Recent Improvements in MOV Field Test Programs

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Abstract

Recent improvements in plant testing programs and diagnostic technology have strengthened the overall quality of data available from in-plant MOV testing. This data, coupled with results from the EPRI Performance Prediction Program provides a very detailed picture of MOV performance. This paper will describe the evolution of MOV issues, the complete MOV program, recent field test results and provide insight into actuator efficiency and stem factor performance.

Background

Following the accident at Three Mile Island, EPRI sponsored 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. During the test, 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. Subsequently, based in part on the results of this program and similar in-plant failures later the same year, the Westinghouse Electro-Mechanical Division concluded that components of its actuator sizing calculation for PORV block valves were non-conservative and notified the affected customers under the requirements of 10CFR Part 21 and 50.55(e).

In the following years many industry and regulatory documents were issued identifying failure modes and causes. Failures were often attributed to alterations or degradations that could have been prevented with proper maintenance and programmatic controls.

On June 9, 1985, one of the more significant events in which 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 (i.e. maintenance and programmatic degradations).

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.

IE Bulletin 85-03 generated a large quantity of comparable plant MOV data in a short period of time. One of the more significant findings (beyond the maintenance related problems) was in the differential pressure test data. This data revealed a potential generic problem with the determination of motor operator size and torque switch settings for gate valves.

The IE Bulletin 85-03 differential pressure test results, similar results observed during the design validation testing for Sizewell B at the Siemens Karlstein test facility in Germany and a number of field test experiences reported by individual licensees, increased the NRC's priority on the resolution of Generic Issue (GI) 87, *Failure of HPCI Steam Line Without Isolation*. As part of the resolution of GI 87 and other related concerns, such as GI II.E.6.1, *Insitu Testing of Valves*, the NRC contracted Idaho National Engineering Laboratory (INEL) to determine if valves in high-energy lines that penetrate containment will close to interrupt flow following a high-energy line break.

In late spring of 1988 and summer of 1989, a series of hot water blowdown tests were conducted by INEL. The results of these tests indicated that the standard equation used for determining operator size and torque switch settings would not have provided adequate thrust capability for the valves tested under blowdown conditions. Additionally, the results of these tests supported the generic concern (first raised by Westinghouse in 1982) of the potential under-sizing of MOVs in general.

The INEL testing also revealed differences in actuator performance when operated under static conditions versus full flow dynamic conditions. For many MOVs the effect is a reduction of available thrust under the dynamic condition. The first indicator of this phenomena was a difference in the relationship between springpack displacement measurements and stem thrust under the two conditions. This phenomena has been referred to as "rate-of-loading" or "load sensitive behavior".

As the issues unfolded, the NRC took steps to extend the scope of 85-03 to cover all safety-related MOVs. After much deliberation, the now infamous Generic Letter 89-10 was issued in June of 1989. In response, industry organizations such as INPO, NUMARC (now NEI), EPRI, the MOV Users Group, ASME and others initiated efforts to help improve the industry-wide knowledge and understanding of how MOVs operate.

The EPRI MOV Applications Guide was one of the first attempts to capture all of the known MOV application issues in a plant program friendly format. However, too many issues were unresolved. A complete summary of all MOV performance issues identified in NRC generic communications is provided in Attachment I, *Evolution of MOV Issues*.

During the public workshops on GL 89-10 the NRC encouraged a larger scale cooperative effort in order to address the growing list of MOV issues. The NRC's response to question 26 of GL 89-10 Supplement 1 suggests the use of prototype tests from off-site test facilities in order to establish MOV operating requirements.

The industry infrastructure responded quickly and initiated a comprehensive valve test program under the purview of EPRI. The results of the EPRI Performance Prediction Program provides nuclear plant engineers a sound, fully validated basis for establishing MOV performance requirements. In addition to a thrust calculation methodology, the EPRI research also provided critical information on rate-of-loading and other MOV performance issues.

Most domestic U.S. commercial nuclear licensees have completed the engineering and field validation efforts recommended in GL 89-10. Many plants adopted the EPRI Performance Prediction Methodology for valves that could not be verified by insitu dynamic testing.

In September of 1996 the NRC requested in Generic Letter 96-05 that nuclear plant owners establish programs or modify existing 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 regulatory 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 89-10 margin analysis.

The Evolution Of MOV Diagnostic Technology

Prior to 1983 MOV testing was limited to stroke time measurement and an occasional single channel chart recording of motor current. In 1983 the first commercially available MOV diagnostic system enabled plant engineers to capture real time data representing a wide range of MOV performance characteristics. This equipment played a key role in the elimination of MOV mechanical degradations and improper bypass switch settings. As the MOV issues evolved so did the diagnostic requirements.

In the mid to late 80's the concerns shifted to verification of set-up margin and accuracy. IE Bulletin 85-03 and the INEL test results 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.

Generic Letter 89-10 turned the spotlight to full flow differential pressure testing and measurement of stem torque and thrust. Recognition that the margin of safety in valves was much lower than previously expected greatly increased the need for minimizing test equipment inaccuracy. Diagnostic systems, transducers and the testing process became much more complex and time consuming.

Test equipment accuracy issues were a major problem in the early 90's. A combination of industry sponsored and vendor initiated programs established a new standard for MOV test equipment validation. As a consequence older indirect approaches were replaced by more direct measurements.

Low cost periodic verification approaches receive the most attention in today's economically driven environment. New technology enables measurements that were only available at the valve in the past to be captured at the motor control center. High speed data acquisition and advanced software can extract previously unnoticed features from simple motor current signals and diagnose a wider range of mechanical performance characteristics.

Diagnostic systems that were once dedicated to MOVs alone are now employed in checkvalve and AOV diagnostic programs. Getting the most from the organizations resources and capital investment is a growing trend.

Current State-of-the-Art

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 high 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.

The current initiative of the joint BWR and Westinghouse owner's groups is one program that is expected to reduce the quantity and 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 the 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 increased performance requirement concern of 96-05. A strong technical basis for the amount of valve factor degradation that must be included to address the concerns of 96-05 without excessive conservatism should result from 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 consistency in stem lubrication performance. Rather than testing all MOVs in order to assess potential changes, smaller control groups, usually in the harshest environments, will be tested periodically with enough precision to accurately model stem factor changes.

The current test approach enables MOV engineers to establish or validate stem factor assumptions. Figure 1 identifies one process used to assess stem factor values. Since torque divided by thrust is one method of determining stem factor, the XY correlation provides a simple method of visualizing stem factor. Trending can be done by overlaying these plots from different dates.

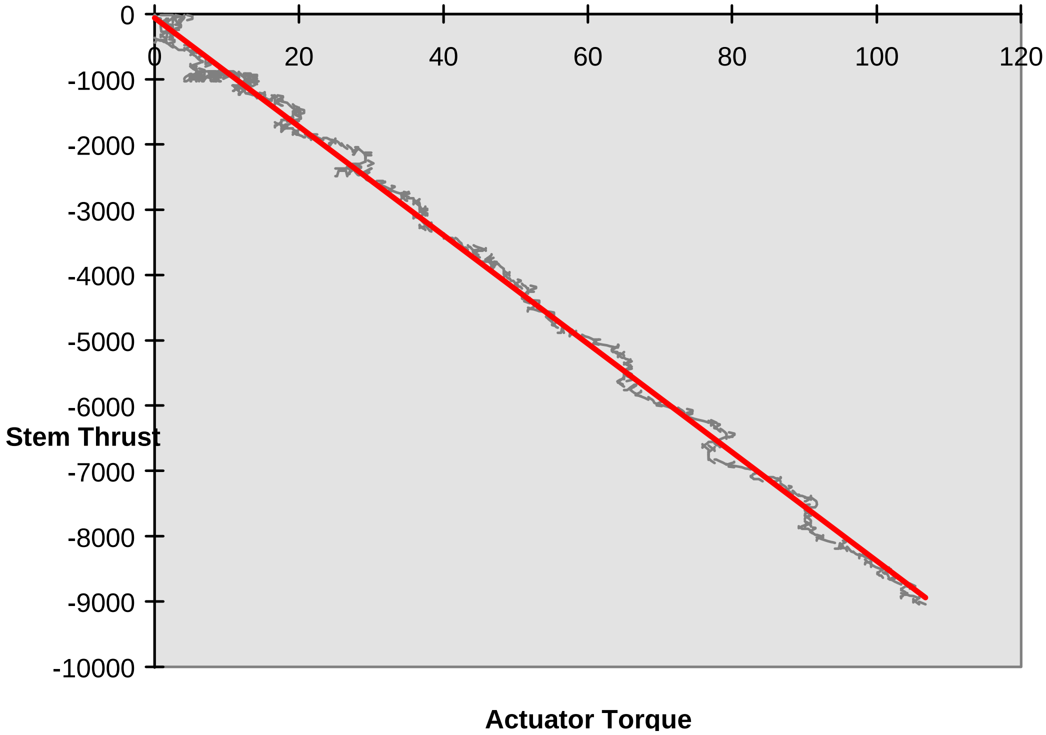

Figure 1. Stem Factor Assessment

The cost concern of periodic verification has also led to improvements in MOV diagnostic technology. Many plant programs will replace costly at-the-valve methods of verifying margin with MCC based technologies.

The Vermont Yankee and Farley nuclear plants have each performed extensive validation of the motor torque based MCC technologies of CRANE MOVATS. During the fall 1996 refueling outage at Vermont Yankee, MOV motors were tested on precision dynamometers in order to 1.) generate new motor performance curves, 2.) validate the CRANE MOVATS MC^2 torque model and 3.) capture DC motor torque data for development of a motor torque model for DC powered MOVs. A representative set of field generated motor torque-speed curves for 60 ft-lb motors is shown in Figure 2.

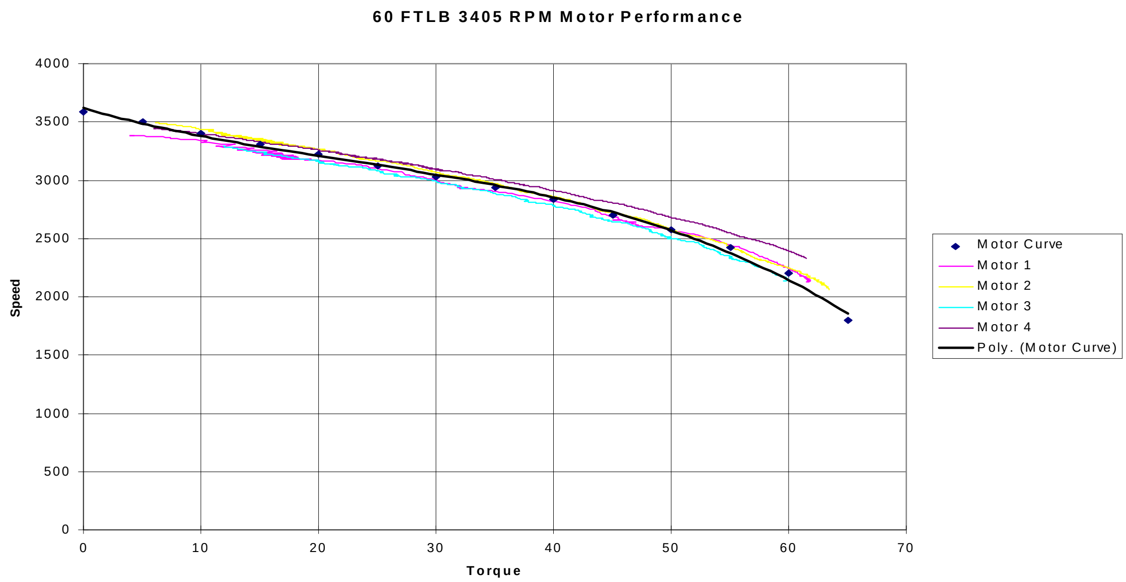

Figure 2. Field Generated Motor Curves

During the spring 1997 refuel at the Farley Nuclear Plant, MOV motors were tested on a precision dynamometer for the purpose of validating the MC^2 motor torque model on 575 volt AC motors. An overlay of the reference torque generated by a precision torque cell installed between the dynamometer brake and motor shaft is shown in Figure 3.

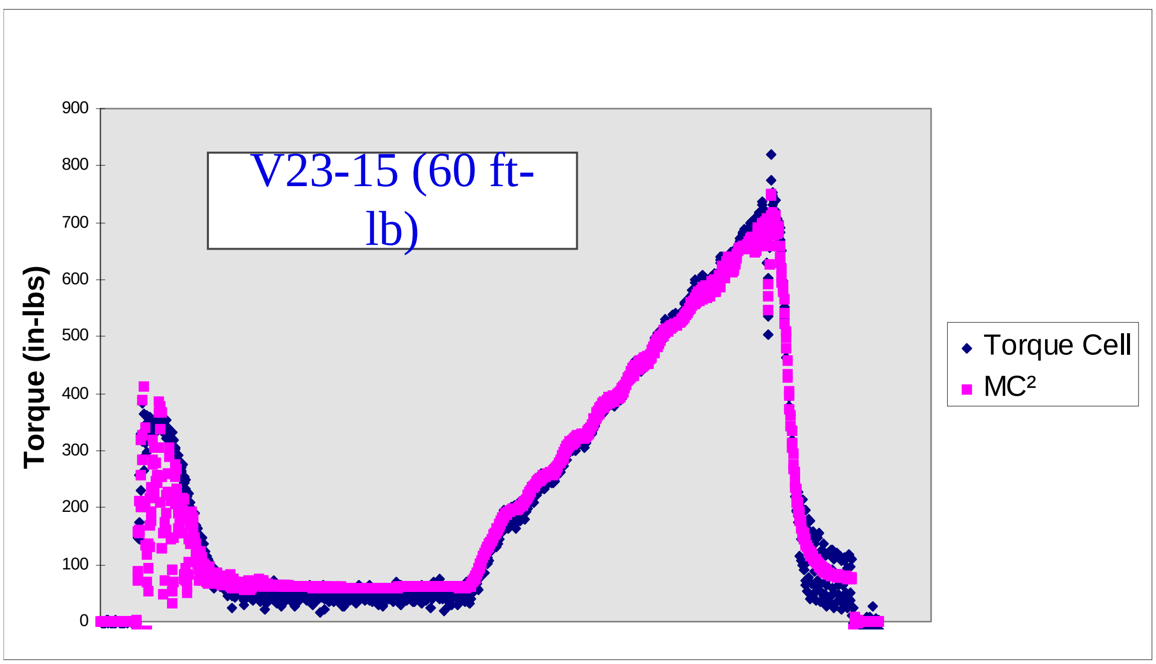

Figure 3. MC^2 Validation Test Data

CRANE MOVATS has completed validation efforts for the MC^2 torque model for AC motors through 60 ft-lbs. Limitorque motors through 250 ft-lbs have been tested and validation data will be published for these motors in the future. CRANE MOVATS and

Vermont Yankee are jointly developing motor torque capability for DC motors using a similar validation approach. In time, motor torque measurement capability from the MCC will be available for all motors.

Now that accurate motor torque measurements can be captured in real time with actuator torque, it is possible to validate the last and most troublesome MOV assumption. Actuator efficiency determines the relationship between input motor torque and actuator output torque. The XY plot in Figure 4 identifies a simple approach for establishing or validating the actuator efficiency assumption. The efficiency is determined from the slope of the line in Figure 4.

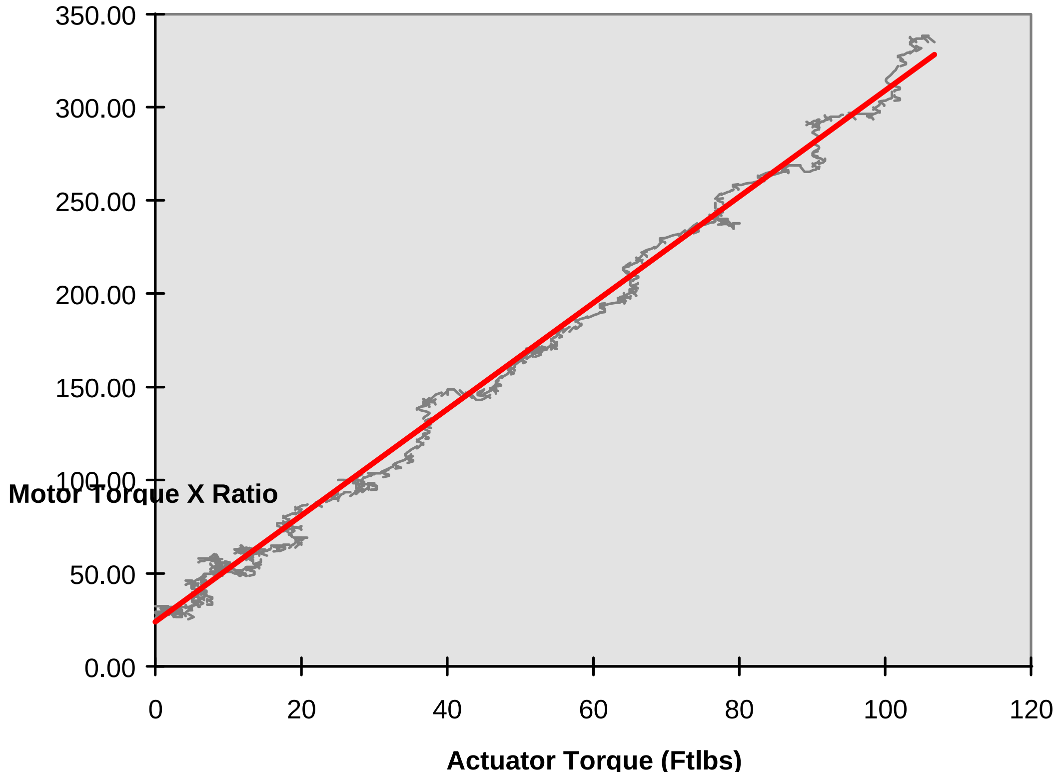

Figure 4. Actuator Efficiency Determination

The Complete Program

The primary objective of today's nuclear plant MOV program is to establish high confidence in the design and setup of installed MOVs and through preventive maintenance and periodic verification ensure that the high confidence is maintained for the life of the plant. Since the typical nuclear plant has over 100 MOVs classified as safety related this is not a minor objective.

Program implementation is typically defined and managed as three separate and independent phases. Phase 1 is often identified as the engineering phase, phase 2 as field implementation followed by phase 3, periodic verification and trending. In today's environment, the engineering and field implementation phases should be complete and most plants positioned for periodic verification and trending.

The first step in developing an MOV periodic verification program involves evaluating the expected service conditions and margin for each valve. The results of this evaluation are then used to establish the appropriate testing method and frequency. A matrix similar to Table 1 can be used as a tool to establish the initial methods and frequencies for each MOV. Different frequencies may be established based on safety significance. Modifications to the initial methods and frequencies should be made as performance history shows that changes are needed.

	DP	Static	PM	MCC	Lube Test
Control Groups Valve Factor, Stem Factor,ROL	each cycle	baseline only	2 cycles	2 cycles	4 cycles
Typical MOV > 20% Margin, <100° F	original DP only	baseline only	2 cycles	2 cycles	4 cycles
Low Margin < 20% Margin	original DP only	2 cycles	2 cycles	each cycle	4 cycles
High Temp > 100° F	original DP only	baseline only	each cycle	2 cycles	2 cycles

Targeted lubrication life is 16 years

Table 1

A comprehensive program relies on the combination of physical observations made during routine preventive maintenance (PM) activities (including periodic gearbox lubrication tests), MC^2 test results and control group studies in order to build the proper "defense-in-depth" confidence in MOV design basis capability.

Preventive Maintenance. Preventive maintenance should include detailed visual inspection for verification of physical appearance and assessment of environment related degradation. Important areas to focus on include stem lubricant condition, gearbox and limit switch lubricant levels, limit switch compartment wiring condition and packing integrity. The PM should be well documented, and unusual observations should be investigated and corrected if necessary. PM documentation should also be trended.

In addition to the standard PM, gearbox lubrication tests should be performed as part of the PM at an extended interval (possibly every fourth cycle) in order to assess lubricant quality, remaining life and indications of mechanical degradation (suspended brass or steel particulate).

MC^2 Testing. MC^2 testing should follow the PM inspection (and precede lubrication or corrective maintenance) for verification of available margin and comparison of FFT signature characteristics. When available margin reaches an unacceptable limit, corrective action and/or baseline testing may be required. Though the margin analysis is critical, the FFT overlay will also help identify minor changes in performance which can be precursors to more significant problems.

Control Groups. Control groups should be set up to assess the effects of age on design basis performance requirements. A representative of each valve design should be full flow tested on a periodic basis in order to assess changes in valve factor. Results from each representative valve must be applied to all valves in the control group. The testing interval should be adjusted based on the test results to avoid unnecessary stress on the valve and to ensure that sufficient margin will remain until the next scheduled test.

Control groups should not necessarily be limited to an individual plant. In fact, the best representation of potential degradation due to age will come from the combination of old and new plants. Valves that are experiencing their first ten years of service or that have recently been refurbished are expected to show the most significant changes in valve factor. Valves that have been in service for greater than ten years are expected to show results consistent with the plateau phenomena of full flow tests conducted in off site facilities with prototype valves (EPRI PPP or similar programs).

Plant specific control groups should also be set-up for assessment of stem factor degradation and potential changes in rate-of-loading.

Taken together, this series of physical verifications and testing builds a “defense-in-depth” program and high confidence in MOV design basis capability. This approach will enable plants to cost effectively address MOV performance and regulatory issues by minimizing the full flow dynamic test population and reserving the costly baseline static tests for MOVs with detected degradation.

Conclusion

Since the early 80’s the commercial nuclear power industry, including the supporting infrastructure, has made a permanent and lasting impact on valve engineering and maintenance in power plant applications. Design and sizing technology based on fully validated prototype test data has enabled plant engineers to modify and adjust the currently installed equipment and greatly improve plant safety. Diagnostic technology has enabled the plant maintenance staffs to validate engineering assumptions in the field and to virtually eliminate failure due to undetected mechanical degradation or incorrect switch settings. Informed preventive maintenance practices and effective periodic verification will help to maintain high confidence in MOV reliability through the retirement of the current fleet of commercial nuclear power facilities.

Attachment 1
Evolution Of MOV Issues

Mechanical Degradations

Handwheel to Motor Clutch	IE Circular 78-16
Limit Switch Lubricant Degradation	IE Notice 79-03
Loose Stem Nut Locknut	IE Notice 79-04
Valve Shaft to Actuator Key	IE Circular 80-12
Motor-to-Shaft Key Failure	IE Notice 81-08
Various Mechanical Degradations	AEOD C203 May, 1982
Loose Anti-Rotation Device Setscrew	IE Notice 83-70
Loose Worm Bearing Locknut	IE Notice 84-36
Loose Worm Bearing Locknut	IE Notice 84-36 Supp. 1
Loose Anti-Rotation Device Setscrew	AEOD E502 Jan, 1985
Loose Anti-Rotation Device Setscrew	IE Notice 83-70 Supp. 1
Various Mechanical Degradations	AEOD C603 Dec, 1986
Various Mechanical Degradations	Generic Letter 89-10
Butterfly Valve Spline Adapter	IN 94-67
MOV Key Failures	IN 96-48

Switch Settings

Incorrect Torque Switch Bypass Settings	IE Circular 77-01
Incorrect TOL and Torque Switch Settings	EPRI NP-241
Incorrect Torque and Bypass Switch Settings	AEOD C203 May, 1982
Low Torque Switch Settings	IE Notice 83-46
Torque Switch Set Below Manu. Recommend	IE Notice 84-10
Valve Damage Due to Backseating	IE Notice 84-48
Incorrect Bypass Switch Settings (Davis Besse)	IE Notice 85-50
Incorrect Bypass Switch Settings (Davis Besse)	NUREG 1154
Improper Switch Settings	IE Bulletin 85-03
Effects of Changing MOV Switch Settings	IE Notice 86-29
Improper Torque Switch Settings	IE Notice 86-93

Incorrect Switch Settings	AEOD C603 Dec, 1986
Improper Switch Settings	IE Bulletin 85-03 Supp. 1
Incorrect Switch Settings	Generic Letter 89-10
Incorrect Switch Settings	Generic Letter 89-10 Supp. 1

Sizing Calculations

Failure to Close Against DP (EPRI Marshall Results)	IE Bulletin 81-02
Failure to Close Against DP (EPRI Marshall Results)	IE Bulletin 81-02 Supp. 1
Failure to Open Against DP	AEOD T420 Aug, 1984
Potentially Undersized Valve Actuators	IN 88-94
Industry Sizing Equation Issues	Generic Letter 89-10
Higher Than Expected Valve Factors	IN 89-61
INEL Results	IN 89-88
Underestimated Valve Seat Friction	IN 90-21
INEL Results	IN 90-40
Industry Sizing Equation Issues	GL 89-10 Supp. 1
Results of NRC Sponsored Tests	GL 89-10 Supp. 3
Testing Of Parallel Disk Gate Valves In Europe	IN 90-72
Justification Of Assumptions	IN 92-17
Consideration Of Stem Rejection Load	IN 92-41
Westinghouse Stall Thrust Issues	IN 92-70
Thrust Limits And Potential Overstressing	IN 92-83
Butterfly Valve Torque Requirements	IN 94-69
Validation Of Analytical Assumptions	IN 97-07

Design Issues

Torque Switch Bypass Circuit Missing	IE Circular 81-13
Operator Sizing Issues	EPRI NP-241
Isolation Valve Initiating Signals	IE Notice 83-53
Misapplication of Throttle Valves	IE Notice 83-55
Environmental Qualification	IE Notice 83-72
Control Circuit Deficiencies	IE Notice 84-13
Torque Switch Bypass Circuit Missing	AEOD T410 May, 1984
MOV Failures Due To Hammering	AEOD E501 Jan, 1985

MOV Failures Due To Hammering	IE Notice 85-20
MOV Failures Due To Hammering	IE Notice 85-20 Supp. 1
MOV Motor Burnout Events	AEOD S503 Sept, 1985
Magnesium Rotor EQ Issues	IE Notice 86-02
Motor Wiring EQ Deficiencies	IE Notice 86-03
Stop Check Failures Due to Low Flow	IE Notice 86-09
Effects Of Changing MOV Switch Settings	IE Notice 86-29
Limitorque Qualification Issues	IE Notice 86-71
Motor Wiring EQ Deficiencies	IE Notice 87-08
Valve Damage Due to Improper Backseating	IN 87-40
DC Motor Design Issues	IN 88-72
Defective Motor Shaft Keys	IN 88-84
DC Motor Cable Sizing	IN 89-11
Horizontally Installed Gate Valves	IN 92-59
Valve Stem Failure Caused By Embrittlement	IN 92-60
Horizontally Installed Gate Valves	IN 92-59 Supp.1

Maintenance Issues

HBC Orientation	IE Notice 83-02
Marine Growth/Corrosion of Internals	IE Notice 83-46
Incorrect Pinion Gear Installation	IE Notice 85-22
Valve Stem Corrosion Failures	IE Notice 85-59
Valve Stem Key Missing	IE Notice 85-67
MOV Installation Procedures	IE Notice 86-34
Motor Termination Issues	IN 88-27
Coordination Of Personnel During Testing	IN 91-42
Horizontally Installed Gate Valves	IN 92-59
Housing Cover Bolt Material Properties	IN 93-37
Motor Pinion Key Failure	IN 94-10
Failure Of Torque Switch Roll Pins	IN 94-49
Gate Valve Corrosion	IN 94-61
Binding Stems In Governor Valves	IN 94-66
Failures Due To Stem Protector Interference	IN 95-31

Pressure Locking/Thermal Binding

Failure To Open Against DP	AEOD T420 Aug, 1984
Pressure locking Of Flex Wedge Gate Valves	IN 92-26
Valves Susceptible to Pressure Locking	IN 95-14
Potential Pressure Locking Of gate Valves	IN 95-18
Potential Pressure Locking Of gate Valves	IN 95-18 Supp. 1
Pressure Locking And Thermal Binding Of Gate Valves	Generic Letter 95-07
Thermally Induced Pressurization	IN 96-49

Actuator Efficiency

Limitorque Actuator Performance Issues	IN 96-48

EPRI PPM

Summary Of EPRI Performance Prediction Program	IN 96-48

Diagnostic Systems

Results Of Industry Validation Testing	IN 92-23
Inaccuracy Due To Directional Effects	GL 89-10 Supp. 5
Accuracy Of Liberty MOV Diagnostic Equipment	IN 93-01
Accuracy Of MOV Diagnostic Equipment	IN 94-18
BARTS Inaccuracies	IN 96-30

Test Approaches

Guidance On IST Programs	Generic Letter 89-04
Stroke Time Measurement Issues	Generic Letter 89-10
Grouping Strategies	Generic Letter 89-10 Supp. 6
IST Perspectives	NUREG 1482
Periodic Verification	GL 96-05