Use of MCC Based Testing Technology for Static MOV Periodic Verification Testing

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Abstract

Several commercial nuclear plant licensees have provided information to the U. S. Nuclear Regulatory Commission (USNRC) regarding use of motor control center (MCC) technology for periodic verification of motor-operated valve (MOV) operational readiness. The licensee information describes strategies ranging from use of MCC test data to extend at-the-valve test intervals to use of MCC testing alone for certain MOVs.

In late 1998, the MOV Users Group organized a committee of industry experts and commissioned development of an industry guidance document for members to use during development and implementation of MCC-based static testing procedures. The MOV Users Group guidance was issued earlier this year and is available for licensee use. The ASME MOV working group has considered one plant's inquiry on use of a specific MCC testing approach as a suitable alternative to at-the-valve in-service testing of MOVs under certain conditions and is exploring modification of Code Case OMN–1 to better accommodate MCC based approaches. Individual licensees have performed site specific studies to assess the effectiveness of MCC technology while others have utilized more extensive laboratory programs, combined with site specific results, as a basis for transitioning to MCC technology for periodic verification of MOV output capability.

At least four different technologies are currently available for MCC based MOV testing. This paper will discuss the applicability and limitations of each currently available technology and describe how licensees have worked to validate the various approaches and gain confidence in MCC testing as an alternative to at-the-valve testing for the purpose of evaluating MOV operational readiness.

Background

USNRC Generic Letter (GL) 89–10, *Safety-Related Motor-Operated Valve Testing and Surveillance*, GL 96–05, *Periodic Verification of Design-Basis Capability of Safety-Related Motor-Operated Valves* and the in-service testing guidance of ASME Code Case OMN–1, *Alternative Rules for Preservice and Inservice Testing of Certain Electric Motor-Operated Valve Assemblies in LWR Power Plants*, identify the need to monitor MOVs in a comprehensive programmatic fashion in order to ensure operational readiness. A comprehensive MOV periodic verification program employs design basis information, field procedures, grouping strategies, technical basis documents, performance testing and condition monitoring, evaluations and corrective actions, trending results and other technical information necessary to ensure the long term operational readiness of MOVs.

In addition to the above, periodic verification of MOV operational readiness requires maintenance and testing strategies that target potential age related degradation mechanisms. Specific testing strategies must be focused on those degradation mechanisms that: 1) tend to increase the thrust or torque required to operate a valve and 2) decrease the thrust or torque available from the actuator to operate the valve to its required safety position. As a consequence, individual licensees must employ a range of testing and preventive maintenance activities designed to detect and control the various degradations that affect overall MOV performance.

A comprehensive programmatic approach also requires ongoing assessment of critical assumptions used in MOV engineering processes. Valve thrust or torque requirements and actuator capability results make up the critical elements of the engineering process and resulting set-up acceptance criteria. Many licensees employ grouping strategies or "control Groups" in order to assess future change in these parameters. For example, a critical assumption used in the thrust calculation process for rising stem gate valves is valve factor. Though valve factor may be comprised of many components it is typically associated with the sliding friction between the valve seats and seat ring or guides and guide arms under dynamic conditions. Changes in valve factor over time can only be detected through periodic dynamic testing.

As a consequence of the above and to minimize program costs, a key element of many licensee MOV programs is ongoing participation in the joint NSSS owners group (JOG) MOV Periodic Verification Program. This collaborative effort includes a study of variations in valve factor performance over time. Participating plants have agreed to test certain MOVs under dynamic operating conditions over a five-year period and share the results with other participants. The valves have been grouped such that the program covers most designs used in nuclear safety-related applications. One objective of the program is to minimize the amount of insitu dynamic testing required by individual licensees yet identify those valve designs or applications where increases in the thrust or torque requirement may occur over time.

Licensees will make adjustments, as appropriate, to MOV calculations based on the JOG results. This approach of sharing dynamic test data and other information regarding potential increases in valve thrust requirements satisfies part of the periodic verification issue for many valves and is consistent with the grouping strategies recommended in OMN−1. Individual licensees may perform additional dynamic testing as required to evaluate valves not covered by the JOG program.

Actuator capability calculations rely on assumptions for actuator efficiency and stem friction. Control groups should also be used to monitor changes in actuator capability assumptions and the results factored back into the periodic verification program. Because of differences in maintenance and lubrication practices, actuator control groups are typically site specific. Data available from previous testing can often be used to verify these assumptions.

In addition to determining how thrust or torque capability may vary, each licensee must develop site-specific programs and procedures necessary to periodically verify output capability of safety-related MOVs. Some licensees will continue to use at-the-valve diagnostic test methods, similar to those used to establish margin during the initial GL 89–10 program effort. Others will employ a mix of static at-the-valve testing and MCC based testing to periodically assess margin. In some cases licensees will rely more heavily on MCC based approaches as an alternative to at-the-valve testing for certain MOVs. Regardless of the approach used, a comprehensive programmatic effort must include performance testing necessary to facilitate a periodic margin assessment and condition monitoring necessary to evaluate health and other trends that may affect design basis assumptions.

Licensees are employing a range of processes to establish intervals for periodic verification program activities. Factors used to establish the frequency of activities such as preventive maintenance and testing typically include risk importance measures, margin and operating environment. The JOG interim static test matrix is one example of a process used to establish test intervals. The JOG approach employs risk significance and margin in order to establish periodic static test frequencies. Plants that use this approach will test MOVs that fall into the low margin, high-risk category more frequently.

Because of the margin criteria used, low margin MOVs cannot be allowed to degrade over time. In fact, any future change in the performance characteristics of an MOV in this category is unacceptable. Licensees that plan to employ the traditional at-the-valve test approaches each fuel cycle for periodic verification testing must guard against the increased risk caused by manipulation of low margin, high safety significant MOVs during the testing process. Contributors to increased plant risk include potential alteration of the MOV's physical condition during the testing process, misadjustment due to calibration or analysis errors and the impact of MOV unavailability during the testing process.

One approach that may be more practical for low margin, high risk MOVs is to perform condition monitoring at an increased frequency (once per cycle) using MCC based technology. Though these MOVs will not typically have enough margin to employ a performance test acceptance criteria, MCC based condition-monitoring approaches are more effective at detecting subtle changes in MOV performance than at-the-valve methods. The MCC test methodology should be supported by control group results and backed up by periodic at-the-valve testing at an extended interval.

High margin, low safety significant MOVs are ideal candidates for MCC testing alone for periodic verification of actuator output capability. Either of the available MCC based performance test technologies could be employed for this purpose.

Though they are ideal MCC candidates, MOVs in the high margin-low risk category are also well suited for control group service. A limited number of these MOVs should be used for control group studies because there are fewer operational restrictions and the licensee can experiment with different maintenance intervals in order to evaluate the optimal PM frequency. Therefore, certain high margin, low risk MOVs should be marked for control group service and tested as appropriate to assess change over time.

Performance Testing and Condition Monitoring

NUREG/CR–6578, *A Methodology for Evaluation of Inservice Test Intervals for Pumps and Motor-Operated Valves*, looks at periodic verification of MOV operational readiness from the inservice testing perspective and considers the benefits realized from the range of activities commonly included in a comprehensive MOV program. NUREG/CR 6578 also emphasizes the differences between performance testing and condition monitoring. Both serve important roles in a periodic verification program.

As defined in NUREG/CR–6578 performance tests are "...go/no-go tests that seek to determine whether a component meets some performance criteria." The static at-the-valve MOV testing performed during implementation of the GL 89–10 criteria is one type of MOV performance test.

The typical at-the-valve performance testing process involves use of direct thrust or torque sensors that facilitate measurement of MOV output capability. Engineering processes are used to establish minimum and maximum acceptance criteria values for MOV output. The at-the-valve acceptance criteria can be modified and used for evaluation of MCC based data.

NUREG/CR–6578 also recognizes that certain MCC based diagnostic methods, such as MCSA, provide better information on motor capability than traditional at-the-valve techniques. A key element of this conclusion is the use of the MOV motor as a transducer versus the traditional stem measurement approach. The stem measurement approach requires an assumption relating to motor health and internal actuator gearing instead of actual data.

MOV Users Group Guidance Document

In late 1998 the Motor-Operated Valve (MOV) Users Group organized a committee of industry experts for the purpose of reviewing currently available MCC technologies and developing guidance for member utilities to use during development and implementation of MCC related periodic verification test approaches.

The committee maintained a close working relationship with ASME MOV working group (OM–8) and JOG MOV program core group participants during development of this guidance. The committee also solicited feedback from the expanded MOV Users Group MCC committee during the final stages of development.

The MOV Users Group MCC document titled, *Guidance on the Use of MCC-Based Technologies for Static MOV Performance Testing and Condition Monitoring*, provides detailed information on four specific MCC analysis technologies. The document provides detail on how these technologies work and reviews the critical assumptions, applicability/limitations, strengths and weaknesses of each.

The MOV Users group MCC committee followed the guidance of NUREG/CR–6578 and characterized MCC methods based on whether the technology was applied as a performance test or used in a condition–monitoring role.

The MOV Users Group guidance targets use of MCC based technology for static periodic verification testing and discusses a range of conditions important to adoption of MCC technology for periodic verification testing.

MCC Based MOV Technology

There are a number of MOV diagnostic systems commercially available that can be used for MCC based testing of MOVs. These systems capture time based motor supply voltage, motor current and switch actuation events at the remote, MCC location. This basic MCC information may be processed differently depending on the particular system being used.

These systems are similar, portable data acquisition computers that contain signal conditioning hardware and software necessary to acquire signals from motor voltage and current probes attached to the motor power circuit.

The following analysis technologies are currently available for evaluation of MCC data:

1. MPM Equivalent Thrust
2. MC^2 Motor Torque and Motor Torque Correlation
3. Motor Power Analysis
4. Motor Current Signature Analysis (MCSA)

Though each technology utilizes the same basic MCC data, application of the analysis process is significantly different. In some cases it may be appropriate to use a combination of MCC analysis techniques for confirmation and higher confidence in the results. The following discussion on each technology was extracted from the MOV Users Group guidance document:

MPM Equivalent Thrust

"The prior thrust trace is analyzed in order to determine the amount of time between the point indicating hard seat contact and rapid loading begins (C11) and the torque switch trip point (C14) where the motor is de-energized. The corresponding thrust/time relationship is established as well as the fixed running load (packing load) prior to hard seat contact.

At a later date, motor power data acquired at the MCC is analyzed in order to determine the amount of time between hard seat contact and torque switch trip point. The thrust/time relationship that was established during the prior thrust test plus the fixed running load from the prior test is used to determine a new thrust at torque switch trip value."

MC^2 Motor Torque

"The motor torque method employs the time based motor torque history that was generated from motor electrical data acquired during an MCC based test. The motor torque data is used with the Limitorque design performance equations to calculate actuator torque and thrust.

Based on the Limitorque sizing and selection procedures and reiterated in Limitorque Technical Update 98-01, the relationship between stem thrust and motor torque is best described by the following equations:

Actuator Torque = Motor Torque X Ratio X Efficiency*

Thrust = Actuator Torque/Stem Factor

Or

Thrust = Motor Torque X Ratio X (Efficiency/Stem Factor)

* Efficiency is inclusive of application factor"

"The motor torque correlation method requires a simultaneous MCC and at-the-valve test. Data from this test is used to create a linear curve fit of the relationship between motor torque and actuator output torque and/or stem thrust. A representative correlation coefficient is developed. The correlation coefficient is mathematically equal to the product of gear ratio, actuator efficiency and stem factor. These correlation coefficients can be applied to subsequent motor torque signature sets to generate correlated stem thrust and actuator output torque signatures. The correlation coefficient should be adjusted to account for expected degradation over time."

Motor Power

"The 3-phase motor supply voltage and motor current signals can be combined electronically (in a circuit or in software) to create time domain motor power signatures. Motor power analysis provides a qualitative indication of change between tests and can be used for trending."

MCSA

"The MOV motor current frequency spectrum is a product of Fast Fourier Transform (FFT) analysis of induced modulations occurring in the electric supply current to the motor. The motor and internal rotating actuator components create modulations in the 60-cycle line frequency. The FFT algorithm calculates the frequency of cyclic/repetitive events from the instantaneous current signature. The presence of an event/peak usually indicates that energy is being expended at that particular frequency. Efficient gear meshing and good bearings may not contribute observably to the frequency spectrum."

"The primary function of frequency domain analysis is to track changes in the frequency spectrum that have occurred since a baseline test. Shifts in frequency peaks are indications of load changes. Differences in the amplitude of certain peaks indicate changes in energy being expended at certain component frequencies, and differences in sidebanding around certain significant peaks can indicate changes in the actuator efficiency.

The ability to accurately track the condition of internal MOV components and to 'second check' time domain analysis results make frequency domain analysis an integral part of the MCC based periodic static test approach. Frequency domain analysis results, combined with either EQT or motor torque results can provide additional information helpful in extending the frequency of 'at-the-valve' testing."

MCC Technology Critical Assumptions and Applicability

The MCC testing approaches described above can be characterized as either a quantitative performance testing approach or a qualitative condition monitoring approach. The equivalent thrust and motor torque processes are considered performance test approaches because an engineering process closely linked to the original GL 89–10 acceptance criteria process can be used to evaluate the test data. Motor power and MCSA are qualitative condition monitoring approaches because operational readiness is not easily evaluated in watts or as a frequency event.

The critical assumptions, applicability, strengths and weaknesses of each technology are discussed in the following sections:

Equivalent Thrust

The Equivalent Thrust methodology requires an initial static MOV thrust signature to establish the thrust load rate and duration while the valve is seating. During future tests, motor power data acquired at the MCC is used to evaluate changes in the seating duration. The thrust load rate from the initial test provides critical information for the evaluation. In order for the EQT methodology to work correctly the thrust load rate between C11 (hard seat contact) and C14 (torque switch trip) must remain constant over time.

The actuator performance parameter most likely to influence the EQT methodology is packing load. Changes in packing load result in a slower or faster motor speed at C11 and C14 depending on the direction of the change. Other changes that influence load rate to a lesser extent are supply voltage, stem friction and actuator efficiency changes.

The equipment OEM performed a series of field tests on certain Limitorque® SMB actuators with AC motors to assess the accuracy of determining thrust at torque switch trip (C14) with the EQT methodology. The OEM has also conducted a separate effects laboratory test program to assess the magnitude of individual changes that potentially effect accuracy. Detailed information on accuracy can be obtained from the OEM.

An attractive feature of the EQT process is the ability to directly assess thrust at torque switch trip and compare values to MOV program acceptance criteria. Weaknesses include limitations of the methodology to close direction thrust at CST only. There are also limitations due to valve seating characteristics and signature features that are a result of problems identifying C11. Because of the concern over possible load rate changes due to speed alternate methods (such as MCSA) should be used to verify motor speed in parallel with the EQT process.

Motor Torque

The Motor Torque Method requires use of actual or conservative stem factor and efficiency values, which include allowance for expected degradation over time. When evaluating motor torque data, the user employs actuator efficiency and stem factor values for converting motor torque to actuator torque and thrust. Bounding assumptions similar to those used in actuator capability evaluations may be used but this approach unnecessarily consumes available margin. The optimal approach requires analysis of parallel motor torque, actuator torque and stem thrust test data to establish more representative values based on actual equipment condition and maintenance practices.

Though the overall process of using motor torque data to evaluate actuator capability is applicable to all MOVs, the OEM has only validated the accuracy of the MCC based motor torque measurement for certain Limitorque® Motors 60 Ft-Lbs. and less that are commonly used on SMB, SB and SBD Actuators.

A key feature of the motor torque method is that a simultaneous calibration with direct thrust or torque is not necessary.

This allows the user to go directly to the MCC and assess performance. However the use of control group data to establish representative efficiency and stem factor values and expected degradation is required in order to satisfy performance-testing criteria.

Motor Power

Changes in motor power signature events are usually the result of changes in the load on the motor. Increased power consumption (watts) during running indicates a higher load on the motor provided the supply voltage has not changed. Increases or decreases in seating power and other events are also indicative of higher thrust or torque provided the motor has not degraded.

Motor power analysis is typically employed as a qualitative, condition-monitoring tool for trending variations in power signature events over time. Individual licensees have developed site specific procedures for evaluation of motor power data.

Motor power data can be acquired easily with a number of off-the-shelf transducers. The output of these transducers can be configured for input into most commercially available diagnostic systems.

Supply voltage and other changes may effect power levels and complicate the analysis and trending process and limit power analysis to a qualitative, condition monitoring tool.

MCSA

The initial (baseline) frequency spectrum should be analyzed to assess mechanical condition and future tests should be compared to the baseline to assess change. It is imperative that the initial baseline represents a "healthy" mechanical and electrical condition.

MCSA can be applied to all electric motors and actuators however; gear train and motor design data must be available to evaluate the frequency spectrum.

MCSA is sensitive to changes in motor/actuator electrical & mechanical condition and provides confirming data for motor torque and EQT methodologies. However, because of the wide range of actuators and resulting differences in frequency response, MCSA requires significant classroom training and extensive OJT.

Plant Specific Approaches

The number of licensees currently attempting to transition from at-the-valve MOV testing to remote MCC based testing continues to increase. With few exceptions all domestic U.S. licensees own equipment and software necessary to perform MCC based testing. Many are in the early experimental stage and acquire MCC data in parallel with ongoing at-the valve testing. Several licensees have taken a more aggressive posture and have completed site specific and laboratory validation programs. The following discussion identifies how three different licensees have approached development of MCC based testing approaches:

Farley

MCC based testing is used at the Farley Nuclear Plant as a tool to extend the at-the-valve test interval for certain MOVs.

Validation Strategy:

Certain plant installed MOV motors and a number of spare warehouse motors were initially tested on a precision dynamometer at the Farley Nuclear Plant in order to assess the accuracy of MCC based motor torque measurements for specific 550/575 volt motors. Once the motor torque accuracy was validated, simultaneous MCC and at-the-valve test results were evaluated to explore feasibility of the test equipment OEM's recommended analysis process. The simultaneous test results were used to establish the relationship between input motor torque and actuator torque (actuator efficiency) and the relationship between actuator torque and stem thrust (stem factor). The relationship between input motor torque and stem thrust was also evaluated for certain MOV groups.

The licensee worked with the test equipment OEM to develop a technical basis document for use of the data and a process for future MCC based testing. The licensee continues to perform parallel MCC tests when at-the-valve testing is required. This data and other control group data are factored back into the technical basis and adjustments to the analysis process made as appropriate.

Fermi

MCC based testing is used at Fermi as a tool to extend at-the-valve test intervals for certain MOVs and to facilitate an increased frequency for others.

Validation Strategy

In addition to the test equipment OEM's validation, a similar on-site validation was performed. MCC data was gathered in parallel with at-the-valve data and the MCC data used to calculate equivalent thrust. The MCC based results were then compared to the at-the-valve results to assess accuracy.

The Fermi site validation is an ongoing process that is continually updated with parallel test data. Each cycle, a formal evaluation is performed to document any required adjustments to the program.

Sequoyah & Watts Bar

MCC based testing is used at Sequoyah and Watts Bar as the sole test strategy for certain quarter-turn butterfly valves.

Validation Strategy:

The population of safety-related MOVs at the Sequoyah and Watts Bar Nuclear Plants includes certain Henry Pratt butterfly valves with Limitorque HBC gearboxes. The yoke and valve to actuator connections block direct access to the valve stem and prevent installation of strain gages for direct torque measurements. These valves are also soft seated and as a result direct torque measurements (if feasible) only provide meaningful information under design basis flow and differential pressure test conditions. These MOVs are also limit seated without torque switch protection.

The licensee worked with their MCC test equipment OEM to develop and validate a test methodology for the specific Limitorque HBC gearboxes used on quarter-turn butterfly valves at Sequoyah and Watts Bar. Twelve groups of representative Limitorque SMB/HBC actuators were tested under simulated in-plant, static conditions and the relationships between input motor torque and output HBC torque established. The twelve groups cover all SMB/HBC configurations used. A report was developed that provides the technical basis for evaluation of future MCC test data for the specific SMB/HBC gearbox configurations used at Sequoyah and Watts Bar.

Future ASME MOV Working Group Activity

ASME Code Case OMN-1 provides alternatives for inservice testing of MOVs. OMN-1 describes a complete programmatic approach necessary to ensure the long-term operational readiness of certain safety-related MOVs as required by the ASME code.

The ASME MOV Working Group responsible for the technical content of OMN-1 has recently interpreted the role of certain MCC-based static test approaches for inservice testing as part of the code inquiry process. The MOV working group recognized that under certain conditions MCC based approaches could be used to demonstrate margin for MOVs provided uncertainty guidelines and other requirements of OMN-1 are met.

In response to industry activity in this area and other improvements in MOV technology, the ASME MOV working group has begun the process of revising this Code Case to better reflect the current state-of-the-art in MOV testing and surveillance. An expected element of this revision will be features or guidance necessary to employ MCC based technology to meet inservice testing requirements for MOVs.

Conclusions

MOVs in nuclear safety-related applications have received considerable attention since the late 1980s. These MOVs have been subjected to a process of verifying design conditions, verifying and upgrading actuator sizing methods, verifying the field setup through testing and focused preventive maintenance. At the conclusion of GL 89-10 program efforts, industry-wide confidence in the operational readiness of nuclear plant safety-related MOVs was greatly improved.

In today's environment, the question that each licensee must satisfactorily answer is whether MOV performance may have changed or degraded since the original GL 89-10 tests. Though differences exist among licensee programs, all employ three fundamental strategies as part of the overall process of ensuring MOV operational readiness.

One strategy being employed to minimize the potential for change in actuator capability is focused preventive maintenance. A number of MOV degradation mechanisms can be identified and corrected during the preventive maintenance and visual inspection process. Licensees have also repeated at-the-valve testing to evaluate the effectiveness of the preventive maintenance program.

With few exceptions licensees are participating in and closely monitoring the JOG valve factor results. Licensees will modify MOV programs as appropriate based on JOG results.

Licensees are also relying on ongoing performance testing and condition monitoring to evaluate MOV output capability. In many cases this testing should be performed with MCC technologies. With the right combination of MCC and at-the-valve testing, licensees can further improve confidence in MOV operational readiness while shedding much of the testing and schedule burden typically associated with GL 89-10 MOV programs.

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