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IMPROVEMENTS IN VALVE RELIABILITY DUE TO IMPLEMENTATION OF EFFECTIVE CONDITION MONITORING PROGRAMS

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ABSTRACT

Modern diagnostic systems for motor-operated valves, pneumatic control valves and checkvalves have facilitated a shift in the maintenance philosophy for valves and actuators in nuclear power plants from schedule based to condition-based maintenance (CBM). This shift enables plant management to focus resources and schedule priority on the plant equipment that warrants attention thereby not wasting resources or increasing the human factors risk on equipment that has not degraded. The most recent initiatives combine condition monitoring with risk/safety insights to focus attention and resources on the right equipment at the right time consistent with each component's safety-significance.

The activities of the ASME working groups responsible for nuclear O&M codes have kept pace with the technology and process improvements necessary to maximize the technical and economic benefits of condition based and risk informed maintenance. This paper discusses adoption of valve condition monitoring in the nuclear power industry, changes to ASME codes and standards during the 90's to facilitate adoption of condition monitoring technology for in-service testing and recent efforts to combine risk insights with condition monitoring strategies to achieve the highest level of valve reliability and nuclear safety without over inflating maintenance cost.

1. INTRODUCTION

The failure of a critical nuclear power plant valve to open or close on demand can have serious safety and economic consequences. Certain motor-operated valves (MOVs) must open to initiate emergency shutdown measures and to ensure safe shutdown of the plant. Other MOVs are required to close in order to ensure system and containment isolation and prevent off-site release. Though not normally considered in critical safety functions, certain pneumatic control valves have a direct impact on the plants thermal efficiency and power output. Improperly adjusted pneumatic control valves can cost the plant operator millions in lost power output. Checkvalves protect systems and components and ensure flow isolation. Condition-based maintenance strategies for all of these valves have evolved in parallel with diagnostic technology thereby creating the highest level of valve performance while supplanting costly schedule based overhauls.

To set the stage for CBM, nuclear power plant valve performance, reliability and maintenance practices received considerable attention during the late 1980's and early 90's. During this period traditional time based preventive maintenance activities were revealed to be ineffective at identifying and correcting certain valve operational issues that are a consequence of how valves and actuators are installed, setup and maintained in the field. It also became clear during this same period that field-testing instruments play a key role in the maintenance technician's ability to achieve proper valve and actuator setup consistent with the original equipment manufacturer's design. Nowhere is this more visible than in the safety-related MOV testing programs where sophisticated strain measuring instruments and time-domain recordings are employed to validate proper field setup.

In fact, MOV diagnostic equipment and improvements in the maintenance approach for MOVs in general led the charge into implementation of CBM for valves. But the initial focus was not on CBM. Significant safety issues discovered during the initial testing activities for MOVs set the stage for future CBM implementation. Correction of the findings from the initial testing activities significantly improved confidence in MOV performance and provided a baseline from which to compare future performance and condition.

To fully understand how MOV diagnostic technology laid groundwork for broader adoption of risk oriented CBM strategies for valves; close review of the evolution of the MOV issue is required. This review illustrates that for CBM to be effective, accurate diagnostic tools capable of identifying the "real" condition of the equipment are required.

2. BACKGROUND (THE MOV ISSUE AS A CATALYST FOR CHANGE)

Following the accident at Three Mile Island the Electric Power Research Institute (EPRI) conducted a PORV block valve test program at Duke Power Company's Marshall Steam Station. The test program was originally proposed in NUREG 0737 (TMI Action Plan), as an additional means of reducing the number of challenges to the emergency core cooling system and the safety valves during plant operation. This test program represents the earliest known use of strain measuring equipment to record valve performance. During the EPRI testing, three of seven motor-operated block valves selected for the program failed to fully close under conditions that simulated the actual block valve service environment. The ultimate conclusion of this testing was that components of the valve-actuator sizing and selection process were non-conservative.

On June 9, 1985, one of the more significant nuclear power plant events in which motor-operated valves (MOVs) played a major role occurred at the Davis Besse Nuclear Plant. Both auxiliary feedwater containment isolation valves failed to reopen after inadvertent closure. The subsequent transient resulted in both steam generators boiling dry due to the loss of auxiliary feedwater. The failures were attributed to improper torque and torque bypass switch settings for certain critical MOVs (i.e. maintenance/programmatic degradations).

To this point the maintenance philosophy across the nuclear industry was focused on scheduled preventive maintenance activities and periodic overhauls. In fact, overhaul projects were thought to be the sure method of correcting all MOV performance issues. However, these events revealed that flaws in the engineering and maintenance approach for existing valves produced a high probability of common mode failure due to generic issues that could not be corrected by simple preventive maintenance or overhaul. The primary concern was the ease at which misadjustment of control switches during installation, start-up activities or routine maintenance could render the MOV inoperable under design basis conditions. Even more alarming was the fact that indications or "symptoms" of a problem could not be uncovered during the stroke time testing required by the ASME code and the plant's license.

As a result of the Davis Besse event, and other significant events, the NRC issued IE Bulletin 85-03, *Motor Operated Valve Common Mode Failures During Plant Transients Due To Improper Switch Settings*. The bulletin required nuclear power plant licensees to develop and implement programs to ensure that switch settings on certain safety-related motor operated valves were set and maintained correctly to accommodate the maximum design basis loading during both normal and abnormal events within the plants design basis.

As more MOV issues unfolded, the NRC took steps to extend the scope of 85-03 to cover all safety-related MOVs. Generic Letter 89-10, *Safety-Related Motor-Operated Valve Testing and Surveillance*, was issued in June of 1989. In response, industry organizations such as INPO, NUMARC (now NEI), EPRI, ASME and others initiated efforts to help improve the industry-wide knowledge and understanding of how MOVs operate.

During the public workshops on GL 89-10, NRC reviewed the MOV issue and discussed research results that indicated a larger generic issue with methods used to establish thrust requirements for rising stem gate valves. As part of the resolution of Generic Issue 87, *Failure of HPCI Steam Line Without Isolation*, researchers at the Idaho National Engineering and Environmental Laboratory (INEEL) performed full flow isolation tests to evaluate the ability of certain motor-operated gate valves to close under blowdown conditions. The results of these tests supported the contention from the EPRI/Marshall testing that the generic model for calculating valve thrust requirements for gate valves may not always be conservative.

In addition to the findings relating to thrust calculations, the INEEL researchers and participating test equipment suppliers discovered that MOV output capability changed between static and dynamic test conditions. The phenomena termed "load sensitive behavior" or "rate-of-loading" is the difference in the output thrust of an MOV between static and dynamic conditions (usually lower under dynamic conditions).

Based on the INEEL research and an accumulation of related plant events, the NRC suggested in GL 89-10 that MOVs be tested at or near design basis differential pressure for the purpose of demonstrating operability. The NRC suggested this approach because a validated method of calculating thrust requirements was not available, and it was not clear how all of the various phenomena affecting MOV performance could be addressed through a static testing program.

In September of 1996 the NRC requested in Generic Letter 96-05, *Periodic Verification of the Design Basis Capability of Safety-Related Motor-Operated Valves,* that nuclear plant owners establish programs or modify existing MOV programs to periodically verify that safety-related MOVs can perform their intended safety functions. In effect, GL 96-05 requests that MOVs continue to receive the same high level of care and attention established during 89-10 program efforts.

The primary concern at this point is the potential for degradation to increase the design basis performance requirements and/or decrease the MOV's output capability in excess of what was verified or assumed in the GL 89-10 margin analysis. The final analysis reveals that the 85-03 and 89-10 work played a key role in the potential adoption of CBM and risk-based maintenance strategies. As a result of this work nuclear plant owners have high confidence in the installed equipment, have verified the field setup and have a basis and means by which to evaluate future condition. With the newfound knowledge and tools in hand, informed condition based decisions can be employed to prioritize the maintenance schedule and address GL 96-05 concerns. Seventeen years after the first regulatory initiative on MOVs, nuclear power plants continue to adjust MOV programs to gain the highest possible level of safety at the right cost and impact on operations.

3. THE ROLE OF MOV DIAGNOSTIC TECHNOLOGY

Prior to 1984 MOV diagnostic testing in nuclear power plants was limited to stroke time measurement and an occasional single channel chart recording of motor current. The most serious of the known MOV performance issues were thought to be addressed through preventive maintenance activities and periodic overhaul.

The first commercially available MOVATS MOV diagnostic system enabled plant engineers to capture real time data representing a wide range of MOV performance characteristics. For the first time, MOV engineers could assess actual limit switch settings and compare the capability of the actuator, as setup in the field, to the output required to perform design basis functions. This new equipment played a key role in the virtual elimination of MOV mechanical degradations and improper bypass switch settings. As the MOV issues evolved so did the diagnostic requirements and the capability of test systems.

Figure 1

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

MOV 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.

MOV torque output is typically controlled by a torque switch in the close direction. The torque switch lever arm is geared to the worm shaft or springpack assembly within the actuator. Torque switches are set to open at a predetermined springpack displacement. The proper torque switch setting is determined by a thrust or torque calculation or both and torque switches are typically set under static test conditions. The test objective is to establish the torque switch setting that produces adequate thrust to overcome the expected loads due to differential pressure and flow.

Calculations are generally used to determine the desired torque switch setting. The typical calculational process combines forces from the packing load around the stem, forces from the system pressure, which tends to expel the stem from the valve body and forces from the differential pressure acting on the valve disk. The force

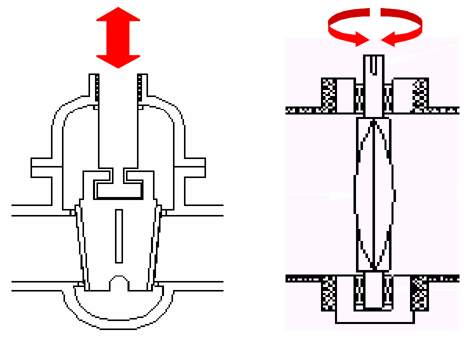

Figure 2

Design Basis Requirements for Rising stem Gate valves are typically expressed in lbs of force or thrust. Design Basis requirements for ¼-turn butterfly valves are typically expressed in ft-lbs or torque.

from the differential pressure acting on the valve disk tends to be the most difficult to predict and is the parameter of interest during full flow testing.

During field testing, the test engineer measures the thrust available at torque switch trip as depicted in Figure 3. The thrust at torque switch trip must meet or exceed the calculated thrust requirement. The motor torque at torque switch trip 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.

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 4 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. It is important to note that in many cases the thrust at torque switch trip may be lower under dynamic conditions due to the rate-of-loading effect.

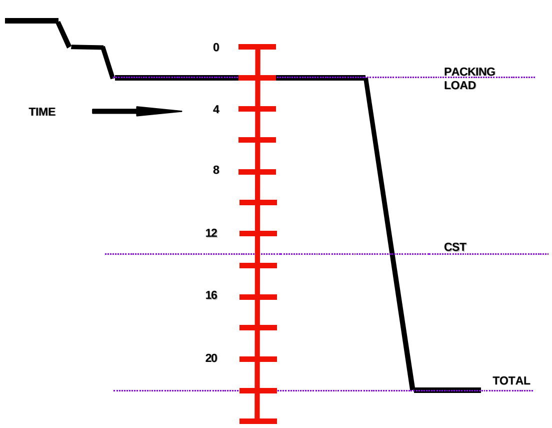

Figure 3

The example in Figures 3 and 4 is for an MOV that can be tested under maximum expected flow and pressure. The margin in this example would be the difference between the maximum DP effect and the dynamic CST value. However, this margin must be adjusted to allow for test equipment uncertainty, actuator repeatability, expected degradation and other factors.

4. THE ROLE OF THE ASME SUB-GROUP ON MOVS

U. S. NRC Generic Letter (GL) 89-10, recommends that licensees perform a series of actions necessary to ensure the operational readiness of certain motor-operated valves installed in nuclear power plant safety-related systems. Action Item b of GL 89-10 recommends that licensees develop a program to establish the correct MOV switch settings to ensure high reliability of safety-related MOVs and Action Item c recommends that the correct switch settings be implemented through field testing. Generic Letter 89-10 describes a thorough programmatic approach to MOV operability versus the traditional stroke time testing required by existing IST programs.

Generic Letters 89-04, 89-10, 96-05 and other industry documents discuss limitations of ASME Section XI MOV stroke time testing as a means of monitoring the operational readiness of MOVs. It was clear by the late 1980s that the MOV IST stroke time test requirement provides little more than a guarantee that most safety-related MOVs will be exercised at some periodicity between a more meaningful diagnostic test.

As a result of the above Generic Letters and other guidance, nuclear plant owners have developed rigorous MOV maintenance and testing programs outside of the IST program in order to ensure the operational readiness of safety-related MOVs. To fill the gap in the ASME codes, the Committee for the Operation and Maintenance

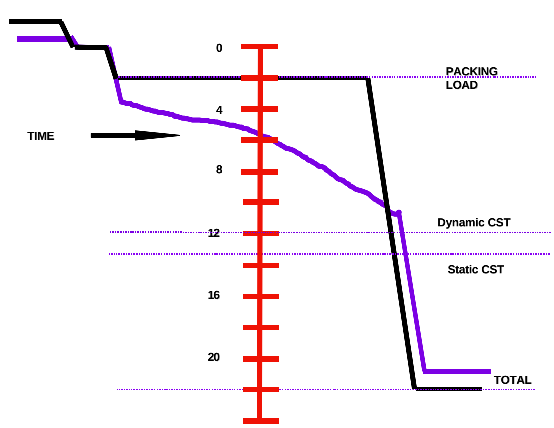

Figure 4

of Nuclear Power Plants, through the Sub-group on MOVs, initiated development of programmatic guidance for nuclear plant owners to address weaknesses identified by MOV test programs of the late 80s and early 90s.

The Sub-Group on MOVs issued guidance through OMN-1, *Alternative Rules for Preservice and Inservice Testing of Certain Electric Motor-Operated Valve Assemblies in LWR Power Plants*, a code case specifically designed to provide complete programmatic guidance for verifying MOV design basis capability. OMN-1 allows replacement of frequent stroke time testing with periodic exercising and more detailed diagnostic testing based on margin and expected degradation over time. NRC has endorsed use of OMN-1 for addressing the requirements of GL 96-05 and specifically for detecting changes in the operating requirements for MOVs and establishing the appropriate test frequencies. Once fully implemented, OMN-1 is a very effective CBM program for MOVs.

6. APPLYING RISK SIGNIFICANCE TO SCHEDULING

MOV periodic evaluation schedules based on risk significance ranking play a key role in many MOV periodic verification programs. Both NRC and industry, working together through collaborative efforts such as ASME Operations and Maintenance (O&M) working groups and the coordinated efforts of the NSSS Owners groups have forged new ground with safety-based prioritization for both MOV and AOV programs.

The joint NSSS Owners Group (JOG) MOV program employs risk ranking methodologies developed by each owners group and functional margin as determined by field testing to establish periodic testing frequencies for individual valves. The JOG methodology recognizes 3 levels of risk and three levels of margin. High-risk valves with low margin are tested more frequently than lower risk valves with higher margin. Risk is a product of the calculated core damage frequency (CDF) contribution due to failure of each MOV.

Risk ranking in accordance with ASME OMN-3 also targets those components, including valves that are contributors to an increased CDF. OMN-3 identifies two levels of risk and sets the requirement for only testing high safety significant component (HSSC) MOVs in accordance with OMN-I. For low safety significant (LSSC) MOVs, the requirements for in-service testing are minimal.

Regulatory Guide 1.175, *An Approach for Plant-Specific Risk Informed Decision Making: Inservice Testing*, provides guidance useful in blending risk importance and other engineering criteria in a more effective approach to component and system performance monitoring and decision making. The use of a particular risk ranking method is not required since all risk-ranking methods are capable of accomplishing the same goal.

Risk ranking plays an important role in prioritizing individual MOVs within a group that is based on margin and deterministic methods. However, OMN-I neither requires risk ranking to be used or a particular risk ranking method to be used. OMN-I allows the use of risk as one part of the overall process in determining test frequency to ensure operational readiness is maintained.

5. OTHER INDUSTRY INITIATIVES

The primary objective of MOV periodic verification is to ensure that the high level of confidence in MOV performance established during the initial 89-10 program effort is maintained for the life of the plant.

The at-the-valve MOV testing required by existing 89-10 programs has increased the cost, complexity and at times, the duration of nuclear plant outages. The direct cost of outages and corresponding unavailability are significant contributors to nuclear plant financial performance.

Because of the overwhelming cost of MOV activities over the past decade and the projected future costs of 96-05, the industry is aggressively in pursuit of innovative lower cost approaches.

A precedent setting initiative of the joint BWR and Westinghouse owners groups is expected to significantly reduce the quantity and thus cost of in-plant full flow tests. The Joint Owners Group (JOG) has identified a relatively small population of valves spread across the industry that will serve as a control group for the majority. Instead of performing full flow tests on all MOVs that can be tested dynamically (the standard 89-10 approach), each participating plant will test two or three assigned valves and feel confident that its remaining population will be well represented by valves in the control group. For many plants this is a reduction in the full flow test population in excess of ninety percent.

The primary objective of the JOG effort is to quantify the magnitude (if any) of valve factor degradation over time. Valve factor degradation is a leading contributor to the increase in the performance requirement concern of 96-05. A strong technical basis for the amount of valve factor degradation that must be accounted for to address the concerns of 96-05 but not create overly restrictive margin requirements is expected to be a result of this program.

The control group concept is catching on in other areas of MOV engineering. The leading contributor to stem factor change is lubricant degradation. Many plants have developed more prescriptive preventive maintenance requirements and frequencies thus creating more consistency in stem lubrication performance. Instead of testing all MOVs in order to assess potential changes in stem factor, smaller control groups, usually in the harshest environments, will be tested periodically with enough precision to accurately model stem factor changes. The activities described above are consistent with the guidance and intent of OMN-1 where performance data from many sources play a role in the programs maintenance and testing requirements.

7. APPLYING MOV LESSONS LEARNED TO PNEUMATIC 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.

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.

Pneumatic control valves are also highly susceptible to misadjustment and other maintenance related issues that effect operability. 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.

The sizing questions, the potential for maintenance induced misadjustment and the potential for contamination from the air supply system suggest that pneumatic control valves warrant the same high level of attention and care given to MOVs. After fully evaluating these issues and the potential for similar operability issues with control valves, the nuclear industry, acting through the various NSSS Owners Groups came together to develop the Joint Owners Group AOV Program initiative. Because of the action of the owners groups, further regulatory action for pneumatic control valves similar to MOVs has been avoided.

The ASME subgroup on air-operated Valves

Figure 5

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

(AOVs) has worked diligently on development of guidance necessary to implement an effective CBM program for pneumatic control valves.

Recognizing the success of the JOG MOV program, those responsible for AOV programs and control valve performance followed the MOV lead and created a similar program for AOVs. The JOG AOV program played a key role in deferring regulatory action on AOVs in the late 90's. The ASME AOV program guidance and JOG program guidance are consistent and complimentary. The JOG program employs risk significance ranking to categorize AOVs and to establish testing and maintenance requirements.

8. WHY 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.

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. Specifically, changes in the inservice test requirements for checkvalves are captured in ASME OMa Code-1996 Addenda to correct certain anomalies in the way check valve exercising is implemented and to establish a process in the ASME Code for monitoring checkvalve performance. The condition monitoring and condition based maintenance approach employed for checkvalves was considered a significant improvement over existing code requirements.

Figure 6

A Test Engineer performing a test on a checkvalve

9. CONCLUSIONS

Some level of scheduled, preventative type maintenance will always play a role in valve performance and reliability. However, diagnostic and condition based decision making ensures that the correct type and amount of maintenance attention is applied to components that need maintenance thereby reducing the cost and schedule impact of unnecessarily maintaining good equipment. The ASME Nuclear O&M subgroups responsible for MOV, AOV and checkvalve performance have kept pace with technology and process improvements and facilitate use of proven technologies quickly and efficiently through the O&M code process. The various valve working groups enthusiastically embraced risk/safety significance strategies and help to focus the right level of attention consistent with each component's role in safe nuclear power generation.

REFERENCES

American Society of Mechanical Engineers, ASME Code Case OMN-1, *Alternative Rules for Preservice and Inservice Testing of Certain Electric Motor-Operated Valve Assemblies in LWR Power Plants*, OM Code-1995, Subsection ISTC

K.L. McElhaney, et al, A methodology for Evaluation of Inservice test Intervals for Pumps and Motor-Operated Valves, NUREG/CR-6578 (ORNL-6932), January 1999

U.S. Nuclear Regulatory Commission, IE Bulletin 85-03, *Motor Operated Valve Common Mode Failures During Plant Transients Due To Improper Switch Settings*

U.S. Nuclear Regulatory Commission, Generic Letter 89-10, *Safety-Related Motor-Operated Valve Testing and Surveillance*, June 1989

U.S. Nuclear Regulatory Commission, Generic Letter 96-05, *Periodic Verification of the Design Basis Capability of Safety-Related Motor-Operated Valves*