Improve Plant Productivity, Uptime, Safety and Product Quality using local and On-line Valve Condition Monitoring Technologies

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ABSTRACT

This paper discusses the value of developing a valve maintenance program that includes condition monitoring of motor-operated block valves and pneumatically operated control valves; particularly those valves in safety-critical, plant-critical and quality-critical applications. Example case histories, presented by a plant owner-user, will demonstrate how the use of valve diagnostic/condition monitoring technologies in a comprehensive valve maintenance program can dramatically improve plant uptime, safety and reduce unscheduled maintenance.

INTRODUCTION

The accident at Three Mile Island led the commercial nuclear power industry to reevaluate valve failure on demand and the potential impact of valve failure on nuclear plant operation. The investigation surrounding the accident identified a failed check valve in a pneumatic line that was responsible for the initial plant trip and transient, a contaminated pneumatic system that affected control valve performance during the accident and failure of MOVs in the auxiliary feedwater system that impeded the operator's ability to recover the plant.

In the final analysis, the TMI accident exposed valve performance and reliability as a significant nuclear plant safety issue. In the years that followed, the Nuclear Regulatory Commission (NRC) documented a long list of valve performance issues and additional plant events that resulted from valve failures and degraded valve performance. Since 1985, the NRC has systematically increased the level of attention required for all types of valves used in nuclear power plants. Working in concert with the ASME code working groups, the NRC has helped move the nuclear industry from time-based, scheduled maintenance to condition-based maintenance (CBM) strategies for power-operated valves. The CBM approach owes its success, in part, to the ongoing advancement in diagnostic and monitoring technology for valves and actuators and to the successful marriage of the technology with valve maintenance programs.

In today's environment, it is unlikely that a valve in any of this nation's 103 operating nuclear power reactors will fail to operate when required. It is important to note that the valves and actuators employed in nuclear power plant applications are essentially the same as those employed in the oil and gas, chemical, conventional electric power, water treatment and any other process industry. Though valve failure rate data is not abundantly available outside of the nuclear industry, the components are essentially the same and correlation of the data may be directly applicable to all of these industries. Since 1997, Norwegian oil companies have been capturing valve failure rate data in the Offshore Reliability Database (OREDA). The current phase of the OREDA project will be completed in the first half of 2003. Valve failure rates in the OREDA Database far exceed those of the commercial nuclear power industry during the darkest days of valve performance. Surveys and discussions with maintenance and engineering personnel from refineries, power plants and other industrial process facilities reveal that on-demand failure of power-operated valves is not uncommon. And, valve failure on demand effects production output, the quality of the output and at times safety in all of these industries. Fortunately the same high level of valve performance and reliability enjoyed by nuclear power plants is available to all process industries where valve failure on demand has negative consequences.

BACKGROUND

Prior to 1984 valve diagnostic testing consisted of stroke time measurements using a hand-held stopwatch. If the valve changed position within the allotted time it passed the test and was considered operable. The first commercially available MOVATS MOV diagnostic system enabled plant engineers to capture real time data representing a wide range of performance characteristics. The new approach made it clear that even though a valve passed the stroke time test under static conditions, there was no correlation of the results to performance under the conditions present when the system is operating.

The basic issue affecting performance was often found to be misadjustment of limit and torque control switches. Prior to diagnostic measurements, symptoms of the incorrect settings could only be observed under dynamic system conditions when the flow and differential pressure challenged the actuator. The new diagnostic equipment played a key role in the virtual elimination of MOV mechanical degradations and improper switch settings.

In the late 80's valve condition monitoring concerns shifted to verification of set-up margin and accuracy. NRC regulation and industry research played a major role in highlighting the importance of an accurate set-up. As a result, diagnostic equipment vendors focused on the development of direct stem force measurement transducers. The diagnostic systems, transducers and the testing process became much more complex and time consuming.

If there is a negative aspect of ongoing valve condition monitoring and improved reliability it may be the fact that the at-the-valve periodic testing processes ads costs and affects outage performance. Since the initial baseline testing process achieves the most noticeable return, recognition of the benefits of ongoing testing programs tends to fade after periods of reliable valve operation. Nuclear industry testing experience has shown that MOVs that are properly applied, were setup correctly during baseline testing and undergo consistent preventive maintenance rarely exhibit significant change between regularly scheduled PMs. Instead, overtightening of packing, incorrect reassembly, pinched wires and other maintenance-related items have been the main contributors to unplanned maintenance actions during outages. In fact, many of today's actuator problems requiring maintenance action have been the result of human errors that occurred during the scheduled at-the-valve testing process.

Improvements in test technology were needed that minimize the effect of MOV testing on outage performance and reduce O&M costs in general. Diagnostic equipment suppliers and aggressive nuclear utilities laid groundwork through the 90s for MCC-based testing of MOVs. MCC-based periodic verification approaches receive the most attention in today's economic driven environment.

To further ease capital, training and other adoption costs, diagnostic systems that were once dedicated to MOVs have evolved into multi-purpose platforms for condition monitoring of virtually any type of plant equipment. It is not uncommon for a single technician to employ the same diagnostic tool to test MOVs, pneumatic control valves, checkvalves, solenoids and electric motor driven equipment

Motor Operated Valves Lead the Charge into CBM

The nuclear power industry attacked the motor-operated valve issue in a systematic, program-oriented manner. The first step required plant operators to take a close look at the design basis or worse case conditions expected for each valve. This review identified the maximum differential pressure and flow that each valve would be expected to operate against. Based on the results of the design basis review, actuator output requirements and settings were calculated for each valve. The industry used mathematical models validated by full flow test data to ensure confidence in the field set up. The industry then embarked on an overhaul and field test program to ensure that the required switch settings were achieved. Today nuclear plant maintenance programs are oriented around maintaining the correct settings for the life of the plant.

Figure 1

A Test Engineer at work with the latest Valve Diagnostic Platform configured for MOV testing

The MOVs limit and bypass switches are generally set based on stem travel, light indications and desired bypass coverage. Limit switches are geared to the motor and change position after a certain number of motor revolutions. Time domain recordings of valve/stem position and switch actuation enable technicians to confidently adjust MOV settings.

During field testing, the test engineer measures the thrust available at control switch trip (CST) as depicted in Figure 2. The thrust at CST must meet or exceed the calculated thrust requirement. The motor torque at CST must be less than the reduced voltage capability of the actuator motor and the total thrust and torque must be less than structural weak links.

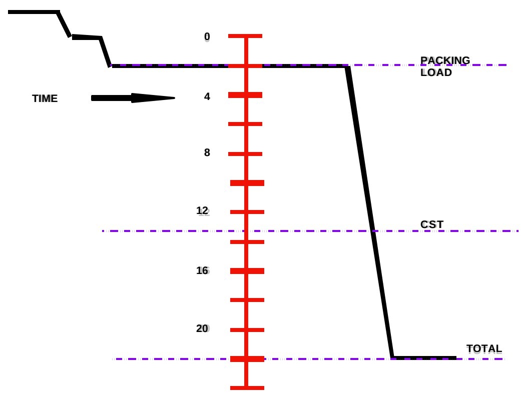

Figure 2

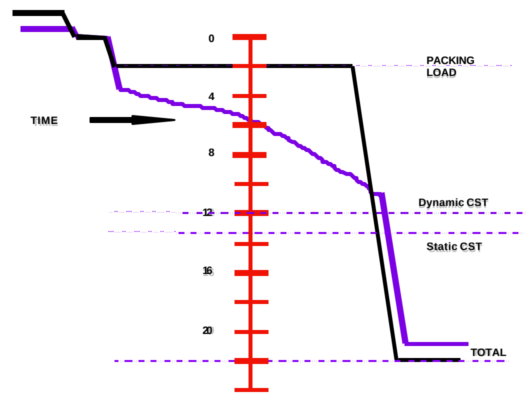

Figure 3

Under dynamic conditions the load profile will change to reflect the gradual thrust buildup that results from the increasing differential pressure force on the valve disk. Figure 3 identifies the normally expected change in the load profile due to differential pressure. The MOV torque switch is set correctly when the torque switch setting is higher than the region of the dynamic thrust signature that indicates hard seat contact.

As the nuclear industry dug into valve issues a series of questions that had not been addressed very well in the design and engineering process emerged. For many years, valves and actuators had been sized using a simple mathematical process that combined forces from differential pressure acting on the valve, the system pressure that works to expel the valve stem from the piping and friction loads from the packing gland. A critical factor in this equation is the friction assumption for the valve seats and guides. Nuclear industry research during the late 80's and early 90's revealed that this value could be significantly higher than what was assumed in the sizing equations used during the plants design work. Inadequate thrust settings for power-operated valves results in critical isolation valves with insufficient capacity to close and fully isolate systems when required to operate under conditions such as those expected during an accident or when the system is operating near full capacity.

In addition to the concerns with design calculations, the nuclear industry also learned that actuator output varies depending on how load develops during the actuator closing operation. Under static conditions, such as those required for baseline testing and switch adjustment, the actuator output is highest. However under dynamic conditions, such as those encountered while the system is under operation the actuator output changes. The cause has been attributed to changes in friction in the valve stem and actuator due differences in the load profile. For example under static conditions the actuator and valve operates against a constant packing load up until the valve seats. When the valve seats, the load increases rapidly until the torque control switch opens. Under dynamic conditions, the differential pressure ads load early in the load profile and slows the motor and all components in the drive train as the load increases. This difference leads to changes in the output available to close a rising stem valve.

Case Studies

Nuclear Power Plant MOV Program Example

There are a number of very good MOV program examples among the nation's fleet of commercial power reactors. Southern Company's Joseph M. Farley Nuclear Plant (FNP) is generally recognized as implementing one of the more innovative programs and has served as a model for those attempting to transition from costly at-the-valve testing to an MCC-based approach.

The population of safety-related MOVs at FNP includes rising stem gate and globe valves with Limitorque SMB or SB actuators and butterfly valves with Limitorque HBC gearboxes. Design basis thrust and/or torque requirements have been established for these valves utilizing a mix of dynamic testing and calculations. These MOVs have been baseline tested to ensure adequate margin exists between the as-left MOV setup and design basis requirements.

Stem lubrication effects the relationship between actuator output torque and stem thrust and is commonly referred to as stem factor. The current PM Program at FNP minimizes changes in conditions that affect the output capability of safety-related MOV actuators. Periodic stem inspection/lubrication maintains the stem factor conditions consistent with the stem factor present during the baseline test. Figures 4 and 5 below highlight improvement in stem factor achieved by the PM program. Figure 4 reflects significant variation in stem factor results during the 1992 refuel outage. The PM program was implemented after the 92 outage and by 1996 the values were consistently lower. This trend has continued through 2002.

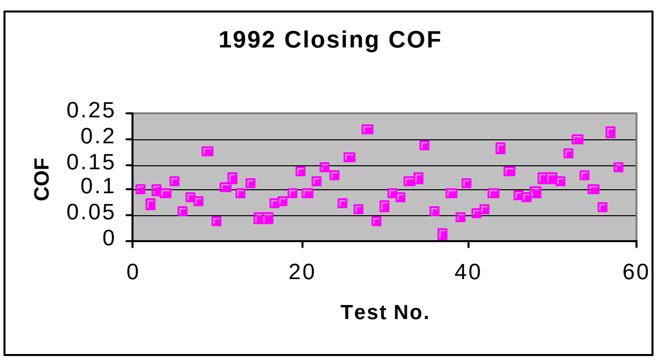

Figure 4

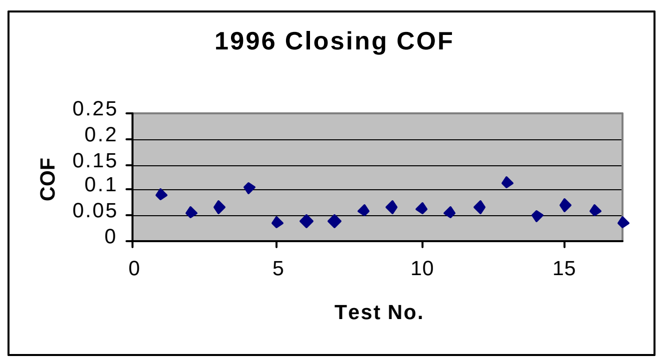

Figure 5

Certain periodic verification tests are performed “at-the-valve” at a frequency determined based on safety significance, margin and other considerations. The consistency in stem factor results also facilitates use of MCC-based measurements to assess margin. The MCC-based test approach employed at FNP utilizes measurements of the motor’s power supply circuit to evaluate changes in motor torque. The motor torque is converted to actuator torque based on actuator gear ratios and converted to stem thrust using the known stem factor relationships. These results are compared to the thrust requirement values to assess margin.

Currently, MCC-based testing is used at FNP to compliment at-the-valve testing, for trending, troubleshooting MOV concerns, and As Found/As-Left testing before and after minor maintenance. Non-Intrusive, MCC based testing minimizes the potential for human errors that can lead to unplanned maintenance and/or may effect performance.

Figure 6 below is a testimonial to the success of the MCC-based periodic verification program at FNP. The chart contains overlay graphs of MCC data taken over a 3-year period. The data indicates that performance has not changed during this period. Prior to MCC-based testing, technicians would have been required to perform these tests at-the-valve to prove that nothing was changing. The difference in cost is substantial.

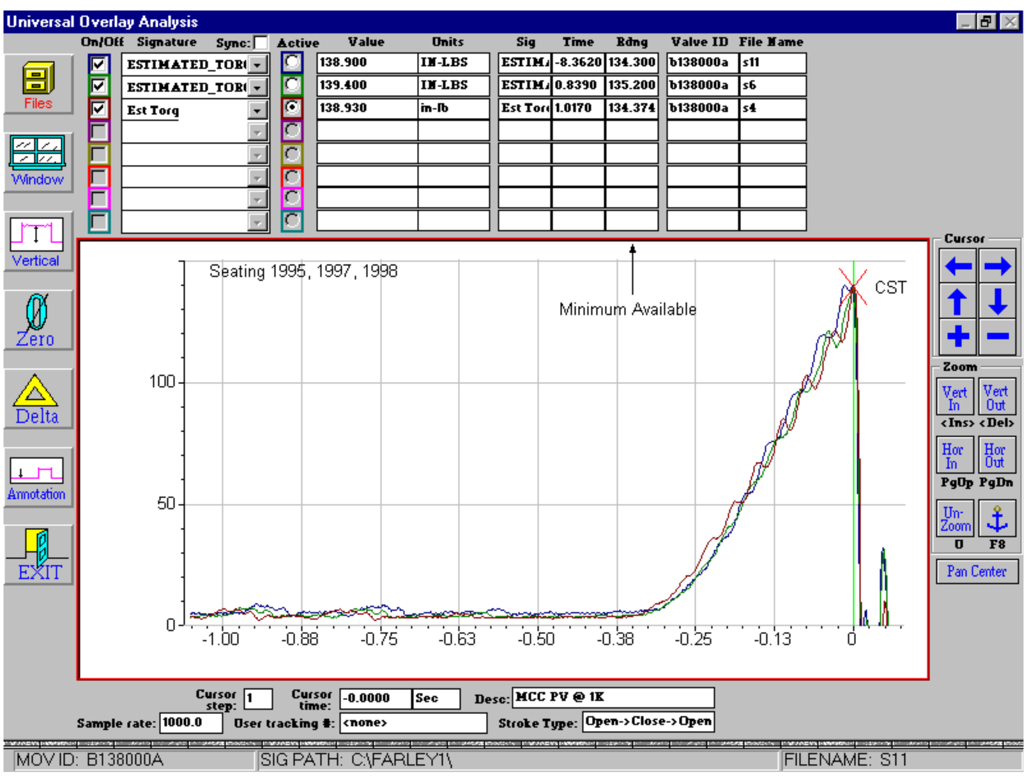

Figure 6

Reliant Energy Experience

As discussed above, valve issues that effect plant performance and output are not just a nuclear plant problem but plague conventional electric power production as well. Reliant Energy has dedicated resources to improving valve performance among it's fleet of conventional electric power stations as part of their reliability centered maintenance program. Unlike their nuclear cousins, it is not economically feasible to embark on the front-end engineering and highly precise field testing methods in conventional power plant applications. The issues are more basic and the consequences of valve failure not nearly as threatening. The basic issue was achieving reliable operation of often-neglected equipment (IE make it run but it does not have to compete in the Indy 500).

The purpose of Reliant's Motor Operated Valve Testing Program is to determine the condition of critical valves and dampers, actuators, and the motors that drive them. Reliant's goal is to ensure that MOV's are setup for proper operation and those in need of maintenance are identified and scheduled in advance. This in turn enables the generating stations to operate more efficiently.

The Reliant RCM program focuses on valves and actuators at 27 conventional electric power units at 10 sites. Approximately 92% of the near 1000 MOVs currently in the program have been tested to date. Table 2 provides insight into the magnitude of the program and the resource commitment through early 2003.

Site Identifier	# of Units	# of MOVs	% Complete
Site 1	3	146	98%
Site 2	1	10	100%
Site 3	1	41	100%
Site 4	2	122	79%
Site 5	4	181	96%
Site 6	4	56	98%
Site 7	3	99	95%
Site 8	4	98	100%
Site 9	4	234	85%
Site 10	1	12	100%
Totals	**27**	**999**	**92%**

Table 2

Reliant employs both at-the-valve direct measurements and MCC-based testing for MOVs. The MCC-based test system acquires all three phases of motor current and voltage at 1000 samples per second while simultaneously acquiring the control current in the limit and torque switches. Five amp clamps and three voltage probes (if voltage is accessible) are attached to the actuator or in the MCC for acquisition. The resulting data can be compared to similar valves and is stored as a baseline for future reference. Influences from the motor, actuator, and valve can all be seen in the power signature.

Analysis of the motor power and switch actuation times, along with a visual inspection of the actuator and control switches assists in identifying the problems listed in Table 1 below.

Incorrectly set open torque bypass
High motor current unbalance
Torque switch related problems
Electrical control problems
Declutching problems
Valve Back Seating
Loose stem nut lock nut
Excessive contactor dropout time
Valve binding in mid-stroke
Incorrect Limit switch settings
Incorrect wiring
Excessive Corrosion

Table 1

MOV test data analysis is similar to the EKG analysis performed by skilled medical technicians during a physical examination. The actuators rotating gears and other mechanical events provide the “pulse” that the analyst is looking for. A skilled analyst can easily distinguish healthy equipment characteristics from those indicating a problem.

In Figure 7 below MCC data for the first 4 seconds of the open stroke is displayed. The Pink Trace is motor power and the gray trace is the control current. The first small peak in the power data identifies an expected hammerblow event within the actuator followed by the main valve unseating event. The control circuit data indicates that the open direction torque switch opened during unseating but the parallel path provided by the bypass switch served its function and the actuator continued to pull the valve from the seat.

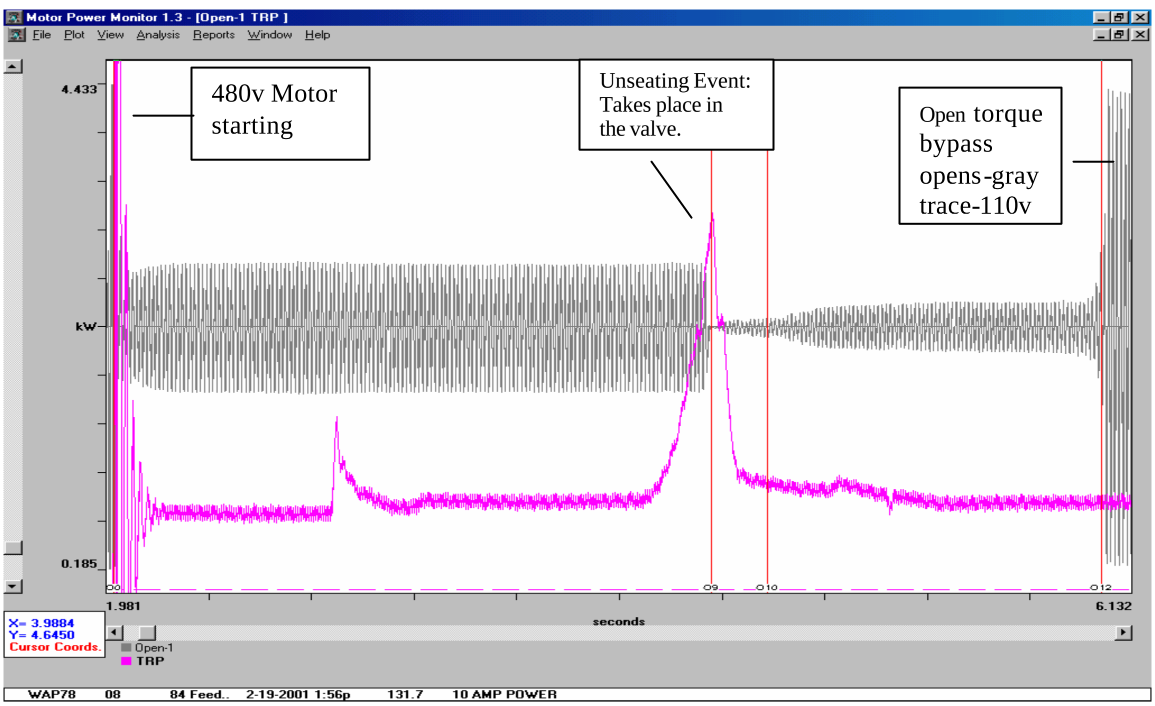

Figure 7

At-the-valve measurements of stem thrust are obtained with the Valve Vision System. The Valve Vision system is used by Reliant to measure small changes in the diameter of the valve stem due to changes in stem load. Measurements are taken with a C-Clamp type strain gage mounted on the valve stem. By entering the stem material and diameter, the system calculates the actual thrust output of the actuator. Analysis of the signature reveals valve running friction (packing friction) and seating force of the valve.

Figure 8 below identifies the increase in thrust output due to stem lubrication. This is consistent with the Farley observations discussed above and reveals one of the more likely causes of poor MOV performance. When the stem lubrication is poor the thrust output from the actuator is low. When the stem is lubricated the output thrust increases. It is important to note that the thrust required to close the valve does not change nor does the torque output of the actuator.

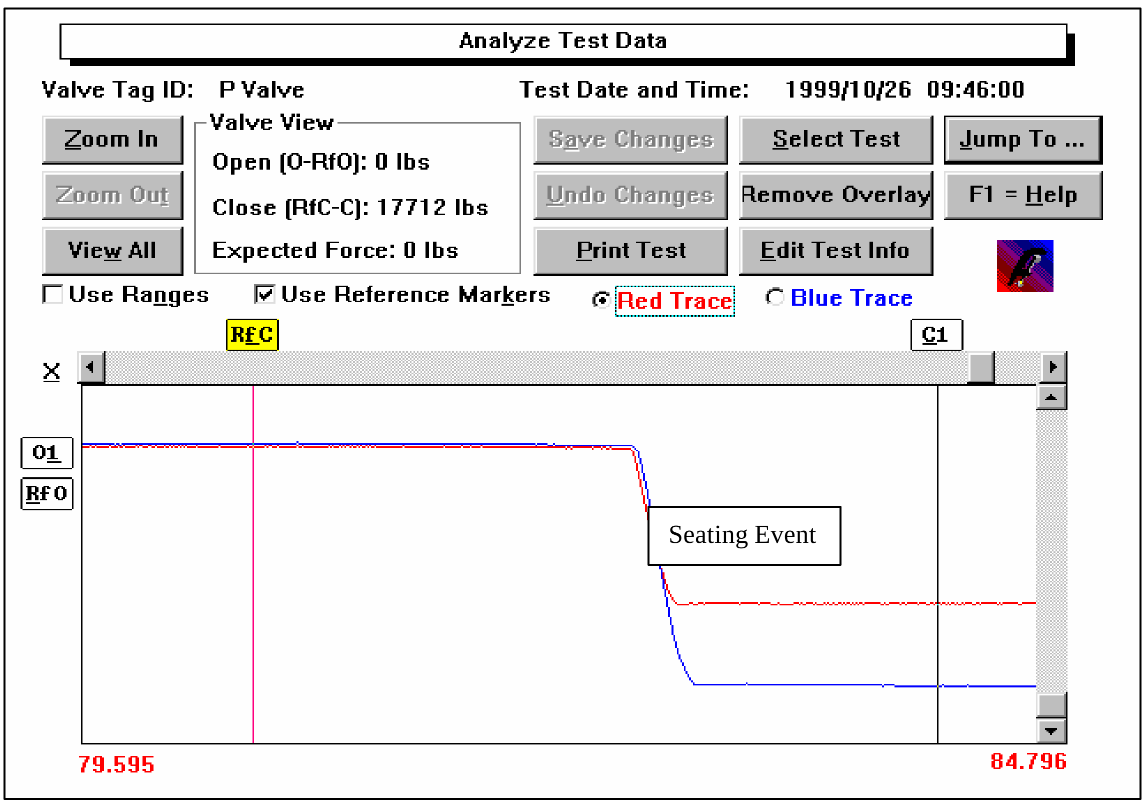

Figure 8

MCC-based condition monitoring is not only effective at identifying changes that occur in the valve and actuator but can also detect problems in the electrical components used to control the actuator. In Figure 9, the motor continues to run even though the open control switch has opened and current flow has been interrupted in the control circuit. When presented graphically, technicians can quickly diagnose the problem in the electrical contactor.

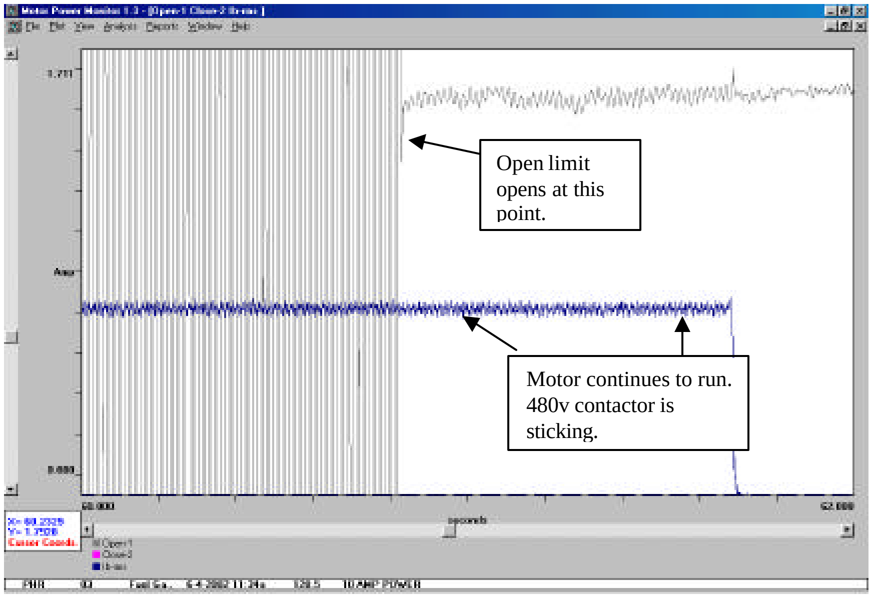

Figure 9

Figure 10 identifies a valve motor starting with the 480v contactor not making good contact on one phase. (This same problem signature was acquired on a valve with a loose 480v connection at the motor starter). The "A" phase (gray trace) makes just long enough to start the motor in the correct direction then drops out leaving the motor running on "B" and "C" phases only. On some starts "A" phase would not make and the motor would not start leaving it in a locked rotor, high current condition.

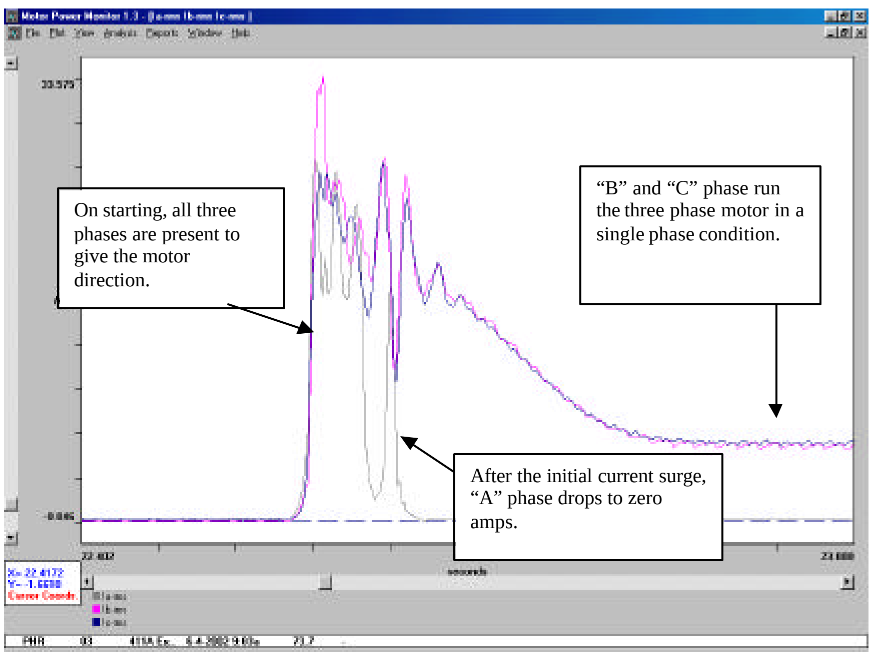

Figure 10

Reliant's focus on MOVs has been in place for several years and though the number of MOVs that are found inoperable is decreasing, a long list of degradations and other problems that effect MOV performance and reliability still exists. Table 3 provides a summary of MOV degradations found between January 1 and December 31, 2002. It is important to note that this list is very similar to the NRC's list of documented MOV issues published in mid 1980's for the commercial nuclear power industry. 454 MOVs were tested at the Reliant stations during 2002.

Types of Problems Found	# of Problems Found	Percentage W/Problem
MOV Inoperable (one or both directions)	31	7%
High Motor Current	21	5%
Incorrect Open Torque Bypass	53	12%
Noisy (Bad bearings or grease)	16	4%
Declutching Problems	36	8%
Incorrect Limit Switch Settings	39	9%
Binding in Mid-Stroke	21	5%
Back Seating	38	8%
Improper Seating Control	9	2%
Torque Switch Problems	20	4%
Excessive Contactor Drop out time	6	1%
Excessive Corrosion	12	3%
CWD Incorrect	1	0%
Incorrect Wiring	15	3%
Actuator Springpack problem	2	0%
Torque Switch Setting Incorrect	13	3%
Loose Stemnut Locknu	8	2%
Misc. Other Problems	102	22%
Total # of Problems Found	443	

Table 3

OTHER CBM APPLICATIONS

Successful valve CBM practices are not limited to MOVs. Sensor technologies for pneumatic control valves, checkvalves and solenoid operated valves have been employed with the data acquisition systems to create effective condition monitoring strategies and improve overall plant performance. The MCC-based technology first developed for MOVs in the mid-80s has also become a popular condition-monitoring tool for all types of plant motors. Motor Current Signature Analysis (MCSA) has proven to be very effective in detecting rotor bar, stator and other mechanical and electrical degradations in electric motor driven machinery.

PNUEMATIC CONTROL VALVES

The single most significant finding of nuclear plant MOV program activities is the effect of non-conservative actuator sizing and selection methods. A review of sizing calculations for pneumatic control valves reveals that the same basic equations are employed in the sizing process. As a consequence it is clear that pneumatic control valves, that must provide isolation functions, may not have the required capacity to fully isolate as required in the safety analysis.

Figure 11

A Test Engineer Configuring a System for Testing a Pneumatic Control Valve.

However, pneumatic control valves also provide flow control functions and must be responsive to the operator's commands. As a consequence, the AOV solution is not as simple as employing an overly conservative sizing process because responsive control would be lost in overcapacity. Because of the range that pneumatic control valves must operate in they tend to be susceptible to misadjustment and other maintenance related issues that effect performance. Improperly adjusted control valves result in valve positions and flow rates that are not consistent with the signals being provided by the operator. Incorrect flow rates degrade process performance and tend to have negative economic effects on production. In addition to a range of valve issues, the accident at TMI also highlighted the consequence of a contaminated air supply system. The initiating event of the TMI accident was attributed to the presence of water in the instrument air system that caused the condensate polisher air outlet valves to close. The water in the system and a failed checkvalve led to loss of the main feedwater pumps and the subsequent turbine and reactor trip.

CHECKVALVES

Checkvalves are flow actuated with all components completely encased within the piping system. As a consequence it is not possible for technicians to view mechanical operation while the valve is in service. Valve movement is often verified by flow or the valve is disassembled and visually inspected to ensure proper mechanical operation. However, system manipulation to facilitate checkvalve movement is not always possible and disassembly and visual inspection is costly and hampers outage operations.

Figure 12

A Test Engineer performing a test on a checkvalve

Non-intrusive diagnostic technology for checkvalves gained popularity in the early 90s as a means of identifying valve movement/position without costly disassembly and visual inspection. Several technologies are routinely employed to help technicians identify what is going on inside the valve without actually opening the valve for inspection. When employed in a programmatic fashion, non-intrusive technology for checkvalves improves confidence in valve performance and satisfies ASME code requirements. The condition monitoring and condition based maintenance approach employed for checkvalves is considered a significant improvement over existing code requirements.

ELECTRIC MOTORS

Time domain recordings of electric motor parameters originated in the nuclear power industry as a method of trending performance of motor-operated valves. The 3-phase MOV electric motor is turned into a sensor and used to assess loads in the downstream load path such as those caused by increased packing loads, increases in friction due to lubricant degradation or mechanical degradations. Sophisticated algorithms were developed to allow conversion of electric current and power measurements to torque load on the motor. These torque measurements became useful in quantifying performance capability from the remote MCC locations versus costly at-the-valve testing.

Motor Current Signature Analysis (MCSA) was initially developed by Oak Ridge National Laboratories during the mid-80's under an NRC sponsored program directed at evaluation of aging of nuclear plant components (specifically MOVs). MCSA has evolved into a powerful tool for MOV evaluation and has gained widespread popularity beyond MOVs. High speed data acquisition and advanced software can now extract once unnoticed features from simple motor current signals and diagnose a wider range of mechanical performance characteristics.

ONLINE SYSTEMS

In today's environment it is not uncommon to find valves that are monitored continuously with some type of online monitoring system. Some of these systems are capable of self-diagnosis and alerting the plant operator of a problem via the plant's computer network.

A unique valve maintenance and testing issue solved by online monitoring was periodic verification of leakage for Emergency Shutdown valves used on offshore platforms and on-shore processing facilities fed from offshore pipelines. These valves stay in the open-full flow position until called on to isolate a break or other event where continual flow of oil or gas in undesirable. Valvewatch systems have been installed on a number of offshore platforms in the North Sea and the onshore gas processing facility at Kollsness.

CONCLUSIONS

Motor-operated valves, pneumatic control valves, checkvalves, solenoids and electric motor driven machinery are just a few of the targets for condition monitoring programs. Whether taken as individual plant components or at the system or plant level, the proper maintenance and operation of these components has a direct and measurable effect on the economics of process plant performance.

Properly applied, condition monitoring technology and regular preventive maintenance can eliminate costly failures, inefficient operation and lower overall maintenance costs by allowing the operator to focus on the equipment that needs attention when it needs attention. As has been done in the nuclear power industry, it is possible to eliminate poor valve performance.

In the coming years maintenance and engineering will not be overly concerned with troublesome valves and actuators. Online monitoring technology will identify faults and call for maintenance action without human intervention. In some cases, individual valves will summons a vendor for maintenance action well in advance of scheduled shutdowns. Operators will have higher confidence in their actions and processes will operate at the highest possible level of efficiency.