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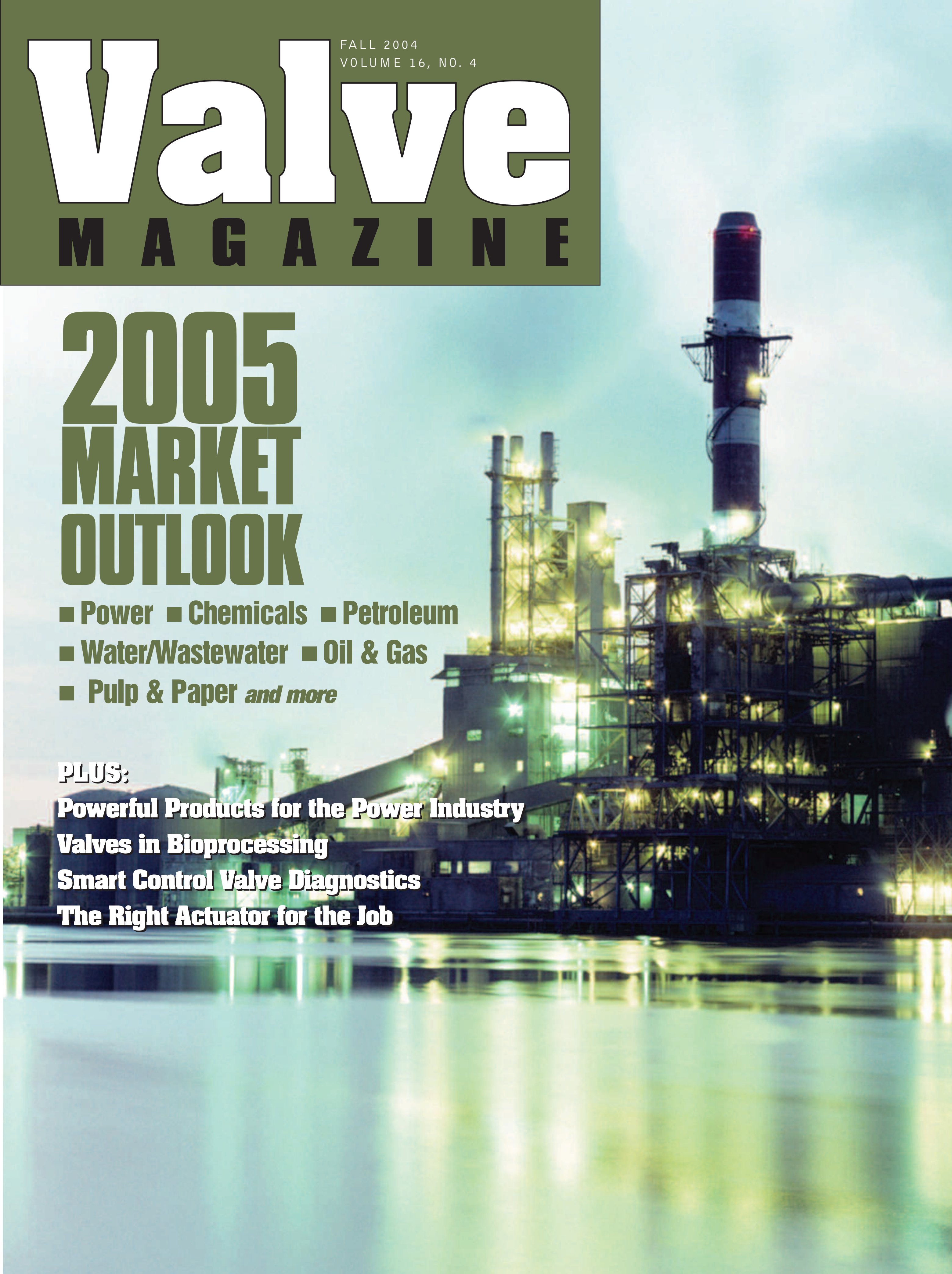

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SMART CONTROL VALVE DIAGNOSTICS:
PREDICTIVE MAINTENANCE AND BEYOND

EXTENDED RUN TIMES MEAN LESS OPPORTUNITY FOR OUT-OF-SERVICE DIAGNOSTICS, SO PLANTS ARE TURNING MORE TO IN-SERVICE EVALUATION TO ANALYZE VALVE PERFORMANCE.

BY NEAL RINEHART AND DAVID INGRAM

The speed at which control valve diagnostics has been developed and applied in the last decade has been nothing short of spectacular. In the early 1990s, evaluating control valve condition had to be accomplished with the valve bypassed or with the process shut down. Microprocessor-based valve instrumentation and sensor technology have changed all that: The health of a control valve assembly can be evaluated easily while the valve is in service. Data can be collected without intruding on normal process operations, and this data can be analyzed in real-time providing maintenance recommendations specific to the problem at hand.

The desire for in-service control valve diagnostics has been driven by economic pressure. Operators feel the need to maximize process up-time using fewer and fewer resources. In many cases, process companies have extended the average time between turnarounds to three, four, and even five years or more. These extended run times mean less opportunity for out-of-service diagnostics. The ability to evaluate valve performance in-service allows for better turnaround planning because the information gathered can be used to plan maintenance without working on valves that are healthy.

In this article, we will look at several key areas related to development of today's predictive maintenance technology for control valves. First, we will examine the typical maintenance process for problem detection, evaluation, recovery, and validation. Off-line (first-generation) diagnostics will be briefly reviewed to provide background on overall diagnostic capabilities. Next, today's in-service (predictive) diagnostics will be examined to demonstrate the breadth of what has occurred with this new technology. Specific customer successes with in-service valve diagnostics will be presented. Finally, we will take a brief look at what the future holds for control valve diagnostic technology.

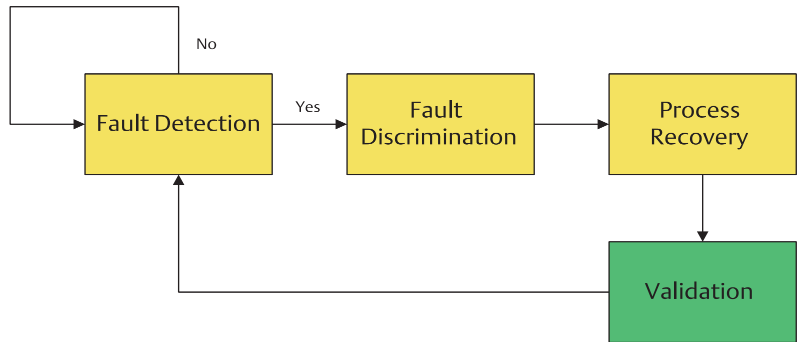

Figure 1. Valve maintenance process

Typical Maintenance Process

The typical valve maintenance process (Figure 1) includes four distinct modes:

- **Fault Detection.** A majority of the valve maintenance process time is spent in this mode. In fault detection, the valve assets are in-service and monitored to detect the occurrence of a fault. If no fault occurs, the fault detection process will continue until a fault does occur. When a fault is detected, the maintenance process transitions to fault discrimination.
- **Fault Discrimination.** During fault discrimination, valve assets are evaluated to determine the cause of the fault and to establish a course of corrective action. When the fault's cause has been identified and corrective action established, the maintenance process transitions to process recovery.
- **Process Recovery.** Here, corrective action is taken to fix the source of the defect. When process recovery is completed, the maintenance process transitions to validation.
- **Validation.** In this mode, the valve assets are evaluated relative to as-new condition or the last established baseline condition and, once validated, the maintenance process returns to the fault detection mode.

First-Generation Diagnostics

First-generation smart valve diagnostics are out-of-service diagnostics. They include diagnostics of the valve assembly as well as in-service trending and alert information about the valve assembly and the digital valve controller (DVC).

Out-of-service diagnostics include tests such as valve signature, dynamic error band, and step response. To provide insight into the dynamic performance of the valve assembly, these diagnostics vary the DVC set-point and plotted valve operation. The valve signature test provides assembly friction, bench set, spring rate, and seat load. The dynamic error band diagnostic is a combination of hysteresis and deadband plus dynamic error. The step response diagnostic provides insight into the valve assembly's ability to respond to changes in input signal.

Trending diagnostics provide the ability to collect and view data over time. Trending typically can be customized to display up to 30 days of data. Trended data usually includes travel, travel set point, input signal, digital valve controller output pressure, and temperature. In addition, trending provides graphic representation of travel activity including travel reversals, total travel, and a travel histogram.

In-service alerts include valve assembly alerts, DVC failure alerts, and operational status alerts. Valve assembly alerts include travel deviation from set point, travel-high, travel-low, and drive signal. DVC failure alerts include sensor failure, drive current failure, reference voltage failure, non-volatile memory failure, and read-only memory failure. Operational status alerts include information on instrument mode out-of-service, calibration in progress, or diagnostic in progress.

Today's Valve Diagnostics

Today, smart valve diagnostics are truly predictive and include in-service diagnostics for monitoring the health of the valve assembly and customized diagnostics for advanced troubleshooting. These diagnostics analyze the valve assembly while the valve is being controlled in the control system's normal mode of operation. The monitoring diagnostics are preconfigured to collect data, correlate the data, and execute an analysis to establish the cause and provide specific recommended corrective action. In-service diagnostics can detect problems with instrument air leakage, valve assembly friction and deadband, instrument air quality, loose connections, supply pressure restrictions, and valve assembly calibration. Presently, almost 200 different faults can be identified with in-service diagnostics.

When a problem is identified, its severity is reported. The problem is described, a possible cause identified, and a course of action recommended. In the context of the maintenance process depicted in Figure 1, these diagnostics can conduct both fault detection and fault discrimination.

Predictive diagnostics typically result in one of three conditions:

- **No fault** detected (green). The valve should remain in service, and monitoring should continue.
- A **warning** that a fault has been detected but control remains unaffected (yellow). A predictive indication that the problem detected has the potential to affect control, and future maintenance should be planned. This

warning allows for proactive planning to avoid the potential for an unplanned shutdown.

- An **error** report that a fault affecting control has been detected (red). This fault is likely to be adversely affecting the process, which generally requires immediate attention.

In-service diagnostics for troubleshooting allow the maintenance technician to create custom diagnostics that can collect data at a high-frequency rate and present that data in a graphical format. When an issue is so complex it requires external expertise, the data may be exported from the custom diagnostic and sent to the expert for evaluation, thereby eliminating the need for an on-site visit (see example below).

Fitting Predictive Diagnostics into the Maintenance Process

If we further examine the maintenance process, identifying where the various smart valve diagnostics fit into the maintenance process, we find that off-line diagnostics and predictive (in-service) diagnostics complement each other (Figure 2).

Smart valve diagnostics fall into one of two categories: in-service or out-of-service. Again, because turnaround times have been extended and costs have become tighter, most processes require that the valve be in-service and run by the control system most of the time.

First-generation diagnostics offer some diagnostics in each control mode (Figure 2). Out-of-service diagnostics include valve signature, dynamic error band, and step response. In-service diagnostics include alerts and trending.

Today's predictive diagnostics have been developed exclusively for the in-service portion of the maintenance process (Figure 2). These diagnostics include both in-service monitoring and in-service custom diagnostics. Predictive fault detection and discrimination report a fault before it has progressed to the point where control is affected. In-service monitoring diagnostics also differ from first-generation diagnostics in that they can recommend precise corrective actions for identified faults. This allows proactive maintenance to prevent unplanned shutdowns, to reduce the length of planned shutdowns, and to extend the intervals between shutdowns.

Smart valve diagnostics may be either network based or route based. Network-based diagnostics are performed remotely with the network communicating to the digital valve controller. In a networked environment, in-service diagnostics also may be scheduled to run automatically. Out-of-service diagnostics also may be set to run automatically on any smart valve accessible on the network.

With route-based diagnostics, testing is a manual process performed on one valve at a time. Unfortunately, smart valve diagnostics are sometimes overlooked in a route-based environment. However, the benefits of route-based diagnostics are the same as for networked-based diagnostics, and many world-class companies are using route-based diagnostics with great success.

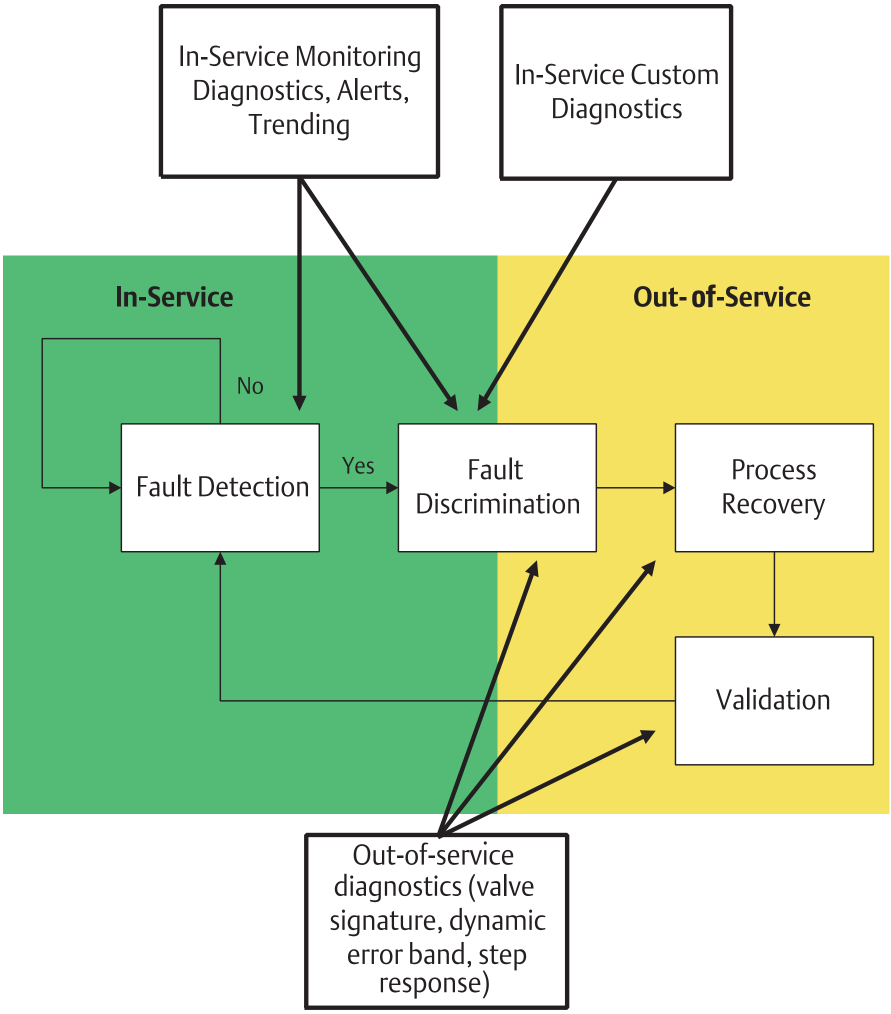

Figure 2. In-service and out-of-service regions of valve maintenance process

How Control Valve Diagnostics Are Being Used

Today's smart valve diagnostics are being used successfully in many process industry facilities. With the advent of sophisticated in-service diagnostics, companies are redesigning their control valve maintenance work practices to enhance their plants' performance and to achieve higher overall reliability.

In the following examples, we will examine several of these new, in-service monitoring diagnostics and see how users are making the most of their facilities by using predictive tools.

Instrument Air Leakage

Air mass flow diagnostics measure instrument air flow through the control valve assembly. Because of multiple sensors, this diagnostic can detect both positive (supply) and negative (exhaust) air mass flow from the DVC. This diagnostic not only detects leaks in the actuator or tubing to the actuator but also much more difficult problems. For example, in piston actuators, the air mass flow diagnostic can detect leaking piston seals or damaged O-rings.

At a large North American Purified Terephthalic Acid (PTA) facility, a routine air mass flow diagnostic on a critical control valve that had a double-acting piston actuator identified a sustained positive air mass flow from one port of the DVC and a sustained negative air mass flow from the other port. The diagnostic also revealed that the air mass flow was high, but that control remained unaffected. As part of the automated analysis, the probable cause was identified as a leak in the actuator piston seal, and the recommendation was made that the actuator be checked for piston seal leakage.

Maintenance personnel visually inspected the valve and could not determine if there was a leak. Since piston seal leakage is internal and exhausts through the valve instrument, no outside indication of a problem existed. The initial maintenance response was to monitor the air mass flow continually and watch for changes in leakage to occur (Figure 3). When changes occurred, the actuator was disassembled and it was discovered that the piston seal was compromised and close to catastrophic failure. The predictive air mass flow diagnostic allowed this problem to be detected and monitored, which ultimately prevented a costly unplanned shutdown and loss of approximately $400,000 worth of catalyst.

Figure 3. Results of in-service diagnostics in a North American PTA facility: A leaking actuator piston seal was detected and monitored without impact on the process.

Supply Pressure Diagnostic

The supply pressure diagnostic detects control valve problems related to supply pressure. This in-service diagnostic will detect both low- and high-supply pressure readings. In addition to checking for adequate supply pressure, this diagnostic can be used to detect and quantify droop in the air supply during large travel excursions. This is particularly helpful for identifying supply line restrictions.

In a Midwest corn-processing facility, the in-service supply pressure diagnostic identified that more than 10 percent of critical control valve assemblies had inadequate supply pressure, and control was being compromised. Although initial out-of-service tests found no valve problems, the dynamic, in-service diagnostic testing identified underlying air supply issues, which allowed for performance improvements in the overall process.

Travel Deviation and Relay Adjustment Diagnostics

The travel deviation diagnostic is used to monitor actuator pressure and travel deviation from set point. This diagnostic is useful for identifying a stuck control valve, active interlocks, low supply pressure, or travel calibration shifts.

The relay adjustment diagnostic is used to monitor crossover pressure on double-acting actuators. If the crossover pressure is too low, the actuator loses stiffness, making the plug position susceptible to buffeting by fluid forces. If the crossover pressure is set too high, both chambers will be near supply, the pneumatic forces will be roughly equal, the spring force becomes dominant, and the actuator will move to its spring-fail position.

At a paper mill, the main steam valve was experiencing intermittent deviations from travel set point. The actuator was a double-acting piston actuator. A travel deviation diagnostic showed that a change in travel was occurring in advance of a change in actuator pressure. A relay adjustment diagnostic indicated that the crossover was too low. The low crossover pressure and the associated loss of stiffness in the actuator allowed this valve to be susceptible to the fluid forces of the process. The relay adjustment diagnostic was used to adjust the crossover. Afterward, the fluid forces of the process no longer affected valve position, and the travel deviation was eliminated.

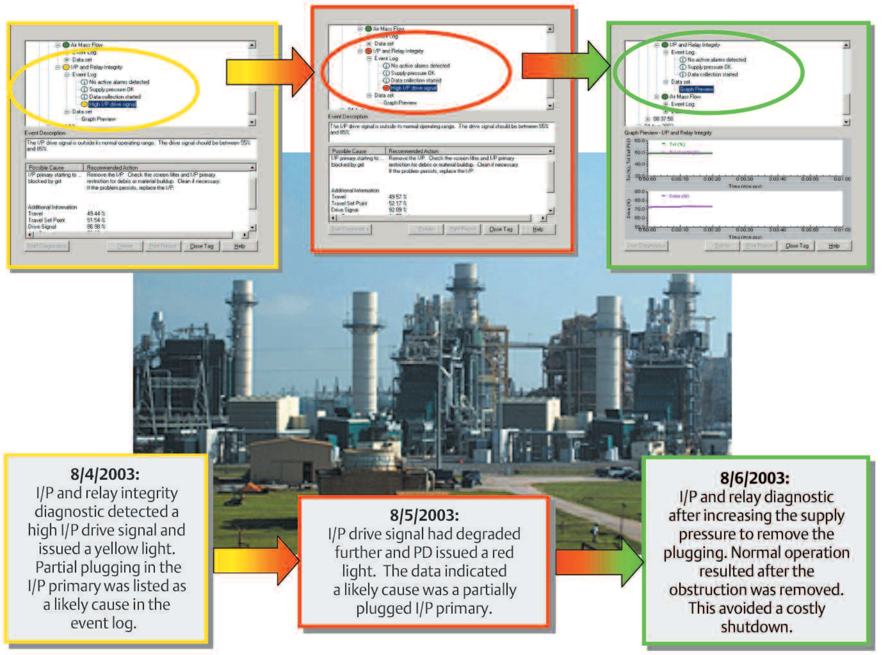

Figure 4. In-service diagnostics at a Gulf Coast combined-cycle power plant: Instrument plugging due to poor instrument air quality was detected, corrected, and verified without requiring a process shutdown.

Instrument Air Quality

The I/P and relay monitoring diagnostic can identify problems such as plugging in the I/P primary or in the I/P nozzle, instrument diaphragm failures, I/P instrument O-ring failures, and I/P calibration shifts. This diagnostic is particularly useful for identifying problems from contaminants in the air supply and from temperature extremes.

At a combined cycle power plant in the Gulf Coast, a routine I/P and relay integrity diagnostic on a main steam valve identified a previously undetected partial plugging in the I/P primary from contaminants in the air supply. The diagnostic detected the fault, identified the cause as partial plugging of the I/P primary, and recommended the I/P be removed and cleaned. Maintenance personnel were able to take proactive corrective action and avoid an unplanned shutdown (Figure 4).

In-Service Friction and Friction Trending

The in-service friction and deadband diagnostic determines friction in the valve assembly as it is controlled by the control system. Friction diagnostics data is collected and trended over time to detect valve changes that affect process control.

At a Canadian oil and gas producer, a control valve in a water injection system was not operating properly. An in-service friction diagnostic indicated higher-than-expected friction. Maintenance personnel took the valve out of service and performed diagnostics. The diagnostic showed normal friction. The valve was disassembled, revealing that the cage was cracked. In this case, high in-service friction was indicative of a problem, but this higher-than-expected friction was only present with process loading on the valve. The combination of in-service and out-of-service friction diagnostics allowed the successful resolution of the problem, illustrating how in-service and out-of-service friction diagnostics can be complementary.

At a paraxylene manufacturer in Thailand, a critical pressure control valve was fluctuating despite a stable signal from the control system. The operator became concerned by the erratic operation of the control valve. Maintenance technicians ran an in-service friction diagnostic and determined the friction was much lower than two years earlier. Adjustments were made to the boosters and tuning to compensate for the decreased friction. As a result of this test, the process remained online and an unnecessary shutdown was avoided. In this case, the end user estimated that a shutdown would have resulted in loss of revenue of approximately $200,000.

Other Interesting Examples

In-service custom diagnostics may be configured to collect and graph any measured variable of a smart valve. Custom diagnostics can detect and discriminate faults not detectable by other means. Often, these faults are complicated and require outside expertise. In such cases, data is collected by local maintenance personnel, and as explained earlier, the data can be sent to an expert for further analysis—thus avoiding the costs and delays associated with an on-site visit.

At a co-gen facility in a chemical plant, a turbine bypass valve was not working properly. An in-service custom diagnostic showed the valve was binding and not fully stroking. In-service and out-of-service diagnostics were run on this valve under no flow conditions while the valve body was cool. No problems were found, but the tests indicated that the problem was likely caused by process flow or temperature effect. The valve was brought up to process temperature and out-of-service diagnostics were again run on the valve under no flow conditions. The valve signature diagnostic showed the valve was sticking at upper travels. It was then determined that temperature gradients introduced a mechanical interference between the valve plug and cage. This very complex problem is hard to diagnose and required outside expertise. Smart valve diagnostic technology allowed data to be collected by local plant personnel and e-mailed to the outside expert, thereby avoiding bringing the expert on site.

Where Do We Go from Here?

As stated in the beginning of this article, control valve diagnostics have evolved rapidly over the past decade. Through digital valve controllers and sophisticated sensor technologies, predictive, in-service diagnostics can be applied easily to today's process plants. This is important since the process industry will continue to demand more and more efficiency, in terms of quality, yield, and reliability. World-class producers also will continue to extend up-times to higher and higher levels, thus lengthening time between turnarounds and making unplanned shutdowns unacceptable. In addition to these demands, there will be fewer and fewer maintenance man-hours available to maintain field instrumentation. Because of these requirements, future diagnostic developments will focus on in-service/non-intrusive tests.

New diagnostics will provide specific documentation of exactly what needs to be fixed; lists of required parts, tools, drawings, and instructions; lists of qualified repair personnel; and other information that will be needed to perform repairs quickly and reliably. In addition, these new diagnostics will link into maintenance systems and allow automatic logging and generation of required maintenance documentation. Developments also will link information from both the maintenance system and the process system to allow the generation of "economic impact" rankings for identified valve maintenance problems.

Benefits from predictive maintenance on control valves are already affecting today's process facilities. Plants are incorporating these technologies into their maintenance work practices and are achieving a solid return on their investments. **VM**

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