A Methodology for Evaluation of Inservice Test Intervals for Pumps and Motor Operated Valves

K. L. McElhaney
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-8038

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Abstract

The nuclear industry has begun efforts to reevaluate inservice tests (ISTs) for key components such as pumps and valves. At issue are two important questions—What kinds of tests provide the most meaningful information about component health, and what periodic test intervals are appropriate? In the past, requirements for component testing were prescribed by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. The tests and test intervals specified in the Code were generic in nature and test intervals were relatively short. Operating experience has shown, however, that performance and safety improvements and cost savings could be realized by tailoring IST programs to similar components with comparable safety importance and service conditions. In many cases, test intervals may be lengthened, resulting in cost savings for utilities and their customers.

To evaluate IST interval extensions, long-term component performance and the methods for mitigating degradation need to be understood. Monitoring, trending, and maintenance practices must be established in addition to test method and test interval determination. A report prepared by Oak Ridge National Laboratory (ORNL), *A Methodology for Evaluation of Inservice Test Intervals for Pumps and Motor-Operated Valves*, published as NUREG/CR-6578, (McElhaney, et. al., 1999), provides engineering information on the performance and monitoring/testing of pumps and motor-operated valves (MOVs), provides an analytical methodology for assessing the bounding effects of aging on component margin behavior, and identifies basic elements of an integrated program to help ensure component operability between test intervals. Although the NUREG focuses on pumps and MOVs, the general methodology is applicable to all components that require periodic IST.

With the advent of electric industry deregulation, the nuclear industry is struggling to provide safer, less expensive electric power in order to stay competitive with other energy sources. Plants have already begun to close, and those that remain in operation will have to figure out ways to become more efficient. Measures such as improvement of component IST are therefore critically important if production and safety are to be maintained while cutting operating costs. The methodology outlined in NUREG/CR-6578 will help provide the guidance necessary for the nuclear industry to improve its IST practices and help keep the industry competitive into the 21st century.

Background

Issues related to verification of the design and operability of safety-related MOVs, and requests for changes to traditional IST programs for pumps and valves have resulted in the need for an improved understanding of degradation effects on their performance. Proposed changes to traditional IST programs toward risk-informed IST and condition monitoring are resulting in relief requests for extended pump and valve test interval allowances. For example, requests are being made to the Nuclear Regulatory Commission (NRC) to change from traditional, relatively short, IST intervals (usually quarterly) to intervals of up to 5 to 10 years. Because component operability may be impacted by undetected degradation or failure between test intervals, an enhanced understanding of methods for mitigating/detecting potential component degradation or failure has become important. The effects of changes to IST programs on component operability therefore need to be assessed for the NRC to be able to evaluate the appropriateness of proposed test intervals.

Because risk-informed and condition monitoring methodologies represent fundamental changes in the implementation of IST programs, the fundamental bases of IST programs should be reexamined. These bases include failure modes, degradation mechanisms, condition assessment, and effectiveness of testing methods. Traditional prescriptive requirements (code-specified tests and quarterly test intervals) are being replaced by more flexible, judgement-based approaches. Thus, from an overall operability assurance perspective, integrated testing, monitoring, maintenance, and trending programs will be important in ensuring safe and reliable operation of components. The NRC has already recognized the need for a programmatic approach to operability assurance by providing guidelines for periodic verification programs in Generic Letter 96-05, "Periodic Verification of Design-Basis Capability of Safety-Related Motor-Operated Valves," (USNRC, 1996). Because the methodologies for implementation of IST programs rely less on prescription and more on engineering judgement, so too, will the bases for future IST program evaluation.

NUREG Overview

<u>Scope and approach</u>

The ORNL report provides guidance to support the NRC's evaluation of IST intervals for pumps and MOVs.[1] The study emphasis is on the complete pump and MOV assemblies (including the valve actuator and the pump driver) rather than on the basic valve and pump components themselves. It is anticipated that these guidelines will be useful to the NRC to assess (1) proposed changes to IST programs based on risk-informed methodologies, (2) relief requests to extend IST intervals, and (3) issues related to margin availability. The report presents specific engineering information pertinent to the performance and monitoring/testing of pumps and MOVs, identifies the basic elements of an integrated program to help ensure component operability between test intervals, and provides an analytical methodology for assessing the bounding effects of component aging on unavailability and margin behavior.

[1] Although the report was developed to assist the NRC in its evaluation of licensee change requests, the information contained within the report can be used by licensees in the development and implementation of their operability assurance programs and associated change requests.

The evaluation of a licensee change request to extend IST intervals for a given set of components should consist of three basic elements:

1. evaluation of the licensee's engineering analysis used to determine IST interval allowances,
2. evaluation of the licensee's overall program to assure component operability, and
3. evaluation of the licensee's trending and feedback mechanisms that ensure that test intervals are reevaluated and updated as necessary.

Guidance for assessing probabilistic methods and the risk importance and safety consequences of the performance of pumps and MOVs is not specifically included within the scope of the report, but these elements may be included in licensee change requests.

The report assumes that the evaluation of such licensee activities will address these three basic elements (i.e., that a balanced evaluation should focus on the engineering and programmatic aspects of the activities as well as specific test intervals).

The focus of the report is on the pump, MOV, and key pump and MOV subcomponents and auxiliary equipment (i.e., the complete component system or assembly), rather than simply on the basic valves and pumps themselves. The pump assembly includes the pump, motor or turbine drive, and the related circuit breaker. The MOV assembly includes the valve, actuator, motor starter, and electrical components. The overall assembly is considered because research has shown that failures in these subcomponents and auxiliary equipment are significant contributors to loss of pump/MOV function and/or operability (Casada, 1996; Cox and Wood, 1996; Staunton, 1997).

The approach outlined in the report is based on the recognition that important differences exist between diagnostic testing (e.g., condition monitoring) and performance testing (e.g., ISTs, margin testing). The objective of a performance test is usually to verify that equipment operations are "within specification" and/or within acceptable limits (i.e., to verify that a functional failure has not occurred). The primary purpose of a diagnostic test is to gather information that, if correctly interpreted, can help to assess the general condition of the monitored equipment. The intent of IST as required by the ASME Code for pumps and valves is to demonstrate operability as an indicator of the ability of the component to meet its design requirements at a given point in time. Likewise, the requirement to verify the design basis of a pump or valve is a requirement to assure the functional operation of the component up to the design basis at that time and is not directly intended to assess the effects of future time or service or environment on the progressive deterioration of the component. Also, the parameters monitored to indicate the design-basis performance may not necessarily be the same as those best suited to monitor progressive deterioration of performance. Typically, the intent in design-basis performance testing is not to derive information about future performance. Efforts to integrate these two types of tests should recognize these distinct differences. To achieve an integrated program, both diagnostic and performance testing should be included.

Content

The NUREG is arranged into four basic sections: (1) failure modes and mechanisms for pumps and MOVs, (2) testing and maintenance practices, (3) guidelines for evaluating effects of changes to IST programs on pump and MOV operability, and (4) a mathematical analysis of the probability of component failure and unavailability as a function of margin and testing characteristics.

Based on analyses of component performance data, the significant failure modes, mechanisms, performance-affecting parameters, and condition indicator parameters for pumps and MOVs are discussed. Time dependence and failure behavior are also addressed, because research has shown that most failures occurring in complex components such as pumps and MOVs result from a combination of factors. Maintenance and testing practices (including margin analysis) are also discussed, as is the effectiveness of various diagnostic and monitoring methods. General guidelines for data collection and trending are presented. A detailed discussion of signature analysis used as a condition indicator or diagnostic technique is also included. Application of this technique in detecting abnormalities or degradations in MOVs is presented as a particular example.

The report contains guidelines to support an integrated regulatory evaluation of proposed changes to IST programs – that is, assessment of the technical bases for such changes, overall operability assurance programs (testing, monitoring, maintenance, and trending and feedback programs), and resulting test intervals. Attributes of well-founded, balanced engineering analyses (including component groupings and failure rate estimation) and operability programs are provided for evaluation of licensee submittals. Recommendations for minimum extension request content, the technical evaluation of such requests for pumps and MOVs, and general considerations for test interval extension are included.

The bases for the computation of failure probabilities from margin trends and margin statistics and numerical results from parametric studies of the effects of test intervals and aging on the component margin and component unavailability are also discussed. Models of exponential deterioration with age and lognormal distributions are used. The parametric studies explore the contributions of varying deterioration rates, statistical parameters, and length of the testing interval. These parameters were selected to assist in the evaluation of adequacies of margins, length of test intervals for margin assessment, and impact of changes in the length of IST intervals. Because actual data on component margin behavior with time is presently unavailable, the inputs used were only intended to illustrate a potential methodology. Because the parametric studies cover different cases and include bounding cases, the appropriate qualifications and assumptions necessary for valid uses of the inputs and results of the studies are included. Results of evaluations of initial and time-dependent probabilities of failure to provide adequate margin are presented. The unavailability of the component is also evaluated as a function of test interval and test downtime with and without repair maintenance.

Results and Conclusions

The following results should be useful in the NRC's evaluation of the engineering and programmatic aspects (as well as specific test intervals) of licensee change requests to modify IST programs and for investigating issues related to margin availability. They may also be used by licensees in the preparation of such programs and change requests:

- Because of unavoidable differences in maintenance practices, human interactions, system transients, and general operating modes and environments, individual components will exhibit individual performance characteristics. ORNL studies have shown that considerable variation exists in the relative performance measurement of components with various parameters and cross-correlations.

- An effective program to assure component operability should be *integrated*; that is, it should consider maintenance, operation, failure prediction, and failure detection. In general, proactive measures that seek to prevent failures should take precedence over those reactive ones that can only detect or correct them.

- For many failure modes, it is possible to identify suitable condition monitoring (diagnostic testing) methods to detect potential failures so that action may be taken to prevent a functional failure from occurring.

- Performance tests need to be able to determine whether any part of a component assembly (i.e., the pump or valve and its associated subcomponents and supporting components) has failed. Of equal importance is that the process of checking for functional failure or performance acceptance not induce failure or degradation. The possibility that the component might be left in the failed state because of the test should also be considered.

- The required frequency of failure detection activities such as margin tests or ISTs is dependent upon two parameters—the desired availability of the component and its reliability (i.e., frequency of failure). Appropriateness of test intervals is determined by the importance of the component and its likelihood of failure.

- Failure and diagnostic data trending and feedback mechanisms are necessary to validate and, where required, to modify test intervals. Both plant-specific and industry data should be considered.

- Analysis has shown that in 92 of 246 (37%) significant[*] pump failures, the affected part was a pump bearing; in 36 of 78 (46%) significant pump motor failures, a motor bearing was the affected part. Yet the current regulatory/code-required monitoring finds very few bearing problems. More significantly, there is no required monitoring for pump circuit breaker condition, and evidence is clear that circuit breaker failures are primary contributors to pump unavailability.

- Pump hydraulic performance does have potential for margin trending because pump performance can gradually deteriorate due to wear-related causes. Bearing life analysis and degradation in the pump motor, turbine drive, or circuit breaker, however, cannot be adequately assessed by margin trending unless detailed analysis, employing modern diagnostic techniques, is applied. Similarly, for MOVs, comparing developed and required torque may provide some indication of overall performance; however, margin testing alone (such as that described in ASME Code Case OMN-1 [ASME, 1995]) cannot likely detect all significant degradation that may be present in either the valve or the actuator. If a very high level of component availability is desirable, performance tests such as margin tests should be considered to be supplemental to, not replacements for, other types of proactive measures such as condition monitoring.

- By relying on torque measurements (converted to thrust via the design-basis stem factor) rather than direct thrust measurements, functional margin as defined in ASME Code Case OMN-1 is always verified under the assumption that the actual stem factor never exceeds the design-basis stem factor. If both torque and thrust are not measured simultaneously, the actual stem factor cannot be determined to prove that it is not greater than the design-basis stem factor. The possibility exists that if the actual stem factor were greater than the design-basis stem factor, insufficient thrust would be delivered to the valve under design-basis conditions, even though the torque-based functional margin was acceptable. The approach allowed by OMN-1 does not take into account a sudden loss of margin and MOV functionality due to degradations that do not directly impact the OMN-1 margin measurement. For example, if the location of the degradation is such that it does not impact the performance parameter being measured, the degradation may go undetected by the performance test and may subsequently lead to an unexpected functional failure.

- A successful performance test cannot by itself guarantee that significant equipment degradation is not present (i.e., the presence of "margin" does not necessarily ensure availability). For example, a successful margin test, as prescribed by OMN-1, can confirm that the MOV motor and gear train together can deliver the desired

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[*] "Significant" in this context means that at least some degradation in pump performance occurred and/or near-term operation of the pump was jeopardized. No plant or system effects were analyzed.

torque to the stem nut, but it cannot identify degradation in these areas as long as sufficient torque is still delivered to trip the torque switch. In this case, the true MOV capability is limited (hidden) by the torque switch. If the degradation has increased so that not enough torque is delivered to the stem nut and the torque switch does not trip the motor, the motor may stall and be at risk of failing catastrophically (if not adequately protected by a thermal overload device).

- The following observations were made for the virtual component considered within the assumptions and limitations of the mathematical models and parametric analyses:

For an inadequate margin failure mode, when the margin is near 1, the failure probability due to inadequate margin has high values when the standard deviation is not low (the margin is not accurately known). For instance, for a mean margin of 1.25, the failure probability due to inadequate margin increased from 10^{-4} to 10^{-1} as the relative standard deviation of the margin increased from 6% to 12%. Margin reduction due to aging further increases the sensitivity to the accuracy of the margin. High failure probabilities can be expected when the margin is low and/or not accurately known, when the test intervals are too large, and when margin degradation is not controlled by renewal or by other means.

Parametric studies of relative changes in unavailability show clearly the positive effect of renewal after testing. With a test interval of 5 years and rate of failure rate change (RFRC) of 10%, the unavailability is approximately a factor of 6 lower when renewal is performed. The effect of testing downtime increased the unavailability in proportion to the downtime duration for all test intervals where the downtime contribution was significant. For the same RFRC of 10% and test interval of 5 years, the unavailability is approximately a factor of 2 lower for no downtime than for 8 hour downtimes.

References

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