

## APPLICATIONS

# Predictive maintenance keeps plant operational

In a nuclear facility, the timing of equipment maintenance is crucial to continued plant operations. In many respects, predictive maintenance is an extension of nuclear industry safety culture. While all nuclear facilities employ predictive maintenance programs to some extent, management at the Monticello nuclear generating plant, located on the Mississippi River near Monticello, Minn., identifies predictive maintenance as part of its corporate culture. The boiling water reactor plant has been in commercial operation since 1971.

In an effort to address equipment operations proactively, predictive maintenance plans were developed and tasks were prioritized based on inspections, surveys, and condition assessments so that repairs could be completed in a systematic manner. Coolant pumps, for example, operate at very high rotating velocities, and any defect in alignment, support, or anchorage can cause excessive vibrations in power shafts and in pump gaskets and seals. Through a predictive maintenance program, monthly assessments of rotating pump vibrational amplitudes and frequencies identified irregularities in pump support mechanisms. Condition assessments of supporting elements revealed voids and delamination in the grout interface between the plant's high-pressure coolant injection (HPCI) pump foundation and steel base plate.

"It is similar to going to the doctor and getting a physical," said Donald Rhoda, a predictive maintenance engineer at Monticello. "We use predictive maintenance tools such as vibration analysis, thermography, motor current analysis, and acoustic monitoring to determine the health of a piece of equipment. With vibration analysis, we can detect bearing degradation, misalignment,

*At Xcel Energy's Monticello plant, the early diagnosis of vibrations led to preemptive pump repairs.*

imbalance, resonance, and many other conditions. With thermography, we can find 'hot spots' in electrical connections, and we also use it for monitoring mechanical issues such as hot bearings. The goal is to identify equipment issues before the equipment fails. This allows time for a planned repair evolution rather than an emergent repair."

## Vibrational fundamentals

Machinery and equipment that rotate in multiple dimensions generate vibrational energy, which typically is dampened by massive concrete support pads or a foundation pad that rests directly on soil. The evaluation of an equipment's foundation dynamic properties (such as spring rate and damping) can be highly indeterminate in many cases, and calculations of the equipment's disturbing frequency on the foundation are complex.

Energy dissipation occurs in the pump's supporting elements and foundation. The rate of damping and the natural frequency, however, are a function of the magnitude of the vibration input and foundation geometry. Each element supporting the vibrating motors and pumps eventually needs to transfer and dissipate energy to the next element and to the foundation soil. Defects that exist at any of the structural interfaces between the rotating part and the soil can amplify vibrational problems.

Poorly designed and installed foundations may amplify vibration, or worse, may settle unevenly and sink. The interaction between the soil and the foundation is equally as important as the interaction between the machine and the foundation.

## Existing conditions

Monticello's HPCI pump base was about 40 years old, and in the 1980s, it had experienced excessive vibrational issues. Additional anchor bolts were added to support the system. Despite those early corrections, two decades later, vibrations began approaching high levels. High-amplitude vibrations can cause the misalignment of pump seals and lead to uneven wear on bearings. Improperly repaired and aligned, the pump could wear out prematurely and cause critical safety equipment component failure. Because the HPCI pump is the first line of defense for a reactor vessel in cases where a loss of normal core coolant inventory occurs, it must remain operational.

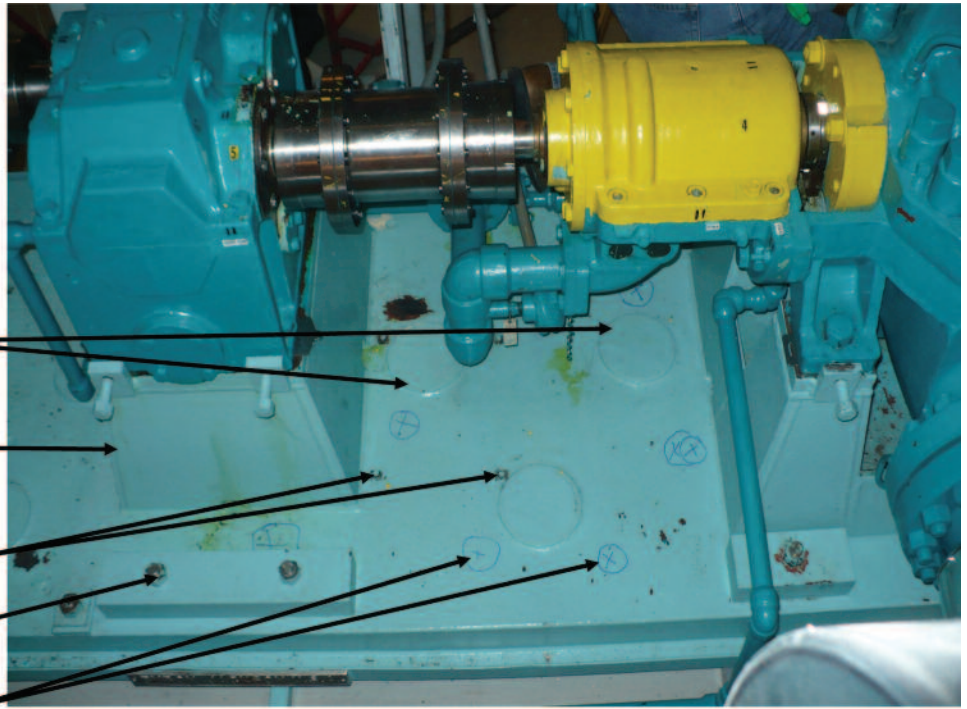
Proper application of cementitious grout during equipment installation is important, as the grout must uniformly transfer loads and energy to the underlying foundation. Gaps, air pockets, and voids in general between the grout and the supporting metal base plate can cause stress and energy concentrations in adjacent areas. Over time, excess vibrational energy over these voids causes micro-cracks (delamination) in the supporting grout in adjacent areas. Eventually, vibrational amplitudes deteriorate the entire support mechanism.

The problem of high-level vibrations could be attributed to a grouting or application error in the original construction, or possibly to the repair methodology that was used in the 1980s.

Structural, a Structural Group company based in Hanover, Md., was signed as the repair contractor to perform the maintenance on the HPCI pump foundation, based on its

## HPCI Main Coolant Pump

- Metal Caps welded over Metal Base Plate, Vent And Supply Holes for Previous Cementitious Grouting
- Elevated Metal Pump Supports Welded to 1/4" Thick Metal Base Plate
- Location of 3/8" drill holes Through 1/4" Metal Base Plate for Epoxy Resin Injection
- Thickened Steel Base Plate, Leveling Rods Below Plate
- Location of Air Pockets and Voids Under Steel Base Plate



expertise working in nuclear facilities and its repair capabilities.

To determine the best strategy for carrying out the needed repairs, Structural worked with Structural Technologies, another Structural Group company, which provides product solutions and engineering support. Structural Technologies' grouting expert led the team in identifying the problem and developing a plan for the materials that would be needed, the method to be used to carry out the repairs, and the quality control and assurance practices that would be used to deliver the final solution.

The Structural Technologies team performed acoustic impact testing to deter-

mine where voids existed under the metal base plate and their extent. The testing detected numerous voids between the metal skid base plate and the grout.

The first step was to drill three pilot holes through the 1/4-inch metal base plate to examine the grout/metal interface. It was noted in all three test holes that corrosion existed at the grout/metal interface and micro-cracking of the cementitious material had occurred, allowing the base plate to vibrate excessively and create energy frequencies and amplitudes that were causing premature wear of the machinery power shafts, gaskets, and seals above the plate.

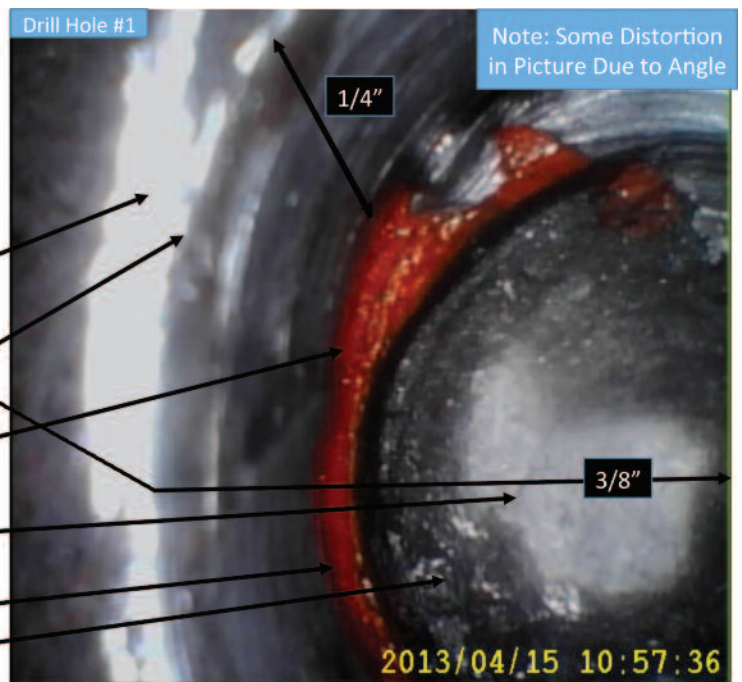
### Repairs at Monticello

Repairs began during a planned plant shutdown. Structural's approach to lessening the equipment vibration included the injection of epoxy-based grout into the voids between the original grout and the skid to improve the bearing support for the skid. The repairs involved pressure injection and gravity fill of cracks, voids, and annular spaces. Spaces where concrete was removed were then repaired with cementitious grout. The pump equipment stayed in place during the repair, so the biggest challenge was to avoid lifting the steel plate while injecting the grout.

Grouting under the large metal base plates required a systematic approach that mini-

## Investigation Holes for Charge and Discharge Holes

- 1/4" Thick Metal Base Plate after Paint Removal
- Grey Lead Based Paint was Removed From Vicinity of 1/4" Metal Base Plate Top Surface Prior to any Drilling
- 3/8" Diameter drill Hole Through 1/4" Metal Base Plate
- Steel Corrosion Deposit in Gap Between top of grout surface and bottom of 1/4" metal base Plate
- Friable Cementitious Grout and Micro-cracks in top of Cementitious Grout at Surface under Base Plate
- Small Unbonded Void (20 mils or 0.5 mm) Between top of grout surface and bottom of 1/4" metal base Plate
- Friable Cementitious Grout Debris at Void interface



mized air pocket buildup under the metal supports. The selection of proper grout material—considering properties such as flowability, pot life, and thixotropy—was critical to achieving success, as was the use of an aggregate grout blend large enough to fill the area below the metal base plates. Lack of flowability almost always results in air pocket buildup and loss of uniform bearing and vibration control under large metal plates.

The most important step in the process was to ensure that the existing anchor bolts penetrating the plate exceeded design capacity. If there were issues with strain creep or anchor-bolt slippage, the grouting would not compensate. To perform the inspection and repair, Structural drilled ½-inch-diameter holes using a grid pattern that was based on the approximate void locations. A borescope was placed down the drill holes

to determine the extent of the voids, particularly if they were in excess of ¾ inch. High-durometer silica sand was vacuum placed prior to resin injection in all suspected large air pockets. After the injection ports were installed and sealed, the epoxy was injected, and the process was repeated as necessary to complete the penetration of the entire skid. When the epoxy had cured, Structural performed acoustic emission testing on the steel skid base plate to ensure that all of the voids were filled.

The successful grout repairs on the HPCI pump stiffened the base plate and moved the natural resonance frequency to where it needed to be to reduce vibrations.

### **Savings in time, dollars**

The Monticello plant has found that the benefits of a predictive maintenance program are numerous: Maintenance is per-

formed when it needs to be done, often without shutting down the facility; the repair costs are lower; and the facility's life is extended.

Because repairs were addressed early on, the entire grout fill did not require the removal and replacement of the HPCI pump. This avoided the added costs of conducting pH, carbonation, and petro-graphical analysis because the pump base did not exhibit considerable micro-cracking and/or dusting at the exposed grout surfaces on the sides of the metal supporting plate.

The entire process took three men working less than a month, without an unplanned plant shutdown, and the repairs were finished on schedule. Rhoda explained that using predictive maintenance at Monticello has resulted in significant savings. "It is hard to calculate," he said, "but it would be in the millions of dollars." **N**