maintenance can be proactive in scheduling and planning. This reduces emergency maintenance labor and parts costs.

Today, integrated online monitoring systems are uncommon. Communication between the monitoring systems and the control or decision support systems has been difficult. Now many systems have adopted new and improved open communication protocols. The importance of integrating machine health information to process control can be seen by the fact that 40 percent of machine anomalies are operator or process induced (Moore, 2002). Also, the predictive technology with built-in automated diagnostics is new and rapidly advancing. Today, machinery protection systems are common. Also, portable or route-base (not online) predictive systems are common. The below paragraphs discuss these systems as well as providing an overview of how vibration signals are converted into health information.

Protection Systems

In 2002 it is estimated that 1700 protection systems were sold worldwide (Frost & Sullivan, 2003). These systems were applied to critical machinery such as turbines, compressors, and pumps. A machine protection system shuts down a machine based on a high overall vibration level that reduces the risk of catastrophic failure. Protection systems operate in a blind mode in their most simplified configuration. For example, they provide relay closures for shutdown with no display or feedback of incremental vibration level changes. Configuration might involve defining a vibration or temperature channel, setting the alarm and shutdown levels, and assigning relays that will initiate a smart shutdown based on high overall vibration. After configuration, if configured through a network computer, the computer or laptop can be disconnected, and the only remaining connections are the vibration sensor inputs and the relay outputs. If the vibration levels are high enough, the protection system will "schedule" an abrupt outage. The purpose of protection is to minimize damage. The word "minimize" is used since damage has already occurred (the damage caused the high vibration), but extreme damage, safety issues, or disaster is avoided.

The machinery protection system can be integrated to a process control system for even greater benefit. Simply the act of integrating systems adds value to systems that were once individual islands. Overall vibration levels can be digitally integrated to the control system to provide the operator with visual feedback when vibration levels begin to trend higher. Overall vibration levels may be integrated to the control system as process parameters that provide feedback to control loops. As vibration levels increase due to changing head levels or valve positions, automatic or manual process changes can be made to reduce the vibration to maximize efficiencies or minimize process induced pump damage. Furthermore, shutdown protection relays can be integrated to a process control system to automatically control the shutdown sequence of a complex machine train that might otherwise suffer damage from the act of an emergency stop (e-stop) type of shutdown.

Prediction

A machinery health prediction system can be either a portable/route-based system or an online/permanently mounted system. Portable systems only provide snapshots of the health when the data are manually collected (usually on a monthly basis). Abnormal situations that occur between data collection intervals are missed. In 2002, it is estimated that over 6000 portable vibration systems were sold worldwide. Portable vibration analyzers are typically applied to many types of rotating machinery, including pumps, that are easily accessible and less critical. Online machinery health prediction systems are usually a business decision upgrade to the protection system. Protection systems are often required by insurance companies. However, for the plant's most critical rotating assets, if it is critical enough for protection, it is critical enough for prediction. Predictive machinery health analysis provides the ability to collect and process raw waveform vibration data. More detailed information is automatically integrated to a machine health management system where software tools are available to analyze trends, waveform, spectrum, and/or orbits that might give clues about complex machine health anomalies allowing time to plan outages or process improvements. For example, a turbine driven feed pump may have a shaft movement restriction issue, bearing fluid film issue, or even a cracked pump vane. Orbit, waveform, and spectral analysis can help the machine health analyst determine the type of fault, severity, and give the plant time to plan. Machinery health prediction systems can detect faults sometimes months before a protection system would shut the machine down.

Process Control System Integration

Machinery health prediction systems can be integrated to process automation systems for even greater benefit. If the analyst finds a specific vibration frequency and amplitude that correlates with other process changes or events, "rules" can be programmed so that process control can "watch" for these events. This eliminates the analyst spending time chasing repetitive problems, and allows for better utilization of the analyst to work on the next problem. In addition, an automated alert to the operator would reduce the amount of time the pump ran in this process induced harsh state, which could both decrease pump efficiency and increase pump damage. Knowing that 40 percent of machine health issues are process induced means that operators, with their hands at the controls, are running blind when it comes to knowing what effect the process has on machine health.

System Components of Online Monitoring

Online vibration monitoring may consist of a vibration sensor such as a dynamic displacement probe or accelerometer input to a specialized field processor with the ability to process raw waveform data produced from the sensors. The field processor then provides results in the form of a relay closure for shutdown protection, simplified machinery health process parameters integrated to process control targeted to operators, and detailed information for machinery health analysts and planners. In addition, an online monitoring system may include machinery health management systems to store and manage data. Some applications include advanced trending, diagnostic, and reporting capabilities.

Vibration Overview

When applied to pumps, vibration analysis is used to:

- Track progressing stages of bearing failure.
- Identify/correct imbalance and misalignment.
- Identify/correct pump flow problems and resonance.
- Identify mechanical wear in couplings, bearings, support structures.
- Detect other defects such as lube failure, soft foot, and broken rotor bars.

These faults generate specific vibration signatures. Vibration signals are collected using displacement, velocity, or acceleration probes connected to key spots on the pump machine trains. These signals are in the form of amplitude versus time and through signal processing may be converted to spectral plots (amplitude versed frequency) for more advanced analysis. Figure 2 shows accelerometers connected to a pump bearing housing.

Figure 2. Pump Bearing Housing with Mounted Accelerometers.

With spectral analysis, specific peaks and frequency bands typically correlate to specific mechanical faults. Figure 3 shows a frequency spectrum for a boiler feed pump with fault areas identified.

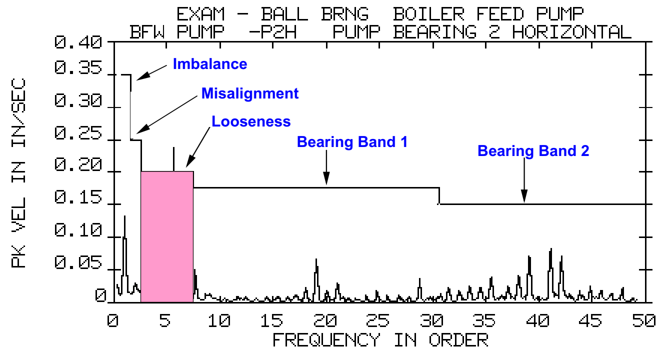

Figure 3. Pump Frequency Spectrum with Fault Correlation.

By identifying the fault areas and trending the changes, faults can be identified and the failure progression monitored. Figure 4 shows how vibration analysis can be used to monitor the faults across an entire pump machine train.

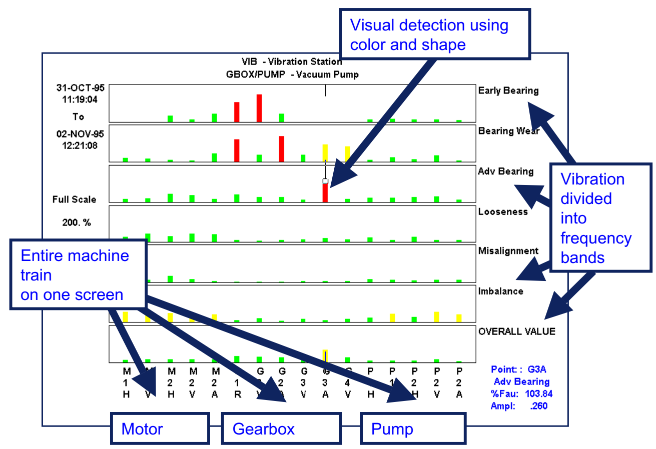

Figure 4. Fault Monitoring for Pump Machine Train.

Some online vibration monitoring applications contain an expert system that is used to automatically screen data and only present exceptions. This reduces the amount of data that has to be evaluated and provides a good first pass for analyzing the data. Simple high level recommendations can be passed to a process control system to notify operators of specific problems. Figure 5 shows an example of an expert system diagnostic report.

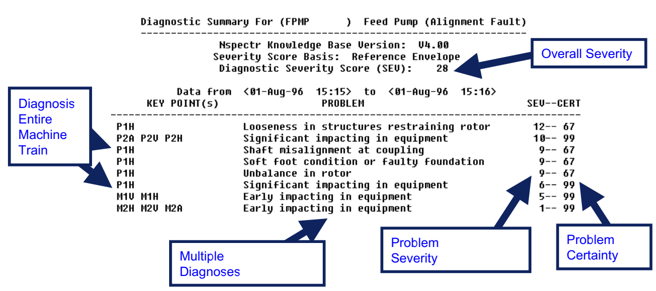

Figure 5. Vibration Expert System Recommendations.

APPLICATION OF INTEGRATED ONLINE MONITORING AT A WATER TRANSPORTATION UTILITY

Situation

This water transportation utility supplies water to 1.5 million people in the Southwest. Water is transported from four reservoirs through six pumping stations that are spread out over 150 miles. The pumping stations contain 34 pumps ranging in size from 1000 to 5500 hp.

The situation for the utility can best be described as a need to assure system reliability with greater manpower efficiency. Over the last 10 years, the day peak water demand has increased by 46 percent. The area population is expected to grow by 66 percent over the next 50 years. Until new pumping infrastructure is completed, the existing system has to run harder. With the increase in water demand, the pumping system at times is running at 80 percent of capacity with less redundancy for emergency backup. This means that the occasional motor or pump failure could now jeopardize production. In addition, the operations and maintenance staffing has decreased by 30 percent. Most of the pumping stations are now unmanned and controlled via a central supervisory control and data acquisition (SCADA) system. Therefore, the utility was challenged with having to maintain overall system reliability with a much smaller staff. In addition, the pumping system efficiency was becoming a key concern because of increasing power rates because of deregulation.

From a historical look at the motor/pump reliability, the most common failures were bearing failures, broken motor rotor bars, resonance, and improper mounting. System efficiency problems related to the pumps were detected as flow problems such as cavitation or recirculation. To detect these problems, the utility conducted daily manual inspections and periodic (portable route-based) predictive maintenance (PdM) inspections. The PdM inspections utilized oil, infrared thermography, and portable vibration analysis. The primary PdM technology was portable vibration analysis. This technology was only partially successful because of the lack of trend data from periodic, usually monthly, data collection from which to build performance trends. As a result, pump and process problems could go undetected and result in unplanned failure or accelerated equipment wear and component damage. This created high emergency maintenance costs because of the reactive nature of the work.

Approach

The utility felt that the pump reliability and the manpower issues could be improved with application of appropriate technology along with the necessary staff training. The approach for the utility focused on integrated online monitoring where both operations and maintenance are automatically presented with pump performance and condition data to better control and maintain the operation. Figure 6 shows a schematic of the approach.

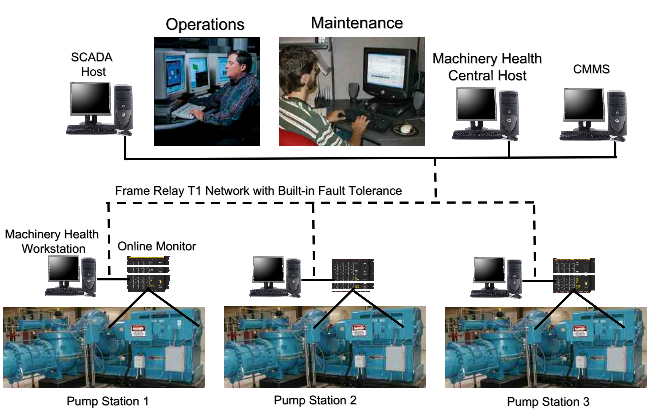

Figure 6. Water Transportation Utility Technology Approach.

With this approach, the pumps and motors at each pumping station are continually monitored for vibration using online monitors. The online monitors perform advanced processing on the input vibration signals to calculate specific analysis parameters. When alarm conditions exist, alarms are presented to both maintenance and operations. The status of the analysis parameters and alarms are displayed on the monitor workstations. In addition the workstation stores all trend data and is used for performance trending and advanced predictive diagnostics. To network the multiple stations together, a frame relay network is used. All stations report to an online central host that is tied into the plant network. The central host stores and backs-up the data from the stations. From the central host, all pumping station critical equipment can be monitored. The central host also has full diagnostic, analysis, and reporting capabilities as the remote monitor workstations. This allows all maintenance and planning to be performed from a central location. The online vibration monitor sits directly next to the SCADA host. The SCADA operators use the central host to monitor the status at all pumping stations. From the central host, maintenance can initiate work orders that automatically feed to the computerized maintenance management systems (CMMS). The system is built so that if the frame relay network was broken, data storage and monitoring can continue independently at the stations. Memory built-in to each monitor can actually store data while the Ethernet network is down. When the frame relay network is restored, the central host is updated and resumes operation.

Figure 7 shows a sample fault dashboard for the online monitor. The left side provides a database tree that shows overall condition at all stations. Using the database tree, detailed alarm and status information can be accessed for each point monitored. The online monitor presents both overall analysis parameter information as well as the real time diagnostics to identify specific failure modes such as unbalance.

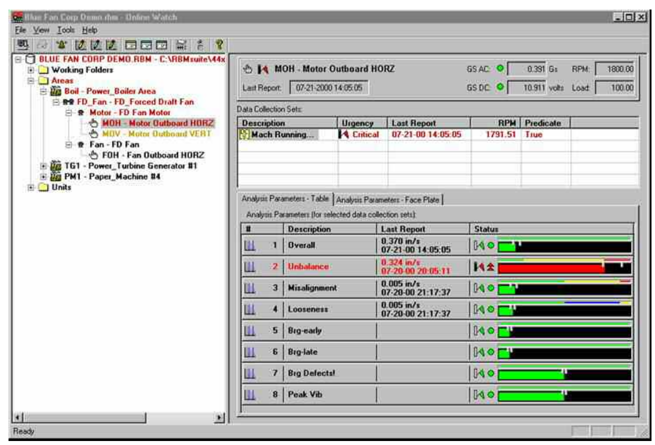

Figure 7. Online Monitor Fault Dashboard Screen.

When a potential problem appears, maintenance can further evaluate and confirm alarming using the online monitor central host to perform advanced diagnostics. Figure 8 shows a sample report and maintenance recommendations for a potential cavitation problem.

The cost justification for this approach evaluated projected 10-year costs and projected-avoidance cost based on previously documented vibration problems. The projected 10-year costs for integrated online monitoring were $94K above the cost of periodic vibration analysis. This was partially due to the extra effort that would be spent analyzing performance trends using data from the online monitor. The projected cost avoided was $400K since the current method of periodic vibration monitoring either failed to identify or would likely not identify the past problems shown in Table 1.

The difference of the two costs provided a financial incentive of $306K to proceed with the approach. The project was also qualitatively justified on enhancements to decision making, planning, scheduling, and forecasting.

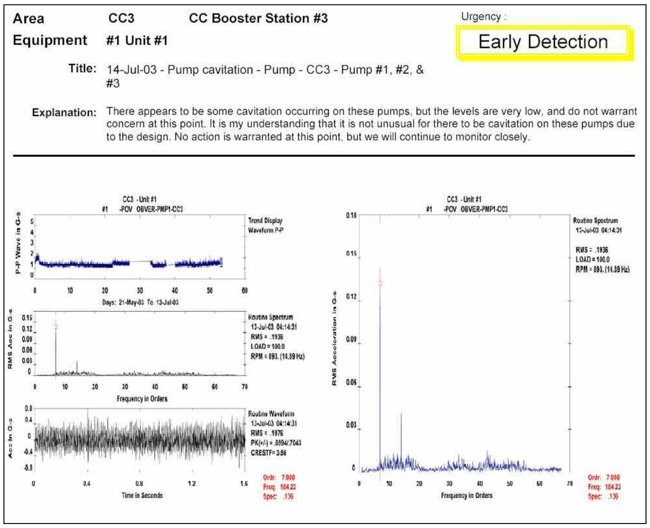

Figure 8. Pump Diagnostic Report.

Table 1. Projected Cost Avoidance with Online Monitoring.

Problem	Potential Avoided Cost
Excessive bearing thrust on 2 units	$120K
Broken motor rotor bars on 2 units	$166K
Failed motor bearing on 1 unit	$114K
total	$400K

Results

The system was implemented in 2001. The results over the last three years can be grouped into the following areas:

- Pumping system reliability,
- Process operational tuning,
- Equipment acceptance testing, and
- Work prioritization and management.

Pumping System Reliability

Since implementing the system, no unexpected pump failures have occurred. Now, both maintenance and operations watch for developing problems and process changes. Problems such as misalignment, loose mounting, cracked rotor bars, and flow problems have been identified, monitored, and strategically corrected. Real-time data collection and alarming provide the opportunity for real-time decision making with time to plan and act before a customer interruption occurs. In addition with real time data collection, the collected data are trended and analyzed to develop operational parameters with normal and abnormal operational ranges. Online monitoring has provided operations and maintenance the ability to "diffuse the ticking time bomb."

Process Operational Tuning

Booster stations exist between the reservoir and treatment facility. Optimum system efficiency is obtained with a minimal booster tank level that still provides adequate net positive suction head for the pumps. This level is not a constant because of varying reservoir levels. Operations can now use vibration as a process variable to optimize the balance of the system. If the tank level falls below minimum, flow noise occurs at the pump. This is quantified with the online monitoring system and presented to the operators. In addition, operators can immediately see cause and effect of their actions. The online system alerts the operators to problems such as resonance and flow problems such as cavitation and recirculation. Integrated online monitoring assists the operator in running the system cooler and smoother for greater output and life.

Equipment Acceptance Testing

When installed, all rebuilt and new equipment must meet performance specifications before being put into service. Integrated online monitoring is used to effectively catch prewarrantee problems. This allows for problems to be identified and corrected before component damage occurs. If problems develop during the warrantee period, documentation in terms of trending and operational performance exists that can be used to verify nonconformance. The approach has been successfully used to identify a bent pump shaft, hydraulic recirculation, and a weak motor base. These problems were identified before the equipment was put into service and resulted with the manufacturer correcting the problem. Equipment problems are now identified before reliability is threatened and capital expense is incurred.

Work Prioritization and Management

With fewer resources, it is important to prioritize and eliminate unnecessary work. The online monitoring system provides greater efficiency in collecting, analyzing, and reporting pump condition data. The data automatically come to the operator or analyst only when necessary in a format appropriate to the skill level. This frees up resources for higher priority activities. In addition work can be based on actual condition rather than recommended time intervals. Prior to online monitoring, actual mechanical condition was questionable. By establishing ranges for operational parameters, current and forecast mechanical condition can be much better approximated. This allows for maintenance to be delayed until necessary. Prior to online, the pumps and motors were rebuilt on a fixed schedule. Now, as seen in Figure 9, efficiency and mechanical condition are carefully considered during the annual planning cycle. Online monitoring effects purchasing, planning, and scheduling and is resulting in a shift from a reactive to proactive culture.

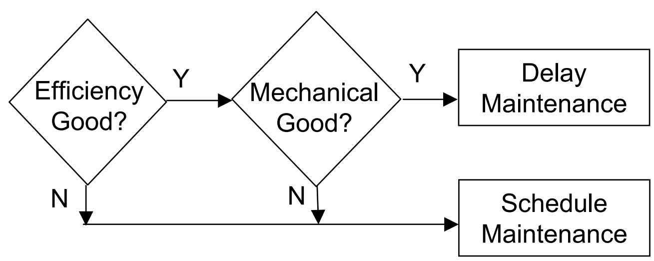

Figure 9. Simplified Maintenance Decision Flow.

Future Direction

Currently, the online alarm information is not directly imported into the SCADA system. The SCADA monitor and online monitor sit side by side. As the SCADA system is upgraded, direct integration to the SCADA system will occur. Vibration analysis parameters then become process control parameters. In addition, all critical information can be accessed via one system.

Currently, no automated emergency shutdown exists. Some sudden failure parameters can be detected with the online system. These will be integrated into the SCADA for controlled emergency stops.

Additionally, the future direction includes continued work on directly linking the online system to the CMMS system. This will allow work orders to be automatically generated. When work is completed, the case histories within the online system are automatically updated.

APPLICATION OF INTEGRATED ONLINE MONITORING AT A POWER PLANT PUMPING STATION

Situation

The station is a fully enclosed system designed to deliver required makeup water from a supply river through a 30 mile pipeline to the power plant. The pumps are arranged in three parallel trains with each train consisting of two pumps in series—for example 1A and 1B, 2A and 2B, and 3A and 3B. The pumps are five-stage rated at 10,010 gpm per pump set. The pumps are driven by 2250 hp motors at 1190 rpm.

The power plant has had shutdown protection on each of the six 2250 hp motors. Until 2002, the pumping station's online monitoring system had shutdown protection only. The problem was that the shutdown protection system was causing false trips and data were not available remotely or integrated to any other plant systems. When a fork truck would drive past, the monitoring system would identify the vibration from the fork lift as high machine vibration and would produce a false trip without providing information regarding the trip. A false trip could result in lower production and loss of availability. False trips also require a technician to travel to the site to analyze the system.

Before 2002, the power company's strategy was for an analyst to drive to the remote pumping station on a time basis and analyze the vibration of each pump/motor using a portable vibration analyzer to determine pump health for predictive analysis. Given the criticality of these pumps, the power company identified a number of shortfalls with this strategy:

- Poor resource utilization of trained vibration experts driving to remote sites and collecting vibration data
- No ability to correlate operator induced damage to equipment with portable machinery health analyzers
- No ability to correlate environmental changes that damage machines
- No ability to correlate a faulty valve, level parameter, or other process parameters to equipment damage or inefficiencies

Correlating portable once-a-month snapshots of vibration data with control system data and attempting to correlate a process event to a machine health change was nearly impossible and very resource intensive. In the past, if the plant found an anomaly with the portable data collector, then data collection intervals were decreased from once per month to once a week to get better resolution of data. Increased frequency in driving 60 miles round-trip to the remote site for monitoring until the anomaly was fixed impacted resource utilization. However, an integrated online monitoring system can catch the change in machine health including time of event. Correlations can be made with the process or environmental changes reducing fault analysis time, and resource utilization will not be impacted with trips to the remote site.

Approach

Based on the frequent false trips, lack of real-time information, and resources required for portable monitoring, new approaches were investigated. A new online monitoring system was selected that first provided advanced protection technology to address the false trips. The protection monitoring technology involves a combination of inline filtering and smart processing and can actually eliminate false spikes or vibration data beyond the frequency range of interest without compromise to the speed of protection. It is important to note that the installer and system commissioner should be well versed in rules such as sensor selection, sensor mounting, cable routing, and shutdown system configuration settings.

The pumps at the remote pumping station are now monitored online from the power plant. Figure 10 shows a simplified schematic of the online monitoring system.

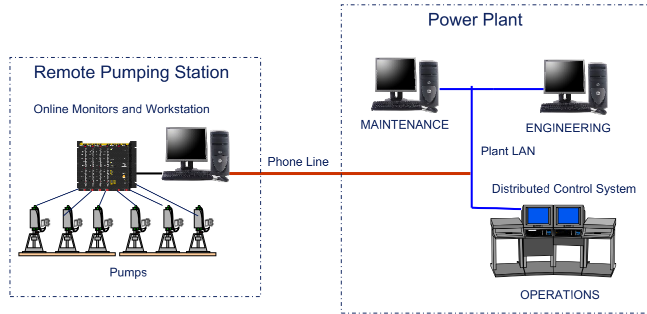

Figure 10. Pumping Station Integrated Online Monitoring Approach.

Results

At the pumping station on June 22, 2002, vibration levels of the 2250 hp motor climbed from 0.001 in/sec (low vibration level) to 8.156 in/sec (very high level) almost instantaneously. The new monitoring system detected this as a real machine problem. The monitoring system automatically shut down the motor and avoided burning up the motor. The cost savings are arguable, but the facts are that the repairs were minimal, so catastrophic damage was avoided, and motor replacement would have been required for a missed shutdown. In addition, the turnaround time for getting the pump back online would have been proportional to any further damage the motor/pump would have sustained. Production or plant yields were not placed at risk, and the company bottom line was not impacted. The pumping station has had no false trips after using this newer technology for vibration protection that has delivered an improvement in plant availability.

After the power station installed a continuous online vibration monitoring system on the river pumps, the time-based collection of vibration data was eliminated. These trained experts now react to alerts as opposed to scheduling their time in search of faults.

After a hard rain, silt or mud can build up on the vanes of the pumps. Operators and the vibration experts are now alerted. The vibration experts determined that when mud builds up in the pumps, a high level of vibration at one times (1×) the turning speed of the pump occurs—the same type of energy that you "feel" in your car when your car tire is imbalanced. The operator can react to this alert by shutting down the pump and turning on a backup pump. Or, with the vibration monitoring dashboard in place, a business decision might be made to continue to run that pump past a peak load time, and then schedule the outage to remove the buildup when electricity is in less demand.

The other problem that the power station encounters is moss buildup on the pump vanes and general wear as the pump ages. The analysts have determined that both of these events cause the one times energy to rise. This event cannot be correlated to an environmental event such as a hard rain, but operators can still be alerted as the pump imbalance condition changes. Time to plan is the deliverable of online monitoring for this scenario. The power station gets the opportunity to plan about four outages per year for these imbalance conditions. In the summer, even though all pump trains are running 24×7, the holding pond level is not quite maintained—the holding pond level drops slightly each day and does not get the opportunity to catch up until Fall. So the machine health dashboard allows planning for pump outages in the critical summer months. Extended outages or untimely outages would be unacceptable.

Future Direction

Based on the success of this integrated online monitoring system at this single power station, the corporate engineering is working on corporate-wide standardization of integration and these work processes. To streamline work order processes, work order generation from the monitoring system to the plant's enterprise resource program is being evaluated. In addition, to simplify the process of balancing the pumps, a local display screen showing real-time vibration peak and phase information is being planned.

CONCLUSION

For companies with pumps performing critical production roles, integrated online monitoring is a smart asset management strategy that enhances reliability and performance while lowering operational and maintenance costs. Examples of applicable pumps include large horsepower, remote location, river pumping, cooling tower feed, boiler feed, and pipeline pumps.

Since machine health issues are largely the result of process induced anomalies (40 percent), an online protection and online prediction system *integrated* to process control adds value to the individual protection and prediction systems that were once islands of information.

Integrated online monitoring systems provide risk avoidance and safety for machine assets. They help the bottom line through:

- Planned outages (parts, tools, and resources).
- Correlating machine health with process control changes.
- Improved process efficiency, reliability, and availability.
- Improved factory acceptance testing.
- Better utilization of human resources.

Online prediction systems that are integrated to control systems and asset management systems provide collateral protection for assets and collateral protection for the bottom line.

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