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Online vibration monitoring integrated with process control and combined with shutdown protection, predictive maintenance and performance monitoring is a sure-fire way to keep your rotating equipment up and generating revenue.

When a steam turbine in a Midwest power plant went down without warning, half of the plant's production was instantly lost for months (along with substantial revenue from the power that should have been generated).

Could the outage have been prevented? Apparently so. Plant management immediately went shopping for a new online system that would not only monitor the turbine's operation continuously, but gather *diagnostic data* capable of revealing unrecognized internal problems in time for corrective action to prevent a similar failure in the future.

In this day of advanced technology, it is both possible and essential to access decision-making information about the operating condition of critical equipment—*not just a "trip" signal that comes only after significant internal damage has actually occurred*
. Some companies are putting productivity at risk by continuing to rely only on "protection" systems for their critically important turbomachinery. Protection is vital, but it is only part of the complete solution for turbomachinery.

A complete strategy for protecting critical machinery covers three real-world scenarios using four monitoring components. These real-world scenarios are:

- Unpredictable events
- Predictable events
- Controllable events

Unpredictable scenarios are events that happen suddenly and without warning. For example, a metallurgical imperfection or slug of water from the boiler may cause a blade to snap suddenly. If such an event occurs, a decision to trip must come instantly and be integrated with process control to orchestrate the machine, area, or plant shutdown. In addition, machine health information gathered before and during the trip will aid the assessment of what happened.

Predictable events are machine malfunctions that are detected and tracked months in advance of a planned outage. Maintenance planners use this information to identify the area of the fault and fault type, to gauge its severity, order parts and plan the outage. When machine malfunctions in this category are monitored, business decisions can be made to continue running the machine and possibly damage the machine versus determining the optimal time for scheduling the outage, manpower and parts. In parallel, the protection system is monitoring for a sudden turn for the worse to protect from catastrophic failure.

Controllable events represent a class of scenarios that provide the largest return on investment for monitoring capital outlay. In addition, controllable scenarios provide the best opportunity to optimize processes and performance. For example, on an unusually cold day, the operator ramps up the turbine and receives an oil whirl vibration alert from the predictive vibration monitoring system and simultaneously sees a low temperature alarm from the process control system on that same bearing. This is a controllable scenario, and the operator knows exactly what to do. Reducing the RPM of the turbine will immediately stop oil whirl from damaging the bearing. Solving the low oil temperature problem will keep the turbine out of the damaging oil whirl condition when the turbine is brought back online. In controllable scenarios, an operator simultaneously has both machine health and process status/health and is able to avoid problems that would otherwise lead to degraded machine health.

The four monitoring components required for a complete solution are:

- Protection monitoring
- Prediction monitoring
- Performance monitoring
- Integration of the above to process control

Predictive maintenance of rotating assets is best practiced using information gathered through vibration monitoring. Sometimes, this data signals big trouble down the road, allowing analysts to make a judgment as to when a failure might be expected. Based on their prediction, immediate repairs may be necessary in time to avoid the failure. It may be possible to delay repairs until a scheduled plant shutdown— *or let them go altogether*. Ultimately, this technology helps the plant and maintenance managers make business decisions about what to do— *and when and how to do it*. The result is generally a far less expensive proposition than reacting after something breaks.

Yet, according to a Deloite & Touche study, more than 50% of industry maintenance man-hours are spent fixing equipment *after* a failure has occurred, whereas less than 18% of those hours are spent determining when equipment might fail and acting accordingly. Those numbers will improve as more maintenance departments implement solid predictive maintenance programs based on online vibration monitoring of key machines.

The "most critical" category usually involves only about 5% of rotating assets, but this small number of machines represents an easy target for a complete online monitoring solution. In layman's terms, it's like picking the proverbial "low hanging fruit"—*with enormous financial returns on a single "find" with a controllable outcome.*

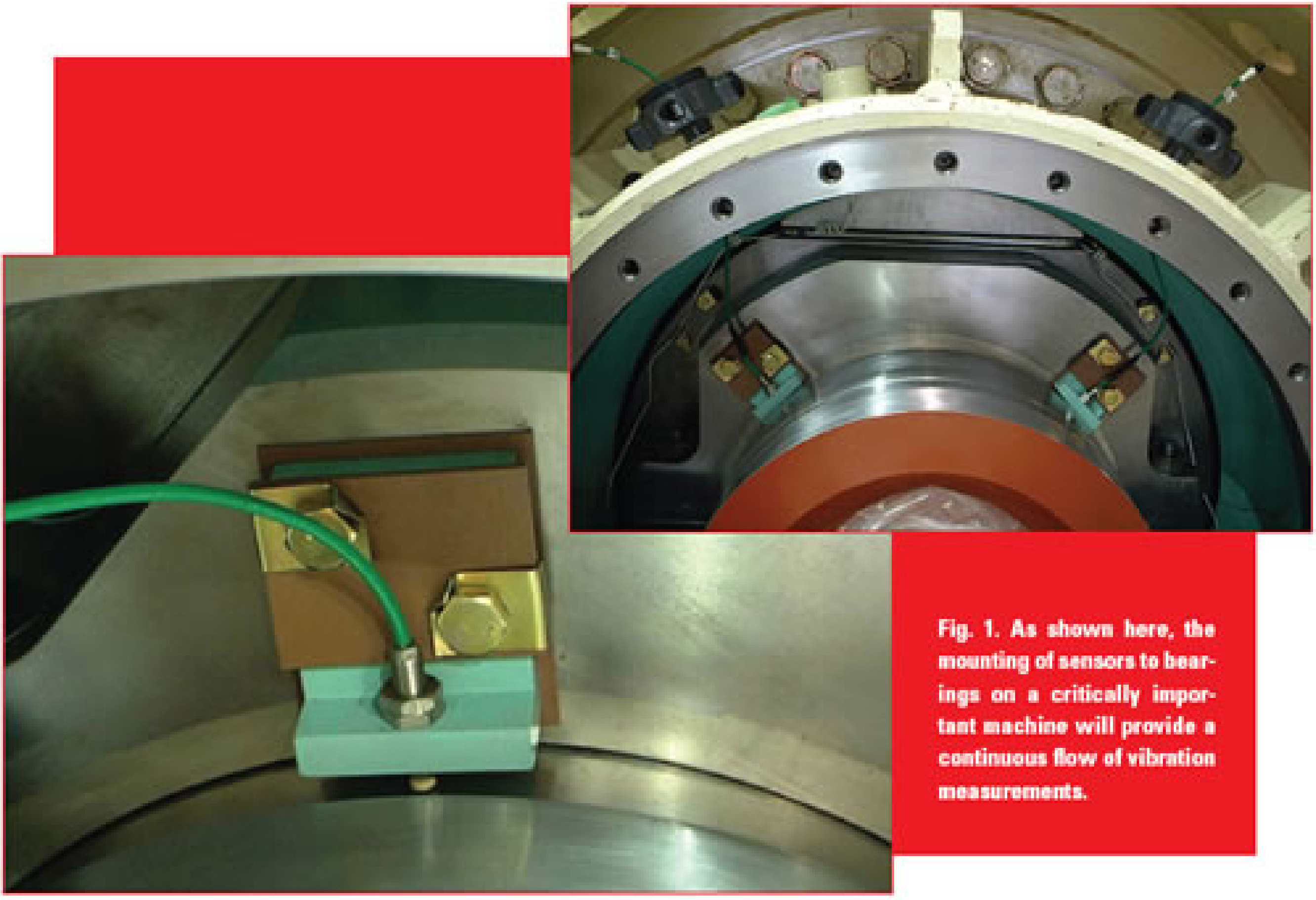

Fig. 1. As shown here, the mounting of sensors to bearings on a critically important machine will provide a continuous flow of vibration measurements.

Online monitoring

Continuous online monitoring of rotating machinery represents technology well beyond systems that provide only periodic snapshots of an operation. Yet, some critical situations can be averted only if a stream of data regarding the current condition of the equipment is available. Fortunately, it is now possible to continuously obtain information about the health of a whole range of gas or steam turbines, generators, compressors, fans, motors, pumps and the like (see

Sidebar). Equipment essential to the success of the operation can be watched automatically for changing vibration patterns and rising temperatures—*sure signs of impending trouble.*

Some of the earliest automated monitoring systems were dedicated to expensive steam-driven power generating turbines. Data received directly from a machine are stored on a hard drive, buffered and presented in a variety of plots that depict exactly what is occurring within that machine. Maintenance engineers and machine specialists suddenly had never-before-available information to use in analyzing changes in the machine's operation.

When properly interpreted, these signals will pinpoint the location, nature and the severity of developing problems. Data from automated monitoring systems enable plant personnel to predict with greater accuracy when a machine will need maintenance to prevent damage and avoid lost production. Machinery health management recognizes the significance of each machine in a production environment, focusing greater attention on those machines that, if stopped, would likely shut down all or a major section of the plant. Online monitoring assures that the condition of these machines is being assessed continuously.

Performance monitoring
Another technology that can be applied to protect critical machinery compares machine performance with a thermodynamic efficiency performance model. Compressors, boilers and steam or gas turbines are the most commonly modeled types of equipment, but a thermodynamic model can be computed on literally any machine in a plant. Equipment performance deteriorates primarily due to fouling or build-up on blades and other surfaces, thus leading to less efficiency. The consequence is more energy usage and potential lost throughput.

Equipment performance monitoring systems use existing process measurements, pass them through the thermodynamic model and provide a true picture of how well that machine is actually performing. In other terms, actual efficiency loss versus design for the given operating conditions is determined. While plant personnel may be aware that the performance of a piece of equipment is below normal, they may not know the significant cost of lost heat rate and excess energy usage. This information also can help lead to the root cause of degradation.

The most important element of performance monitoring is the expertise required to build the thermodynamic model and then distill and validate the large amount of input data. By utilizing the performance model to analyze this information and formulate actionable recommendations, performance specialists are able to identify lagging performance that has not been recognized by either production or maintenance personnel.

Because the model input data comes from the existing process measurements commonly found already in the site's historian, the data can be analyzed by either onsite systems or remotely with off-site specialists. Analysis based on thermodynamic modeling also enables a specialist to predict with reasonable accuracy when a piece of equipment needs to be taken out of service for either recovery of lost efficiency or a comprehensive overhaul. A machine's future performance is evaluated based on its history in order to predict when the efficiency of that unit will drop below a certain financial or performance threshold, signaling when it should be taken out of service. In this way, performance monitoring complements predictive maintenance.

Pulling it all together Let's look at how a complete solution like the one described in this article would work in a typical turbomachinery application. In Fig. 1, the sensors mounted to bearings on a critically important machine provide a continuous flow of vibration measurements. A large turbo generator may have more than 10 bearings with two sensors at each bearing plus other unique instrumentation— *like speed sensors, differential expansion sensors and case expansion sensors.* There could be as many as nine different types of measurements at various locations down a machine train.

The cables leading from these sensors are connected to new online monitoring hardware that is the foundation for the complete online solution. By measuring for detailed vibration, in addition to peak vibration, the new turbomachinery protection system, which is intended as a retrofit on shutdown systems, has the ability to recognize developing machinery conditions as well as detect a severe condition requiring a shutdown to protect the machine.

Ideally, the signs of potential failure have been observed, predicted and attended to so that vibration never gets to the level where "protection," i.e. shutdown, is necessary. In the rare unpredictable scenario of a rapid catastrophic failure, the machine is protected.

Machinery health parameters are integrated with the plant's control system. For the first time, vibration monitoring becomes an extension of the central control system, which often monitors temperature, pressure, load, etc., any one of which could be symptomatic of a problem. Vibration monitoring actually monitors the position and the motion of the shaft *inside* the bearings. That information is now integrated with the control room, making operators aware of what is happening deep inside a critical machine—

such information is of much greater value than just the symptoms of degrading performance.

Up to 50% of machinery problems are process induced. If they are not caused by operators directly, they are the result of standard procedures used by control room personnel. When adjustments are made under these conditions without machine health feedback, tradeoffs occur. Improvements are made to production, but operations personnel are blind to the stress placed on machinery health.

When the operators have real-time supervisory and vibration parameters at their disposal, they can observe the impact of process adjustments on a machine's health and learn what steps can be taken to actually improve performance. For example, during the start-up of a turbine, if case expansion or rotor eccentricity levels are not within acceptable limits, operators can make realtime adjustments to ramp rates and also make business decisions to optimize the ramp rate versus the impact on machinery health. Informed real-time decisions are best made when vibration data is integrated with the process automation system.

Conclusions

For the most critical rotating equipment in the plant environment, three scenarios must be accounted for: the unpredictable, the predictable and the controllable. The complete solution covers all three scenarios by providing protection monitoring, prediction monitoring and performance monitoring all integrated with the process control system.

Monitoring systems utilizing advanced predictive technologies are giving end users newer, faster and more complete methods for analysis and automated analysis—*information that can be acted upon.* **MT**

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