EPRI

Roadmap for Extending Limitorque Actuator Life

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ABSTRACT

The capability of motor operators to operate beyond their original qualification of 2,000 cycles and 40 years will be challenged as power plants reach their initial design life and plant life extensions are permitted by the Nuclear Regulatory Commission. An industry sponsored test program to increase the load rating of Limitorque actuators was conducted by in the early 1990's by Kalsi Engineering, Incorporated. To achieve the industry goal of increasing the thrust rating of the actuators, testing was performed on Limitorque SMB and SB type actuators from size 000 to size 2 at thrust loads as high as twice their rating and for a total of 4,000 cycles. The testing performed under that project, overload stall test data available from Limitorque Corporation combined with additional analyses and/or testing proposed in this report can be used to extend the design life of the Limitorque actuators for the desired goal of 3,000 cycles. This report presents a roadmap which can be used to extend the allowable design life of Limitorque SMB/SB/SBD actuator from Size 000 through Size 4.

ACKNOWLEDGEMENTS

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INTRODUCTION

1.1 Background

The capability of motor operators to operate beyond their original qualification of 2,000 cycles and 40 years will be challenged as power plants reach their initial design life and plant life extensions are permitted by the Nuclear Regulatory Commission. An industry sponsored test program to increase the load rating of Limitorque actuators was conducted by Kalsi Engineering in the early 1990's by Kalsi Engineering, Incorporated. To achieve the industry goal of increasing the thrust rating of the actuators, testing was performed on Limitorque SMB and SB type actuators from size 000 to size 2 at thrust loads as high as twice their rating and for a total of 4,000 cycles. The testing performed under that project, overload stall test data available from Limitorque Corporation combined with additional analyses and/or testing can form the basis to extend the design life of the Limitorque actuators.

1.2 Objective

The objective of this document is to develop a “Roadmap” defining the steps needed to justify operation of Limitorque actuators to at least 3000 cycles at Limitorque defined maximum thrust and torque limits and to the higher thrust and torque limits currently defined by previous testing conducted by Kalsi Engineering, where possible. The roadmap provides a basis for an EPRI/Industry decision on pursuing this activity.

1.3 Scope

The "roadmap" for the life extension of Limitorque actuators will include SMB-000 and SMB/SB/SBD -00 through SMB-4 and takes into consideration the recommendations and guidelines identified in 10CFR50.49, IEEE-382, IEEE-344, and IEEE-323, as applicable [1, 2, 3, 4]. The scope does not include HBC operators.

More specifically the “roadmap” defines the actions needed to provide the technical basis for extending the fatigue life capability beyond 2000 stroke based on thrust and torque level history. It identifies analysis and testing necessary to address the mechanical/structural issues, e.g. structural limits, wear, and fatigue.

The scope of this project does not include testing or analysis needed for evaluating the effect of aging related issues, e.g. environmental temperature, radiation, moisture etc. This task should be addressed by each individual utility and may already fall under existing qualification procedures in place for non-metallic components.

This project also provides estimated projected costs to pursue implementation of the proposed approaches.

Quality Assurance requirements of 10 CFR 50, Appendix B were not imposed on this project.

2

OVERVIEW OF THE LIMITORQUE ACTUATOR PHASE I AND PHASE II TEST PROGRAM

2.1 Purpose

This section provides a description of the key elements of the Phase I and Phase II programs, which resulted in the increased thrust ratings of Limitorque actuators most commonly used in the MOV application in nuclear power plants. A good knowledge of the methodologies developed, key test results and their applicability described in this section is important to understand the technical approach and scope described in Section 3 for actuator life extension.

2.2 Background

During implementation of the U.S. Nuclear Regulatory Commission (NRC) IE Bulletin 85-03 recommendations, utilities performed diagnostic testing of safety related MOVs to ensure that the torque switches and limit switches in the actuators are properly set to allow these MOVs to perform their safety-related opening and closing functions. It was discovered that during plant operation, a significant population of MOVs was being subjected to cyclic thrust overloads that exceeded manufacturer's ratings. To address *utility-specific* overload conditions, Kalsi Engineering performed evaluations for a number of plants using fracture mechanics analysis, fatigue analysis, and cyclic overload testing of actuator components to justify continued operation.

Recognizing that the MOV actuator thrust overloading is an industry-wide issue, Duke Power Company initiated a comprehensive program to generically qualify actuators for higher thrust ratings based upon technically sound bases that could be defended to NRC, even without the manufacturers' endorsement. Several other utilities joined Duke Power to share the project costs and benefit from the results of the program. Duke Power Company, acting as the utility project manager, selected Kalsi Engineering, Inc (KEI) as the technical contractor to develop the detailed scope and conduct the program based on previous in-depth experience relevant to this issue.

The project (Kalsi Study) was conducted in two phases. The detailed results are documented in references 9 through 18. The highlights of the test program and the key results are described below.

2.3 Phase I Testing

2.3.1 Test Fixtures

Under Phase I, four sizes of Limitorque actuators (SMB-000, -00, -0, and –1) were tested using specially designed test fixtures at 200% of their nominal thrust rating for 4,000 cycles [9] as well as seismic testing [10].

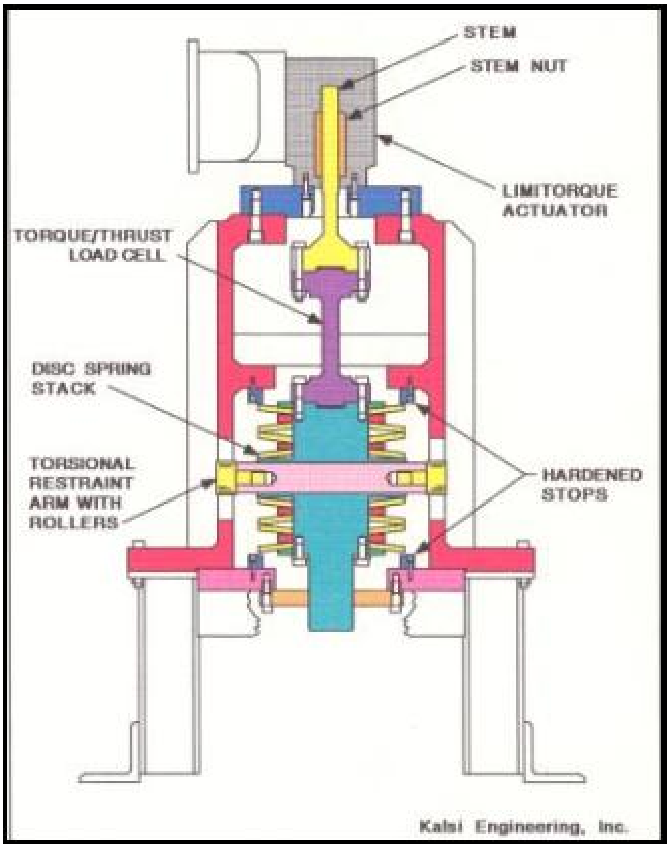
Figures 2-1 & 2-2 show the details of the test fixtures used for testing the SMB-000 through SMB-1 actuators. (A similar design, higher load capacity test fixture used for testing SMB-2 actuators under Phase II of the program is also shown in Figure 2-2.) The fixtures allowed the MOV stiffness to be simulated by using disc springs in both the opening and closing stroke directions. For a given peak thrust, the magnitude of actuator stiffness or the MOV stiffness has no affect on the fatigue life of the actuator *thrust components* because the thrust components are subjected to only one peak stress cycle during each MOV cycle regardless of the stiffness. However, as shown in Figure 2-3, the torsional components (e.g. worm and worm shaft) are subjected to multiple stress cycles, and the MOV/actuator stiffness does affect the number of alternating load cycles (and cumulative fatigue damage) for the actuator *torsional components* during the load ramp. Therefore, the Belleville spring stack stiffnesses used in the test fixture for different sizes of actuators were based upon a survey of representative MOV stiffnesses obtained from in-situ static thrust traces for gate and globe valves provided by Duke Power Company.

2.3.2 Overall Test Plan

Briefly the test plan consisted of the following major steps:

1. 2,000 Cycles of Overload Testing at 200% of Rated Thrust
    - Disassemble and perform initial inspection of all actuator components
    - Complete 500 load cycles, disassemble and inspect
    - Complete 2,000 load cycles, disassemble and inspect
2. Stall Tests
    - Perform 5 load cycles at full motor stall in both open and close directions
    - Disassemble and inspect
3. Seismic Qualification Tests
    - Perform a matrix of seismic qualification tests
    - Disassembly and inspect
4. Extended Overload Testing to 4,000 Cycles
    - Complete 2,500 load cycles, disassemble and inspect
    - Complete 4,000 load cycles, disassemble and inspect

During testing, the actuators were completely disassembled for visual examination, dye penetrant examination and dimensional inspection (if necessary) of critical components at several intermediate steps identified above. The objective of these intermediate inspections was to detect evidence of any crack initiation, monitor crack propagation and to look for any wear-related degradation of internal components, which can provide the basis for developing maintenance/replacement interval recommendations.



Test Fixture Cross Section

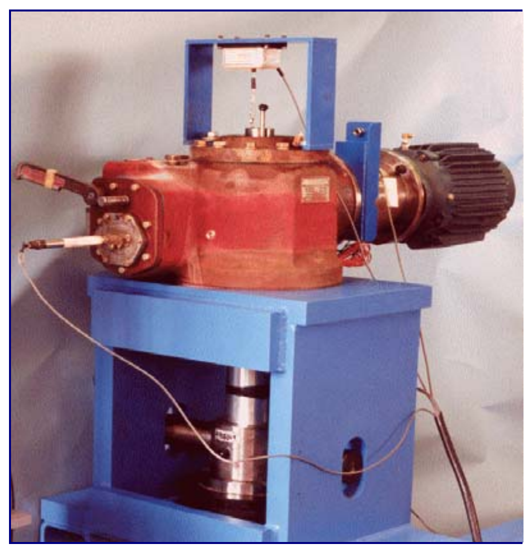


Figure 2-2
Test Fixtures Used for Cyclic Testing of Limitorque SMB-000 through SMB-1 Actuators (shown on the left). A higher load capacity test fixture (shown on the right) was used for SMB-2 Testing

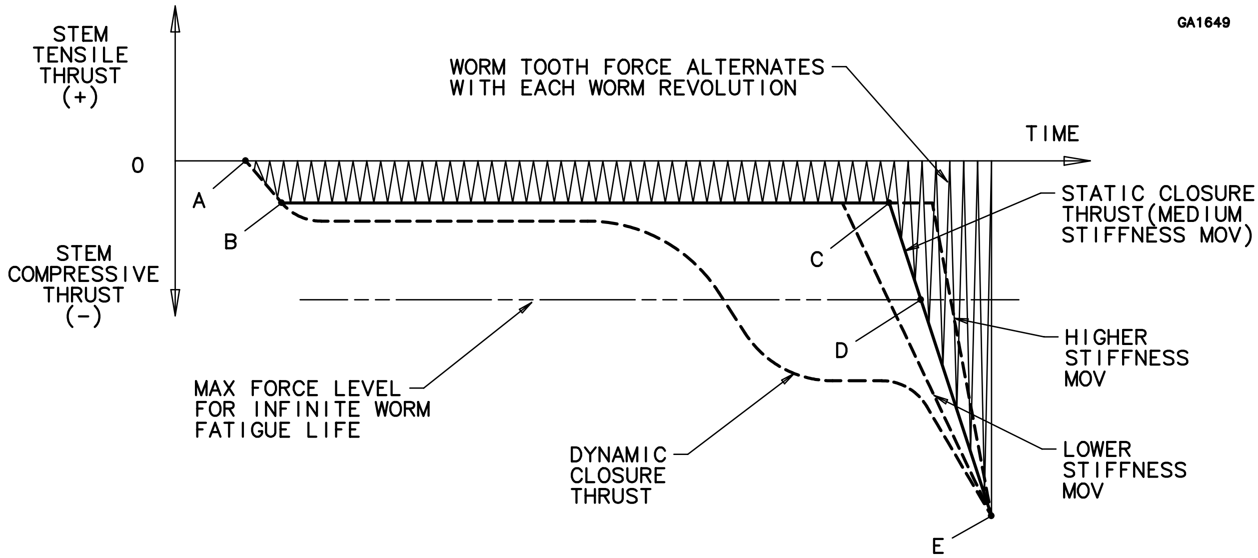


Figure 2-3
The Actuator *Torsional Components* (e.g. worm) are subject to *Multiple* Force Cycles for each MOV Closure Stroke
(in contrast, the *Thrust Components* are subjected to only a *Single* Force Cycle for each MOV Closure Stroke).

2.3.3 Seismic Testing

The Phase I program included seismic qualification testing of four actuator sizes (SMB-000, -00, -0 and –1). Based upon input from the participating utilities, the required seismic response curves were developed to ensure that they enveloped all the PWR and BWR plant requirements. Testing was conducted in accordance with the appropriate sections of IEEE-382/-344 [1, 2, 3] at Wyle Laboratories (Figure 2-4). A very comprehensive matrix of seismic tests was specified to cover MOVs in both *line mounted* and *rigidly mounted* applications. The key elements of the seismic test plan were:

1. Pre-seismic (baseline) operability verification tests
2. Resonance search tests, all three axis
3. Operating Basis Earthquake (OBE) level, 3-axis, Random Multi-Frequency (RMF) input tests, 5 sets
4. Safe Shutdown Earthquake (SSE) level, 3-axis, RMF input tests, 1 set
5. OBE level (3g), sine sweep tests, 1-35-1 Hz, 2 sets each axis
6. SSE level (4.5g), sine beat tests, 1 set each axis
7. Post-seismic operability tests

All of the actuators successfully completed the entire seismic qualification test plan while being cycled both in the closing and opening directions at 200% of the rated thrust.

Figure 2-4
Four Sizes of Limitorque SMB Actuators were Seismically Tested on a 3-Axis Shake Table while being Subjected to Overthrust Conditions

2.3.4 Phase I Test Results

The allowable number of design cycles, and the corresponding allowable design loads for actual plant applications was based upon applying appropriate margins or factors to the 200% of the thrust loads and 4,000 cycles used in the Phase I qualification testing. Even though there are no requirements to apply *any* margin according to the applicable IEEE-382/344 qualification standards [1, 2, 3], it was considered prudent to voluntarily apply a recognized approach for margins used for other equipment e.g. mechanical/structural components, pressure vessels, hydraulic machinery etc. After reviewing various approaches used in different industries, it was decided to use the ASME Section III, Division 1, Appendix II approach which provides factors for allowable number of design cycles and design loads based upon qualification test cycles and loads using one or more test specimens.

Based on this approach, the Limitorque SMB-000, -00, -0 and –1 actuators were qualified for 162% of rated thrust for 2,000 cycles, or 200% of rated thrust for 760 cycles, provided certain implementation constraints related to bolt preloads and inspection criteria are met and Limitorque's published torque ratings are not exceeded. Furthermore, only the SMB-000 actuator "new style" housing cover was qualified. The "new style" housing has a thicker flange and larger bolts than the original housing cover that was provided until the 1980's.

The sponsoring utilities permitted use of partial Phase I results by Limitorque Corp. and non-participating utilities through the release of Limitorque Technical Update 92-01 [24] in exchange for endorsement by Limitorque Corp. For non-sponsoring utilities, this permitted the use of lower thrust levels, up to 140% of Limitorque's published ratings for SMB-000 (with "new style" housing cover only), SMB-00, SMB-0, and SMB-1 actuators with constraints on bolt preload, torque ratings, and inspection criteria stated in Limitorque Technical Update 92-01.

During thrust overload qualification testing of 4,000 cycles, torsional failures (e.g. as shown in Figure 2-5), as well as excessive wear of certain components in some actuator sizes, were encountered. The torsional components were tested under torque levels ranging from 96% to

141% of the Limitorque's published ratings for the 4 different actuators sizes, which are further discussed in Sections 2.4.2 and 2.4.3 in detail. Based upon technical recommendations by Kalsi Engineering and consensus of the sponsoring utilities, it was decided to continue testing to achieve the *thrust* qualification goal by replacing the prematurely failed non-thrust-carrying components, and to address the torsional components fatigue life issue and develop appropriate recommendations under Phase II of the program.

Figure 2-5
Typical Examples of Limitorque Actuator Torsional Component Failures Under Over-torque Conditions during Phase I Testing

2.4 Phase II Test Program and Key Results

Under Phase II, the project scope was expanded to include additional Limitorque models and sizes and to address the technical issues related to the failure of the torsional components encountered during Phase I tests [10, 11, 12, 13, 14, 15, 16, 17, 18]. The following tasks were performed and key results obtained under this phase of the program:

- Analyses were performed to relax the Phase I housing cover bolt preload constraints imposed for utilizing the increased thrust ratings for SMB-000 through SMB-1 actuators [11].
- SMB-000 actuator "old style" housing cover was tested in a separate test fixture for 4,000 cycles at 200% of the rated thrust to qualify it for the same overload as the "new" housing covers tested under Phase I [10] qualified for thrust overloads.
- SMB-2 actuator was tested at 200% of the Limitorque's published ratings to develop basis for allowable overload magnitude and corresponding number of cycles. The SMB-2 actuator failed to meet the goal of 4000 cycles at 200% of thrust rating and the test was terminated when the actuator housing failed (fractured) at 1016 cycles [13]. **Note***: The SMB-2 actuator was later successfully tested at a lower thrust level, as discussed in the Section 2.4.1.*
- HBC-O operator was tested at 125% of the Limitorque's published torque rating to develop basis for allowable overtorque magnitude. The HBC-O operator failed to meet the goal of 125% of actuator rating, and HOBC testing terminated after worm failures under overtorque conditions [18].
- SB-00 through SB-2 compensators were tested for 4,000 cycles of 200% of the rated thrust to qualify them for the same increased thrust ratings as those for their corresponding SMB models. These qualification tests were performed using the compensator mounted in a special fixture and the results were documented in Reference [12].

- The SMB-000 Actuator was cycle tested for 4,000 cycles at a lower average torque level (106% of the torque rating instead of 117% of the torque rating in Phase I testing) to confirm if a significant increase in fatigue life is achieved, and to provide validation data for the torsional component fatigue life analysis methodology. The 4,000 cycle testing was completed, along with 5 stall tests at an average torque level of 182% of the rating without failure of any torsional components [14].
- A torsional fatigue model, based on first principles, was developed to predict life of the SMB/ SB/SBD actuators under torque overload conditions. The model was incorporated in Limitorque Actuator Torsional Fatigue Life Analysis (LTAFLA) Software, which was validated against Phase I, and II test data. This is *a key element of* the EPRI Life Extension Program and is discussed in more detail in Section 2.4.2.

2.4.1 SMB-2 Actuator Testing Beyond Phase II

Kalsi Engineering performed an additional test on SMB-2 actuators, which was not funded by the sponsoring utilities, and as such the results were never formally released and it remains KEI's proprietary information. In this second test, SMB-2 actuator was successfully thrust tested in both opening and closing directions for more than 5,000 cycles at a thrust level of approximately 145% of rating. It was also stall tested five times in both directions at loads greater than 215% of rating. These results will be utilized in establishing the allowable thrust levels for the SMB-2 Actuator under the EPRI Life Extension Project.

2.4.2 Torsional Component Fatigue Life Prediction Methodology

During Phase I and Phase II of the test program, worm and the worm shaft were replaced in order to complete the goal of 4,000 thrust cycles. The critically stressed locations on these components are (1) the base of the worm tooth, (2) the inner contact point between worm and worm shaft, (3) and the limit switch worm thread area of the worm. The critical locations (1) and (2) are applicable to all five of the Limitorque Actuators (SMB-000 through SMB-2), whereas location (3) is applicable to only SMB-0, -1 and –2 actuators.

The configurations of the actuators including the critical torsional components are shown for reference in Figure 2-6. The load on the worm and worm shaft alternates the worm rotation and speed (Figure 2-3). Normally, a valve cycle is made up of a closing and an opening stroke. Each stroke consists of a loading ramp which is represented in the model by a linearly increasing (or decreasing) load profile with a dwell each peak. During each worm revolution, the load (and the generated stress) is increased (or decreased) in proportion to the slope of the ramp. The number of worm revolutions experienced during one loading ramp is proportional to the worm gear set ratio, the lead of the stem screw, MOV stiffness, and the maximum ramp load.

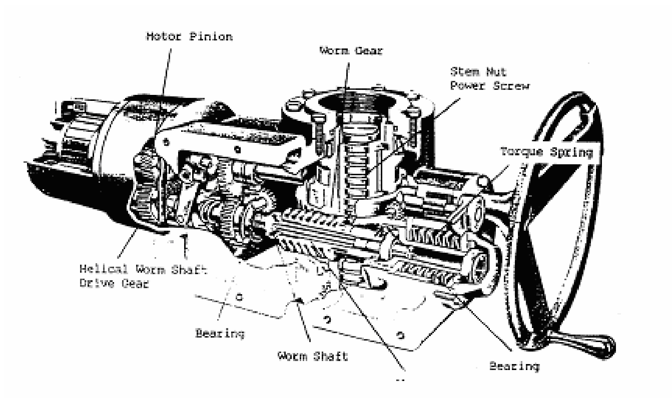


Figure 2-6
Limitorque Actuator Cutaway View

Two mechanical models were developed for describing the critical torsional components in two groups of Limitorque SMB actuator design families. These are shown in Figures 2-7, and 2-8 for the SMB-000/00 and SMB/0/1/2 actuators, respectively. The induced stress fields at the critical locations are highly complex and generally three-dimensional. Classical strength of material formulas available for standard machinery components and structural shapes are used in the model. The alternating and mean stresses at the critical locations are computed by the superposition of stresses obtained by the use of simple beam, statically indeterminate beam, and Hertz contact formulas. Appropriate stress concentration factors are applied to each of the alternating stress components, while mean stresses are computed without stress concentration factors.

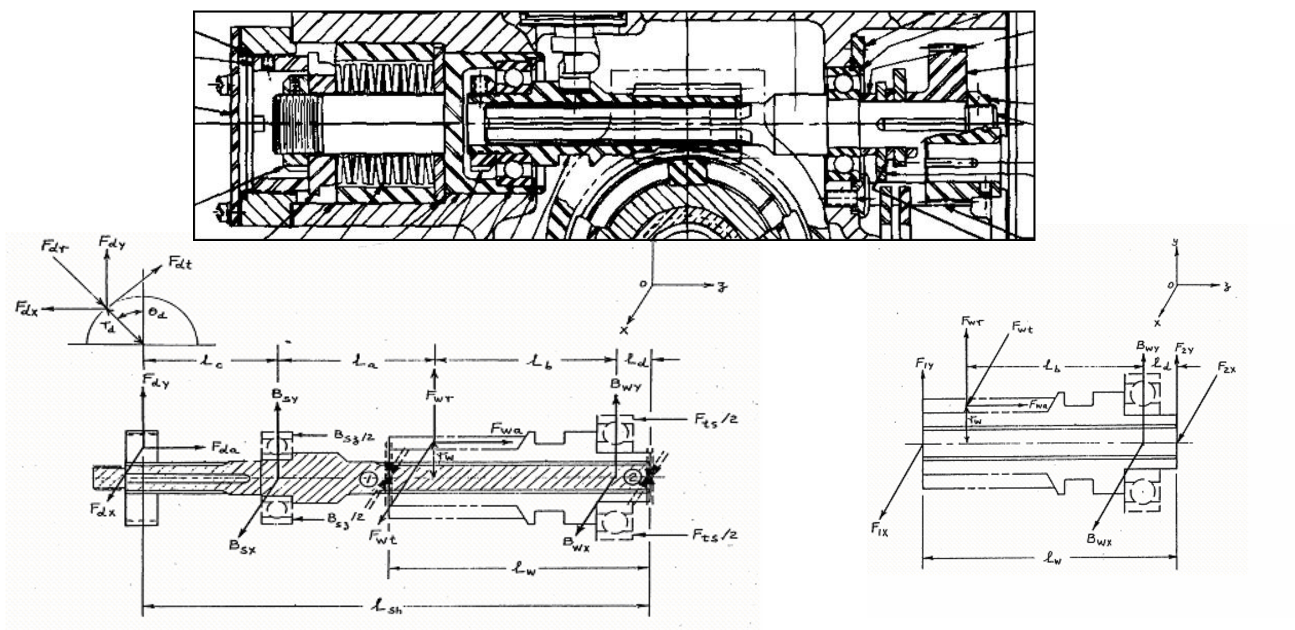


Figure 2-7
Mechanical Model and Load Diagram for the Worm/Worm Shaft Assembly of SMB-000/00 Actuators

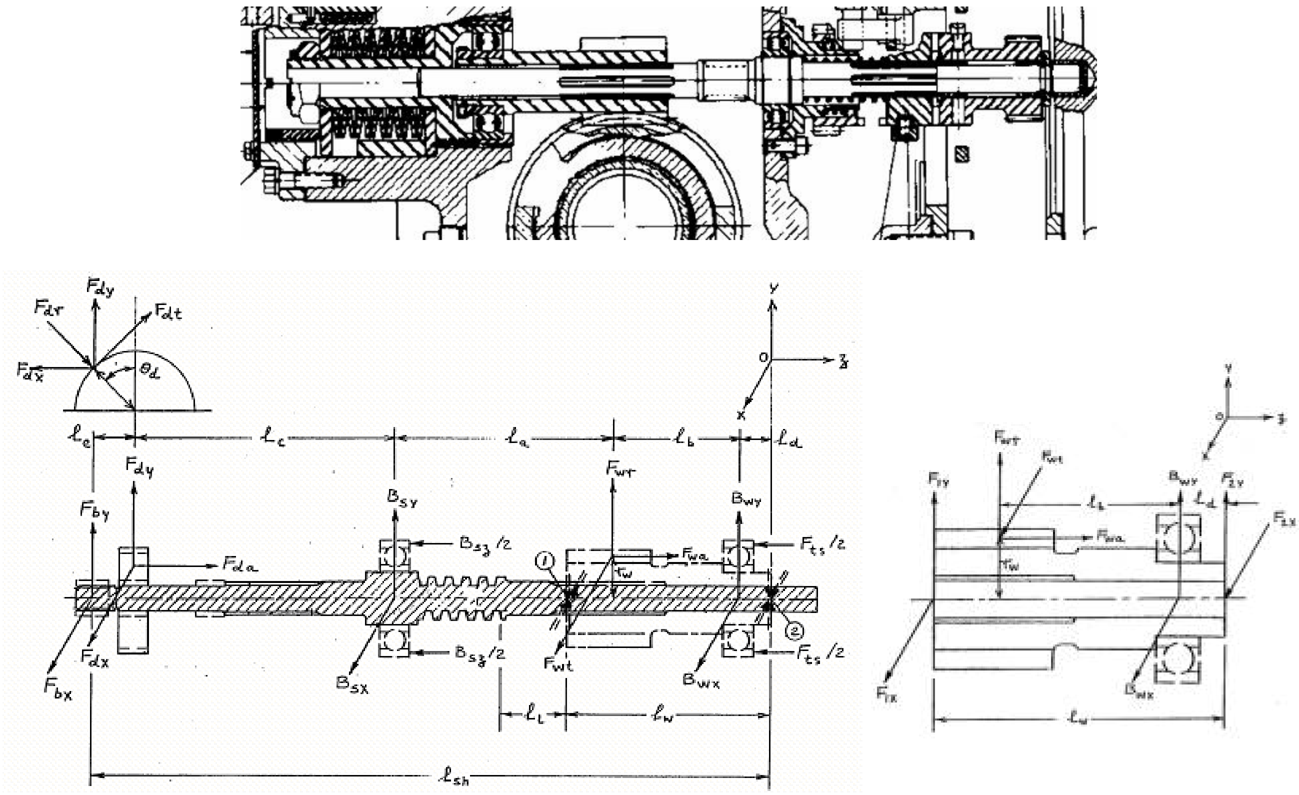


Figure 2-8
Mechanical Model and Load Diagram for the Worm/Worm Shaft Assembly of SMB-0/1/2 Actuators

The fatigue model is based on the 'Distortion Energy Theory' of failure, also known as the 'von Mises-Hencky Theory'. According to this theory, failure is postulated to occur in a material subjected to combined stresses when the energy of distortion reaches a value, which would cause failure in tension only. The governing stress is the von Mises stress which represents those stresses that produce distortion but no volume change. The application to the torsional components, where the principal stresses do not maintain their orientation relative to an element of rotating material, follows the method suggested by Shigley and Mitchell [22]. The method defines two stress tensors, one for the mean and one for the alternating stresses. The mean and alternating stress elements are used to compute values of principal mean and alternating stresses, which in turn are used to generate the von Mises stresses. The resulting von Mises stresses are then applied to the S-N curve in the fatigue model as simple one-dimensional stresses would be.

The form of the material S-N curve used in the fatigue model derived by combining the form adopted by the Society of Automotive Engineers [23] and the empirical correlation given by the ASME Boiler and Pressure Vessel Code [19]. The resultant curve is similar to the ASME form but includes empirical multiplying factors on the material dependent parameters of the ASME equation. The empirical factors were refined by a correlation of analytical results with data from

Phase I and Phase II of the test program. The modification provides for an analytic expression that is useful from the plastic strain region (low-cycle fatigue) all the way to the elastic strain region (high-cycle fatigue). The effects of mean stress on fatigue life were modeled by a generic exponential formula, which with a proper choice of exponents can simulate either the Modified Goodman, the Gerber, or the Kececioglu criteria. The Modified Goodman formula provided the best correlation with the test data, and was therefore built into the model as a default option.

The cumulative damage and fatigue life due to stress cycling is computed by the use of a modification of Miner's rule. The modification employs the definition of a differential accumulated damage for the linearly increasing stress cycles in the loading ramps. The differential accumulated damage was then integrated over the entire actuator cycle to compute total accumulated damage, and thereby the predicted fatigue life.

The computational algorithm for the prediction of fatigue life of the actuator torsional components involves the quantitative evaluation of the equations developed for applied loads, generated stresses, and cumulative damage (and thereby fatigue life). The computational algorithm consists mainly in the evaluation of algebraic equations, with the exception of the equation, which expresses the material cumulative damage. That equation requires a numerical integration scheme, which is accomplished by the use of Simpson’s quadrature.

2.4.3 LTAFLA Software

The first principles methodology described above was coded into a computer program, Limitorque Actuator Fatigue Life Analysis (*LTAFLA)*, for computating structural strength capability and fatigue life of the actuator torsional components [15, 16, and 17]. The program requires input of the actuator type (such as SMB-000 or SMB-2) that is to be analyzed. Selection of the specific type automatically fixes a number of geometric parameters such as shaft dimensions including diameter, length, bearing support positions, spline geometry, as well as pinion/shaft drive gear center-to-center distance, and worm/worm gear center-to-center distance. These actuator specific fixed parameters are included in the computer program and do not need to be provided as input data. Each of the Limitorque actuators within the range of applicability of this program is supplied by Limitorque with a range of motor pinion/shaft gear ratios and a range of worm/worm gear ratios. Therefore, to completely specify the actuator selection, both of these gear ratios are required in the input data. Selection of actuator type and gear ratios establishes some, but not all, of the gear tooth and worm thread parameters, for example, additional information is needed on whether the worm has single or double thread configuration. Valve stem thread parameters must also be input since these depend on specific valve applications.

The torsional fatigue model and software program, LTAFLA were validated against all Phase I and II test data as shown in Table 1 and Figure 2-9 [9, 13, 14]. The LTAFLA analytical model appropriately accounts for all the key parameters, thus permitting a rigorous and complete evaluation of the MOV actuators under thrust overload conditions and corresponding torque levels.

The LTAFLA has been recently upgraded and validated to allow a more accurate evaluation of cumulative fatigue damage during a dynamic MOV closure stroke, for which the load does not increase as a linear ramp, as in the case of a static stroke. The upgrade also includes thrust-rating increase tables and enhanced user friendliness. The new version is compatible with

Windows 2000/XP. The LTAFLA Software is an important element of the technical approach to be used under the EPRI Limitorque Actuator Life Extension Program.

2.5 NRC Interaction and Resolutions of NRC Comments/Concerns

Based on the consensus of the sponsoring utilities, the Limitorque Actuator Thrust Rating Increase Program results were presented to the NRC at their offices in Washington, D.C. in April 1992. NRC issued the minutes of the meeting to the utility Project Manager, Duke Power Company, along with their comments, questions and concerns. NRC also issued an Information Notice 92-83, *"Thrust Limits for Limitorque Actuators and Potential Overstress of MOVs"*. The Duke Power Company project manager, and Kalsi Engineering prepared and submitted a detailed response to the NRC questions and concerns in January 1993 on behalf of the sponsoring utilities. This response satisfactorily addressed and resolved all of the NRC concerns, thus permitting the implementation of the Limitorque Actuator Thrust Rating Increase Program results within the recommended applicability requirements and limitations by all of the sponsoring utilities.

Table 2-1. Summary of Torsional Components Predicted and Experimental Fatigue Life Data Used to Validate the LTAFLA Software

Torsional Component	Average Test Torque (% of Rating)	No. of Cycles to Failure In Test	Predicted No. of Cycles to failure	Ratio Test/Prediction
SMB-000				
8620 worm	117	755	610	1.24
4320 worm	117	2,458	2,039	1.21
4320 worm	117	1,648	2,039	0.81
Worm shaft	106	4,870	4,818	1.01
SMB-00				
Worm	96	3,774	3,767	1.01
Worm Shaft	96	none (>4000)	10,430	*
SMB-0				
Worm	104	none (>4000)	none	*
Worm shaft	104	none (>4000)	7,400	*
SMB-1				
Worm	141	none (>4000)	none	*
Worm shaft	141	none (>1974)	1,178	>1.67
Worm shaft	141	1167	1,178	0.99
Worm shaft	141	714	1,178	0.61
SMB-2				
Worm	113	none (>4000)	none	*
Worm Shaft	113	none (>4000)	none	*
Average, for all tests	NA	2,198	2,233	0.98
Range, for all tests	NA	755-4,870	610-4,818	0.61-1.67

*No failure encountered during 4000 cycle testing, therefore, ratio can not be calculated.

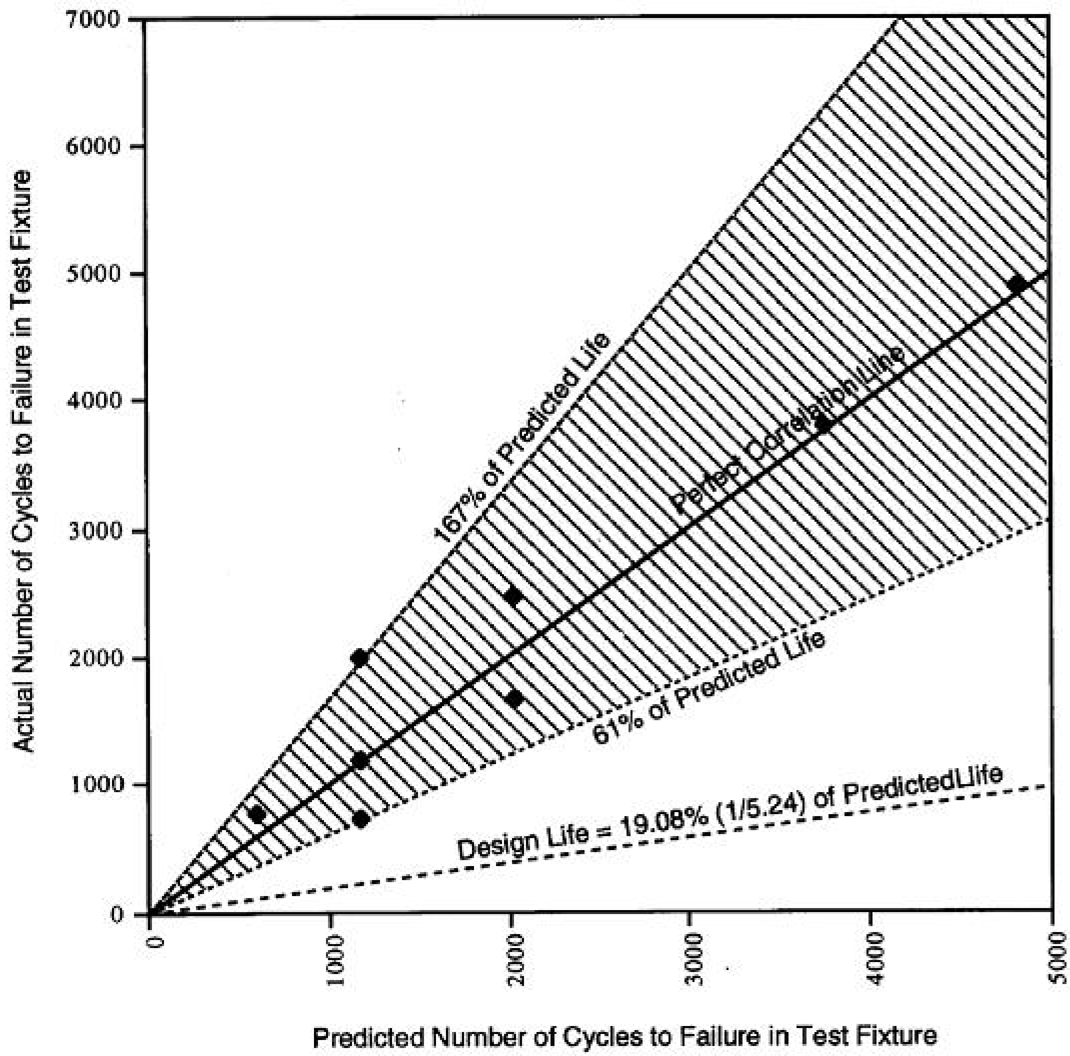


Figure 2-9

LTAFLA Software Predictions were Validated against Test Data for Fatigue Life (both failure and no-failure data), and Allowable Design Life of Actuator Torsional Components

3

METHODOLOGY FOR LIFE EXTENSION

3.1 Purpose

This section defines the “roadmap” that was developed to meet the industry goal of qualifying the operation of Limitorque Actuators to at least 3,000 cycles, corresponding to a plant life extension of 60 years. A key goal of this project was to utilize the results of the previous tests performed under Limitorque Actuator Phase I and Phase II programs, and extend them by appropriate, technically defensible analytical approaches, if possible. The objective was also to identify if any additional testing is needed to supplement the analytical methodologies to meet the Life Extension goals.

3.2 Overview of the Technical Approach

The applicable industry standards for qualifying actuators were reviewed, along with the original Limitorque Corporation’s qualification reports available to Kalsi Engineering, Inc. (KEI) from the previous test program [1 through8]. KEI reports [9 through18] documenting the test results, analytical methodologies and software to predict Limitorque Actuator Life under overthrust and overtorque conditions were reviewed in detail to identify the technical issues to be addressed to meet the scope of the actuator life extensions goal defined by EPRI’s Technical Advisory Group during the kick-off meeting.

The overall qualification of the Limitorque Actuators for plant life extension will rely on the mechanical aging (i.e. fatigue life prediction wear) of the actuators based on the overload cyclic testing data, seismic qualification testing data, analytical methodologies and the validated LTAFLA Software developed under Phases I and II of the previous industry program.

Analytical approaches employed will include classical strength of materials structural stress analysis, finite element analyses, conventional fatigue analysis and fracture mechanical analyses for various thrust-related and torque-related actuator components. For the larger actuator sizes, SMB/SB/SBD-3 and –4 that were not previously tested under the earlier industry sponsored rating increase program will be qualified by using analytical methodologies that are validated against all the available test data from the earlier test programs [9 through 17], as well as stall test data for SMB-000 through SMB-4 actuators documented by Limitorque Corporation [21]. The validated analytical methodology for predicting fatigue life of torsional components can be used to provide reliable predictions for the torsional components of SMB-3 and SMB-4 actuators. The thrust components (i.e. the actuator housing, the housing cap, the drive sleeve) will be qualified by performing finite element analysis, fatigue and fracture mechanics analyses of the SMB-1, -2, -3 and –4 actuators. The reason for including the SMB-1 and SMB-2 actuators is that they belong to the same family of actuators as SMB-3 and SMB-4; and test data under different thrust levels and number of cycles for SMB-1 and –2 failed and no-failed actuators are available from the KEI test reports [9 through17], as well as Limitorque Corporation test report [21]. After the analytical predictions are validated for SMB-1 and –2, the same validated analytical approach can be extended to qualify SMB-3 and –4 under extended life goals.

The Seismic qualifications will be extended to SMB-3 and SMB-4 actuators as well as SB and SBD type actuators based on using the "Combined Analysis and Testing" approach permitted by Section 4 of the applicable seismic qualification standard IEEE-344 [3].

Environmental qualification of the non-metallic, age-sensitive components subject to thermal and radiation related degradation is outside the scope of this life extension project. Individual plants will have to review their design basis requirements and Limitorque Corporation's original generic environmental qualification report to determine if the extended life requirements are met by the original qualification. An example calculation provided by one of the technical advisory group members for Duke Power Corporation showing that the Oconee's plant requirements were satisfied by this approach, is included in Appendix A.

In addition to the structural, fatigue, seismic qualification and environmental aging concerns, the actuator life extensions methodology will also provide guidance to the utilities for preventive maintenance component inspections and/or replacement based upon a detailed review of the periodic disc assemblies inspections, replacements (of certain wear components) that were performed during Phase I and Phase II testing.

The details of the methodology are discussed in the following sections.

3.3 Discussion of the Life Extension Methodology Approach

3.3.1 Review of Qualification Standards

For nuclear power plant applications, Limitorque Corporation generically qualified their actuators for inside and outside containment safety-related service. The results of those tests are documented in Limitorque LC-40 5/80 [5]. That document qualifies the actuators for 40 years and 2,000 cycles and it cover Limitorque SMB, SB and HBC actuators with three phase A.C. motors and D.C. motors. The qualification scope is not applicable to SBD type actuators, but it does include SMC-04 and SMC-05 actuators based on their similarity to SMB actuators.

More specifically, the three phase AC motor design actuators were qualified per IEEE 323, IEEE 344, and IEEE 382 per Limitorque Test Report 600376 for BWRs and Test Report 600456 for PWRs. DC "RH" design actuators are qualified per IEEE-323 and IEEE-32 per Limitorque Test Report B0009. These reports, along with other relevant Limitorque reports will be reviewed in detail under the scope of the life extension project.

The specific revisions of the IEEE standards applicable to the original generic qualification by Limitorque Corporation are:

IEEE Std 323-1974, *IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations*

IEEE Std 382 -1972, *IEEE Trial-Use Guide for Type Test of Class I Electric Valve Operators for Nuclear Power Generating Stations*.

IEEE Std 344 -1975, *IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*.

Since original qualification, the above mentioned standards have been significantly revised and the current revisions are IEEE 323-1987, IEEE 382-1996, and IEEE 344-2003. For the life extension project, the original qualification standards will be used to determine the analysis and testing requirement for extending the life of the actuators. This is based upon feedback from the Technical Advisory Group members for this project regarding the revisions of these standards applicable to their plants.

In addition to the above standards, the EPRI Agreement imposes requirements of 10CFR50.49, *Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants* [4]. These requirements are general and they do not impose any quantitative criteria; only qualification guidelines are provided. 10CFR50.49 references IEEE-323-1974 for its definition of "Class 1E" safety-related electric equipment.

3.3.2 Survey of MOV Valve & Actuator Plant Data

As discussed in Section 2.3.1 and Figure 2-3, there is a fundamental difference in parameters that influence the fatigue life of the *thrust* related and *torque* related components. The thrust components are subjected to only a single force cycle (or stress cycle) for each cycle of MOV operation. In contrast the torsional components (e.g. worm and worm shaft) are subject to multiple force and stress cycles for each cycle of MOV operation. These multiple revolutions subject the torque carrying components to varying number of stress cycles and varying degrees of stress amplitudes. The parameters that influence the number of stress cycles and stress amplitudes on the torque carrying components are:

- actuator model: SMB, SB, SBD
- worm to worm gear ratio
- motor pinion and worm shaft gear
- valve type and stiffness
- stem thrust history: static stroke or dynamic stroke (pump flow, high flow, blowdown)
- stroke length
- spring pack stiffness

In order to determine allowable torque levels and corresponding number of cycles for the torque related components for different categories of applications, data will be obtained by performing a survey from nuclear power plants in different categories of MOV applications.

Kalsi Engineering will specify the data that needs to be gathered and will perform the necessary calculations after receipt and review of the test data. The analyses will be performed using the LTAFLA software, which was developed under Phase II of the industry-sponsored program and was validated against test data as discussed in Section 2.4.2 and 2.4.3. Additional validation of the software against any new test data will be performed within the scope of the life extension project.

3.3.3 Existing Test Data

As described in Chapter 2, Kalsi Engineering has test data for SMB-000 and SMB/SB-00 through SMB/SB-2 actuators. These test data do not cover the SMB/SB-3 and SMB/SB-4 actuators. No industry test data are available for the SB-00 and SBD type actuators of any size.

In addition to the data available from the industry sponsored program conducted by KEI, overload thrust data are available from Limitorque Corporation for several SMB actuators. Limitorque has performed overload testing on SMB-000 through SMB-4 actuators and the results of these tests are given in Table 3-1 [21]. Additional controlled test data that may be available from nuclear power plants will be taken into account in developing and validating the life extension methodology. It is recognized that there have been some failures of Limitorque actuators in the operating plants. However, those failures are generally due to undocumented, "un-controlled" overload conditions during plant operations (e.g. resulting from use of cheater bars) that cannot be used for validating the life extension methodology. Under the life extension project, detailed root cause analysis reports available from these plants will be obtained and reviewed to ensure that the recommendations take into account the lessons learned from these failures.

Table 3-1
Summary of Actuator Stall Tests Conducted by Limitorque Corporation

Unit Size	Thrust Rating	Tested Thrust Load	Load Rating Ratio	Damage
SMB-000	8,000	27,000	3.4	Housing cover failed
SMB-00	14,000	44,400	3.2	None
SMB-0	24,000	70,700	3.0	None
SMB-1	45,000	178,378	4.0	Housing cracked
SMB-2	70,000	207,462	3.0	Housing cracked
SMB-3	140,000	540,953	3.9	Housing cracked
SMB-4	250,000	648,562	2.6	Housing cracked

3.3.4 Thrust-Related Components Issues to be Addressed for Life Extension

1. During industry-sponsored Phase I and II Program conducted by KEI, the seismic tests were performed on the SMB-000 through SMB-1 actuators at the end of 2,000 opening and closing cycles. IEEE Standard 382-1972 specifies that the actuator be subjected to the following sequence of conditions to simulate the design basis service conditions, that is, (1) aging, (2) seismic, and (3) accident or other special environment, as applicable. The aging simulation includes effects of environment (temperature, humidity, nuclear radiations, and contaminants), voltage stress, and mechanical stresses and wear (starting forces, vibration, and driven load). This requires that the seismic qualification loads be applied after the mechanical aging ,or cycling. However, it is important to note that for determining the affect of mechanical stresses of various levels and number of cycles on fatigue life of a

component, the ASME Section III paragraph N32242.4, *Analysis for Cyclic Operation*, does not impose a sequence of load history when calculating the cumulative fatigue usage factor [19]. Thus it is possible, within the guidelines of ASME Section III, to assign the fatigue damage due to seismically induced loads at any time during analysis or testing without influencing the total fatigue usage factor. Furthermore, it is anticipated that stresses in the actuator components due to seismic loads will be relatively smaller in magnitude as compared to stresses due to 200% thrust overload.

2. Cycle test data are not available for the SBD type actuators of any size. The design life of this additional configuration will need to be determined either by analysis, testing, or a combination. The configuration of these components is relatively simple and amenable to reliable quantification by structural analysis. This evaluation should include the effects of the additional mass on the seismic qualification.

3. The initial test of the SMB-2 actuator did not successfully complete 2,000 cycles at 200% of rated thrust and was thus never stall tested or seismically tested. A second test was performed as discussed in Section 2.4.1 in which the SMB-2 Actuator was cycle tested for more than 5,000 cycles at a thrust level of approximately 145% of the rating. The test report for the second test on the SMB-2 actuator was never finalized. The documentation of these tests will need to be formally completed so that it can be properly utilized in the life extension program.

4. The SMB-2 actuator was not seismically tested and it will need to be seismically qualified in accordance with IEEE Standard IEEE 382 and IEEE 344. The IEEE 344 Standard permits a Combined Analysis and Testing Approach to qualify components that belong to the same group.

5. The SB compensators were tested in a fixture with no rotation imparted to the thrust bearings. The bearing life under the desired thrust rating will need to be analytically determined by the empirical equations for bearing dynamic life under various load levels.

6. The SMB-3 and SMB-4 actuators were not cycle tested under the industry sponsored program conducted by KEI. Kalsi Engineering has information related to stall testing performed by Limitorque Corporation on these actuators as summarized in Table 3-1. These data for failure loads of SMB actuators can be used in validating the predictions based upon analysis.

3.3.5 Torque-Related Components Issues to be Addressed for Life Extension

During Phase I and II of the industry-sponsored program, the torque-related components of the actuator experienced fatigue failure during testing, as summarized in Section 2 and Table 2-1. It should be noted that the loading on the torque related components was significantly above the torque ratings on two of the actuators. The actual levels of loading on the torque related components was different for each actuator, and it ranged from 96% to as high as 141% of the rated torque based on actual gear ratios and motor sizes that were used in the test actuators (for the same Limitorque actuator size, different OAR have different torque ratings). Data on the worm and worm shaft failures show that fatigue life increases significantly under lower torque levels as is shown for the SMB-000 actuator which was retested in Phase II [14]. The validated LTAFLA Software properly takes into account the differences between test conditions and correctly predicts the increased fatigue life.

It is important to note that only one overall gear ratio (OAR) was used any one size actuator. This means that only one worm-to-worm gear ratio was tested for each size, although there are several other worm ratios available within each actuator size. Table 3-3 lists all the worm ratios and motor and worm shaft pinions available for each size and the worm ratio tested.

The motor pinion key failures in SMB-0 encountered during the industry-sponsored testing were found to be due to weak key material, as reported in NRC Information Notice No. 90-37, *Sheared Pinion Gear-to-Shaft Keys in Limitorque Motor Actuators*. Based upon the recommendations by Limitorque contained in this notice, the key material in the SMB-0 actuator was changed to a higher strength alloy steel, (4140 steel). This change eliminated the key failures encountered during the industry-sponsored testing.

Table 3-2
Summary of Gears Sets for SMB Actuators

Model	Motor Teeth Range	Pinion Teeth Range	Available Worm Set Ratios	Worm Set Ratio Tested
000	27-15	18-30	18-2/3, 50, 68	50:1
00	43-19	22-46	19, 45, 76	45:1
0	42-20	30-52	15-2/3, 37, 58, 95	37:1
1	40-20	32-52	14-1/2, 34, 66, 90	34:1
2	39-20	31-50	13.3, 33, 60, 85	33:1
3	32-18	28-42	13-1/3, 16, 41, 57, 80	no test
4	40-20	32-51	12-2/3, 19, 49, 58, 86	not test

3.3.6 Torque Related Components Issues to be Addressed for Life Extension

1. The selection of the design margins between predicted failure and design life can vary significantly. A margin of 5.24 based on ASME Section III, Appendix 2 testing approach has been used by KEI when test data are available for the specific worm geometry [19]. When the worm geometry is different than that tested, then KEI has used a margin of 20 based upon analytical methodology criteria of ASME Sections III and VIII, Division 2 [20]. These two approaches are based on ASME Section III criteria, but other industry approaches are also available that can be used for actuator margins since the applicable qualification standards specify no margin between test conditions and allowable design conditions. Under life extension project, other industry approaches will be reviewed in detail and appropriate selection of the margin to be used will be made.

2. The current methodology does not address motor pinion stresses since this had not been identified as a critically stressed location/weak link based on the past industry experience. The tests performed under Phase I and II of the industry-sponsored program were conducted on only specific worm set ratio as summarized in Table 3-3. The methodology will need to be enhanced to include the motor pinion evaluation so that the methodology is applicable for all motor/worm shaft pinion combinations.

3. Significant wear of the worm gear was observed only on the SMB-000 actuator during the Phase I and Phase II of the industry-sponsored program. However, wear data for worm gear wear for other actuator sizes will need to be reviewed to determine if wear is an issue and to develop appropriate preventive maintenance recommendations for all worm geometries and actuator sizes.
4. Geometry and material data of the torque carrying components was developed as part of Phase I and II testing. Currently KEI has only limited geometric data and no material data for the SMB-3 and SMB-4 actuators. These data will need to be developed by performing dimensional inspections or obtained from Limitorque Corporation.
5. Rolling element and journal bearings that support the worm and worm shaft were subjected to a specific motor speed and side load based on the motor and worm shaft pinions and the delivered torque. The effect of pinion ratios on bearing life will need to be assessed by using empirical equations provided by the manufacturers of these bearings.
6. Limitorque actuators are available with 1800 and 3600 rpm motors. All industry-sponsored cycle testing conducted by KEI used the 1800 rpm motors. The motor difference can have an effect on the seismic qualification (weight increase), impact loads on the clutch and drive sleeve, and life of the bearings. Analysis will be performed to address the differences in the weight and center of gravity on the seismic qualification.
7. Only the highest stiffness spring pack was used during actuator testing to achieve the thrust overload conditions tested in the industry-sponsored program. The effect of cycling on the other spring packs of each actuator will need to be evaluated in the life extension project.

3.4 Analysis Approach for Life Extension

Life extension of actuators which have already been cycle tested by Kalsi Engineering will require that some analysis be performed to address the issues previously identified with the thrust and torque components. Analysis can also be used to determine the life of the SMB-3 and SMB-4 actuators, which have not been cycled tested. A combination of finite element analysis, classical strength of materials analysis, fatigue and fracture mechanics analysis would be employed for the thrust components while the previously validated software LTAFLA would be used to predict the design life of the torque components. The effect of seismic excitation is discussed separately because that evaluation will be required regardless if the actuators are qualified by analysis or testing.

3.4.1 SMB Thrust Components

The SMB components that are subjected to stress as a result of applied thrust are the housing, housing cover, drive sleeve, the stem nut retainer, thrust bearings, the housing cover and mounting fasteners; the stem nut is excluded. All of these components except the housing lend themselves to closed-form solutions or to simple axis-symmetric finite element analyses. Because the housing has an irregular shape it will need to be evaluated using three-dimensional finite element techniques.

One of the more difficult characteristics to determine for any of the analysis approaches is to quantify the mechanical properties of the materials. Except for the stem nut retainer, the materials of construction are either cast iron or ductile iron. Material data are available from literature for the different material grades of these cast materials but their performance in these irregular shapes will be validated by performing analysis of sample actuators for which static overload and cyclic test data exist. For validation purposes, it is proposed that analysis be performed for two different actuator sizes tested within the scope of Phase I and Phase II to validate analytical predictions against actual performance of both failed and not failed actuators. SMB-1 and SMB-2 actuators will be selected for this purpose because failure overload data to cause failure for these two actuators are also available from Limitorque Corporation .This validated analytical methodology would then be used to qualify the SMB-3 and SMB-4 actuators, that belong to the same design family, for life extension program.

The SMB-3 and SMB-4 actuators belong to the same design family as the SMB-0, SMB-1, and SMB-2 actuators. Since KEI has direct experience with failed and non-failed SMB-2 actuators, the SMB-2 actuator would be one of the actuators that would be analyzed. The other actuator can be either the SMB-0 or SMB-1. Using the larger size actuator would offer a better comparison because it would offer a closer match to the inherent casting attributes associated with making these large parts. The components that would be analyzed to obtain validation data include the housing, housing cover, and drive sleeve.

The following technical approach is recommended for the finite element analyses.

1. Dimensionally inspect the component of actuators already tested, paying particular attention to the geometric discontinuities and fillet radii.

2. Gather material property data.

3 Develop the three-dimensional FEA models.

4. Perform linear elastic static analysis to determine the overall structure strength

5. Using the linear elastic static analysis, select the location(s) of highest peak stress and perform fatigue/fracture mechanics analyses to determine failure life.

6. Compare the analytical predictions to the actual test data (KEI, Limitorque, & industry) to validate the methodology, and if necessary, refine the analytical methodology..

7. Using the same approach as outlined in Steps 1 through 5, perform analyses of the SMB-3 and SMB-4 actuators. The geometric data for these two actuators will need to be developed by performing dimensional inspections or obtained from Limitorque Corporation.

3.4.1.1 Parametric Analysis to Address SMB Thrust Component Analysis Assumptions

Using analysis techniques to determine the structural strength and design life of the SMB-3 and SMB-4 actuator thrust components will require certain assumptions. A matrix parametric analyses will be performed to address the effect of these assumptions on the predicted fatigue life. Appropriate margins will be applied to bound the effect of these assumptions and ensure comfortable margins between fatigue life and allowable design life in the plant. The matrix of analysis will include evaluation of the following assumptions/parameters:

1. Initial flaw size in the casting critical sections.

2. Homogeneity of material properties.
3. Geometric/dimensional variances
4. Actual material properties versus published values
5. Non linear behavior of mechanical properties (e.g. modulus of elasticity, Poisson's ratio) in tension as compared to compression and the effect of stress on Poisson's ratio.
6. Margin to be used between failure and design.

3.4.2 SB/SBD Compensator Thrust Components

The SB and SBD compensator are added to the SMB gear boxes to provide additional axial structural flexibility of the MOV in the closing and opening direction and are subjected primarily to load in the axial direction. The only rotary components that would need to be analyzed would be the thrust bearings.

The SB compensators need only be qualified in the closing (downward) direction because it shares the same type components with the SMB in the opening (upward) direction and the SMB actuators have been tested or analyzed in both directions. SB compensator components will be qualified for life extension to 3,000 cycles by performing analysis.

No SBD compensators have been cycle tested by Kalsi Engineering and no cycle data are presently available. The compensator housing for the SBD is comprised of an upper section and a lower section. The upper section is the same as the SB and the lower section is a cylinder, which simply makes the assembly taller. Because of the simplicity of the lower housing, it can be easily analyzed. The SBD compensators appear to have the same Belleville springs as used in the SB compensators but the carriers that transmit the axial load from the stem nut to the spring assembly are different. These load carriers are simple axis-symmetric structures and can easily be analyzed using closed-form solution methods or using simple FEA models.

3.4.3 *SMB/SB/SBD Torque Components*

The components that transmit torque are the same within the three types of actuators (SMB/SB/SBD) and of axis-symmetric shapes, which lend themselves to much easier closed-form solutions and to analysis using LTAFLA. Secondly the materials of construction for the critical torque carrying components are carbon and alloy steels, materials having well defined and predictable mechanical properties. It is expected that solutions obtained using LTAFLA can be faithfully relied upon since the assumption are minimal.

It is important to note that there are many more configurations that would require evaluation because of the large number of different gear ratios possible. As shown in Table 3-2 there are at least three different worms for each actuator size and an even larger number of pinion combinations.

In addition to the number of geometry variations of the actuators, the design life of the actuator, in terms of valves strokes, is also highly dependent upon the number of worm revolutions under load. The number of worm revolutions under load is dependent upon the valve stiffness, the actuator type (SMB, SB, SBD), the stem thrust (static vs. dynamic) history, and the spring pack response. The number of combinations would be immense but bounding values of these parameters can be used to bracket the design life.

The matrix of torsional fatigue life analysis predictions to provide useful guidelines is estimated to be over 300. These analyses will account for all the key design parameters for the 7 SMB/SB/SBD actuator sizes. Based on the plant survey data obtained as described in Section 3.3.2. The MOV stiffnesses obtained from review of the plan data for gate and globe valves of different designs will be used to broadly categorize and define 3 stiffnesses for torsional fatigue evaluations for each MOV actuator size. The matrix of analyses will include 3 MOV stiffness, 3 to 5 different gear ratios based on actuator size, and application parameters (static stroke operation, and dynamic stroke operation with DP profile for 3 different flow velocities). The analyses will be performed by using the most current version of the LTAFLA software, which will be revised under the life extension program to address motor pinions as another potential critically stressed component for fatigue life evaluation.

3.4.3.1 Torque Components Analysis Limitations

The current LTAFLA software can be used with a high degree of confidence to determine the fatigue life of the worm and worm shaft. The software does not address the wear that might occur in the worm, worm gear, and bearings. Wear evaluation and preventive maintenance/component replacement recommendations for components that are likely to experience high wear rates will be based upon test data obtained under Phases I and II of the industry-sponsored actuator test program.

For performing LTAFLA analyses, additional dimensional and material information will need to be obtained for the torsional components. At present KEI has the needed information for the helix dimensions for all the worm geometries of the subject actuators. The remaining data will be obtained either from Limitorque Corporation or from measurements of actual components. In particular the following additional data, as a minimum, are required:

- Worm shaft dimensions
- Worm internal spline dimensions
- Worm/worm shaft bearing location
- Worm to worm shaft interfaces
- Localized geometry discontinuities and blending radii
- Motor pinion dimensions.
- Worm shaft bushing dimensions

3.5 Testing Option for Qualifying SMB-3 and SMB-4 Actuators

Even though SMB-3 and SMB-4 actuators, which are part of a Limitorque actuator family of SMB-0, -1, -2, -3, and –4 actuators can be qualified by analyses, testing provides the most reliable means of qualifying that the actuator life for extended life goal of 3,000 cycles. Even when the testing option is pursued, and the test results can completely qualify the thrust carrying components without any supporting analysis, torsional component analyses must still be performed to determine their fatigue life, simply because it is not economically feasible to test every gear combination.

Cyclic test data for the qualification of SMB-3 and SMB-4 actuators are not available either from Limitorque Corporation or from other industry sources. Therefore, under this option, these two actuators will be cycle tested in order to extend their life to 3,000 cycles. To accomplish this test new fixtures of a larger load capacity than the previously available test fixtures will be designed and built. The following test sequence is proposed:

1. 3,000 cycles at 147% of thrust rating in the open and close directions. The value of 147% is selected based on the ASME Section III, Appendix 2 criteria for design margin between test load and design load [19].
2. 5 stalls in the open and close directions

For these actuators the gear ratio and stem thread geometry will be selected so that the applied torque will be at or slightly below the torque rating at the target thrust. It is not the intent of this test to purposely cause any failure of the torque components. However, if torque components do fail, they will be replaced and testing will continue until the extended life goal has been achieved or a thrust component fails.

Like the SMB-2 actuator, seismic testing of the SMB-3 and SMB-4 actuators is not planned. These actuators will be seismically qualified by using the analyses approach combined with previous testing of actuators performed belonging to the same design family under the industry-sponsored project.

3.6 Seismic Analysis of SMB/SB/SBD Actuators

Limitorque SMB-000 through SMB-1 actuators were previously qualified by testing and it is expected that no additional analysis are required for qualification to 3,000 cycles. This conclusion is based on the interpretation of ASME Section III paragraph N32242.4, *Analysis for Cyclic Operation*. Paragraph N32242.4 does not impose a sequence of load applications when calculating the cumulative fatigue usage factor [19].

None of the SB/SBD actuators were seismically tested within the scope of the Kalsi Study. The effect of the added mass of the compensators is to increase the stresses in the gear box but it is expected that the additional stresses will be small in comparison to the stresses caused by thrust and torque delivered by actuator operation. Similarly, it is expected that the seismically induced stresses on the internal components of the SB and SBD compensator will be small in comparison to those caused by the actuator operating loads. The stresses due to seismic effects, however, will need to be quantified and appropriately combined with stresses from the operating loads.

The SMB-2 actuator that was previously thrust and torque tested under the Kalsi Study was not seismically tested and it is not proposed that the SMB-2 nor SMB-3 and SMB-4 actuators be seismically tested. These actuators will be seismically qualified by using the optional Combined Analyses and Testing Approach permitted under the IEEE 344 standard [3]. This standard permits qualification of a family of actuators based on a test of a representative sample. An evaluation however will need to be conducted to ascertain that these actuators do belong to the same family. Stress analysis will be performed for these actuators, however, they will be limited to the actuator mounting interface and the electric motor mounting interface.

4

ANTICIPATED RESULTS

A review and preliminary evaluation of the previous test data performed under the current project shows that the Limitorque actuators are capable of operating at higher than rated thrust and torque for more than 2,000 cycles. The evaluation shows that the rating can be extended to 3,000 cycles at the current thrust rating or at some thrust level higher than their ratings depending upon the actuator size, model and the MOV application specific conditions. However, for some of the smaller actuator sizes, possibly SMB-000, the torque levels may need to be somewhat lower than the published ratings in order to achieve the extended life goal under severe application conditions. As an alternative some of the torsional components may need to be replaced based on the severity of the application conditions.

4.1 Extended Thrust Rating

Pending resolution of the technical issues outlined and completing all the analyses identified in Section 3, the following thrust design life looks feasible based on the current available data for SMB-000 through SMB-2 actuators. No data are available to determine life expectancy of the larger SMB-3 and SMB-4 actuators.

Table 4-1
Summary of Potential Thrust Design Life of SMB Actuators that can be achieved under the Life Extension Project

Actuator Size	Allowable Cycles	Allowable Thrust, % Rating
SMB-000	3,000	145%
SMB/SB/SBD-00 to SMB/SB/SBD-1	3,000	145%
SMB/SB/SBD -2	3,000	112%

4.2 Extended Torque Rating

The design life of the torque carrying components can not be as easily determined from test data without performing extensive analysis to address the effects discussed earlier in Chapter 2, such as worm ratio, MOV stiffness, stem thrust load profile, etc. A sample of what can be achieved for a *static stroke* and using one gear ratio in each size is given in Table 4-2. The results shown in Table 4.2 are for a specific valve/actuator stiffness and actuator gear ratio and using a design margin of 5.24 between predicted failure and allowable design life. This margin of 5.24 is based on Appendix 2 of ASME Section III and is based on actual testing [19]. Other appropriate margins based upon conclusions under the life extension project will be used in developing the final recommendations. Based on these preliminary analyses, the actuators, except for the SMB-000 and SMB-00, were found to be capable of operating for 3,000 cycles at the rated torque. To achieve a design life of 3,000 cycles from torsional components without replacement in the SMB-000 and SMB-00 actuators, the allowable torque may have to be decreased to 90% of the rating.

The configurations shown in Table 4.2 are based upon representative valve installations for which Kalsi Engineering has performed design fatigue life analyses in the past.

Table 4-2
Applied Torque Limits to Achieve a Design Life of 3,000 Cycles for SMB Actuators Under Static Closing Stroke Conditions
(Life can be significantly less under DP strokes)

Actuator Size	Rated Torque ft-lb	Applied Torque ft-lb	Overall Gear Ratio	Valve Stiffness lb/Inch
SMB-000	90	80	62.5	107,000
SMB-00	250	225	67.5	237,000
SMB-0	500	500	46.25	311,000
SMB-1	850	850	40.15	425,000
SMB-2	1800	1800	95.5	530,000

5

ESTIMATED COST AND SCHEDULE

Estimated Cost

Based on the scope of work defined in this roadmap the estimated cost to complete the project will be dependent upon the methods used to qualify the actuators for extended life. Cost savings can be realized by using analysis techniques extensively and including some limited testing on the SMB-000 through SMB-2 actuators. The uncertainties associated with analyses techniques are given in Chapter 3.

Cycle testing the SMB-3 and SMB-4 actuators will increase the project cost moderately but will yield extremely reliable data for determining the extent of life extension and will provide an additional validation data point for qualifying the torque components. As can be seen, substantial analyses of all actuators will be required regardless of the method used to qualify the SMB models of these large actuators.

The technical scope and the related estimated costs for these two general approaches are listed below.

OPTION	**Estimated Cost**
Option 1: Using analysis to qualify the design life of the SMB-3 and SMB-4 actuators, the following tasks will be performed Project administration Perform analyses to qualify the cycle life of the SBD-00 through -2 spring compensators Perform analysis to seismically qualify the SB/SBD-00 through -2 actuators Perform analysis to qualify the cycle life of the SMB-3 and -4 actuators Perform analysis to qualify the cycle life of the SB/SBD-3 and -4 compensators Perform analysis to seismically qualify the SMB/SB/SBD-3 and -4 actuators Perform analyses to develop generic life predictions for torque components of all actuator	To be provided separately

Option 2: Using testing to qualify the design life of the SMB-3 and SMB-4 actuators, the following tasks will be performed Project administration Perform analyses to qualify the cycle life of the SBD-00 through -2 spring compensators Perform analysis to seismically qualify the SB/SBD-00 through -2 actuators Perform testing to qualify the cycle life of the SMB-3 and -4 actuators Perform analysis to qualify the cycle life of the SB/SBD-3 and -4 compensators Perform analysis to seismically qualify the SMB/SB/SBD-3 and -4 actuators Perform analyses to develop generic life predictions for torque components of all actuator	To be provided separately

Schedule

The schedule to complete the entire project, including NRC interaction, is estimated to be between two and three years.

6

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22. Shigley, J. E., and Mitchell, L. D., *Mechanical Engineering Design*, Fourth Edition, McGraw-Hill Book Company, New York, 1983.

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A

APPENDIX

AN EXAMPLE CALCULATION OF ENVIRONMENTAL QUALIFICATION LIFE ANALYSIS FOR LIMITORQUE MOTOR-OPERATED VALVES

Form 01077 (R7-92)

Form 101.1 Revision 14

CERTIFICATION OF ENGINEERING CALCULATION

STATION AND UNIT NUMBER - Oconee Nuclear Station - Units 1, 2, and 3

TITLE OF CALCULATION - Qualified Life Analysis for Limitorque Motor Operated Valves

CALCULATION NUMBER - OSC-7167

ORIGINALLY CONSISTING OF:

PAGES 1 THROUGH 3

TOTAL ATTACHMENTS - 3 TOTAL MICROFICHE ATTACHMENTS - 0

TOTAL VOLUMES - 1 TYPE 1 CALCULATION/ANALYSIS YES [ ] NO [x]
TYPE 1 REVIEW FREQUENCY -

THESE ENGINEERING CALCULATIONS COVER QA CONDITION **1** ITEMS. IN ACCORDANCE WITH ESTABLISHED PROCEDURES, THE QUALITY HAS BEEN ASSURED AND I CERTIFY THAT THE ABOVE CALCULATION HAS BEEN ORIGINATED, CHECKED AND APPROVED AS NOTED BELOW:

ORIGINATED BY____________________ DATE________________

CHECKED BY____________________ DATE________________

APPROVED BY____________________ DATE________________

ISSUED TO TECHNICAL SERVICES DIVISION__________ DATE________________

RECEIVED BY TECHNICAL SERVICES DIVISION__________ DATE________________

MICROFICHE ATTACHMENT LIST: [ ] Yes [X] No SEE FORM 101.4

REV. NO.	CALCULATION PAGES (VOL.) REVISED/DELETED/ADDED	ATTACHMENTS (VOL) REVISED/DELETED/ADDED	VOLUMES DELETED/ADDED	ORIG DATE	CHKD DATE	APPRD DATE	ISSUE DATE REC'D DATE
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A. **PROBLEM**: The Limitorque Motor Operated Vavles (MOV's) are used in the all areas at Oconee Nuclear Station. This analysis will document the qualified life of the MOV's in terms of thermal aging and radiation exposure.

B. **RELATION TO QA CONDITION**: Equipment covered by this calculation is QA Condition 1.

C. **DESIGN METHOD**: An analysis of the qualified life of the MOV's will be done using actual ambient condition parameters, including radiation, to demonstrate a qualified life in excess of 60 years.

D. **APPLICABLE CODES AND STANDARDS**:

1. IEEE Standard 323-1974, "IEEE Standard for Qualifying Class 1E Equipment for
Nuclear Power Generating Stations", December 13, 1973, Revision of IEEE Std.
323-1971 (ANSI N41.5-1971).

2. IEEE Standard 382-1972, "Trial-Use Guide for the Type-Test of Class 1 Electric
Valve Operators for Nuclear Power Generating Stations (ANSI/IEEE)

OTHER DESIGN CRITERIA: Duke Power Company NSD-303, Environmental Qualification Program.

F. **RELATED SAR CRITERIA**: Oconee FSAR, Section 3.11

G. **REFERENCES**:

1. Limitorque Valve Actuator qualification for Nuclear Power Station Service Report B0058 (OM-245-934 - Introduction to test report contained in Attachment 1)

   NOTE: Specific test reports noted in the body of this calculation are part of B0058. See Atta

2. "Clarification of information Related to the Environmental Qualification of Limitorque Motorized Valve Operators", Prepared by Nuclear Utility Group on Equipment Qualification, dated August 1989 (Page 57 contained in Attachment 2)

3. Oconee Environmental Qualification Master List (OLT-2870-03.01-01)

4. Oconee Nuclear Station Environmental Qualification Criteria Manual (EQCM).

5. Unit 2 1995 and 1996 Temperature Monitoring Average Temperatures (Attachment 3)

H. **ASSUMPTIONS**: None.

I. **CALCULATION**:

As stated in Attachment 1, extensive testing and analysis has been done on Limitorque MOV's over the years. Limitorque qualified their MOV's for inside and outside containment applications. The basic difference between the inside containment MOV and the outside containment MOV is the motor insulation class. The inside containment MOV's use Class H, RH and LR motor insulation and the outside containment MOV's use Class B motor insulation.

Inside containment MOV's are qualified under Limitorque test reports 600198, 600376A and 600456. Under these tests the MOV's were aged at 180°C for 100 hours. As stated on page 11 of Attachment 1, " ..ages the motor for 135 years based on 60°C average ambient temperature …". Per attachment 2, the RH motor insulation system has an Activation Energy (Ae) of 1.02 eV which is lower than or equal to the Ae's for all the material in the MOV's. Therefore, the other components were aged in excess of the 135 years. Per Attachment 3, the worse case inside containment average temperature is in the Steam Generator "B" compartment which had an average temperature of 135.67°F(57.59°C) for 1995. All Inside Containment MOV's are qualified in excess of 60 years with substantial margin. It should be noted that Inside containment MOV's are used in outside containment applications and are qualified in excess of 60 years also.

Outside containment MOV's were qualified under Limitorque test report B0003. Under this test report the MOV's were aged at 165°C for 200 hours. Since the Class B motor insulation is the limiting material, an Ae of .93 eV will be used in calculating the 60 year qualified life ambient temperature:

Arrhenius Equation - $t_1 = t_2\, e^{[(Ae/k)(1/T_1 - 1/T_2)]}$

Where:

t_1 = Qualified Life = 60 years
t_2 = Accelerated aging time = 200 hrs
Ae = Activation energy = .93 eV
T_1 = Ambient/Service temperature = ?
T_2 = Accelerated aging Temperature = 329°F(165°C) = 438.15°K
k = Boltzmann's Constant = 8.617E-5 eV/°K

Substituting:

60 years = 200 hours $e^{[(.93/8.617E-5)(1/T_1 - 1/438.15)]}$

T_1 = **58.87°C** = **137.96°F**

The worst case outside containment design ambient temperature is 122°F(50°C) and therefore the outside containment MOV's are qualified for 60 years with substantial margin.

RADIATION ANALYSIS

Per Reference 4, the worst case Reactor Building 40 year radiation dose is 3.0E7 rads. For 60 years the dose equals 4.5E7 rads. The worse case LOCA dose is 6.1E7 rads. The Total Integrated Dose (60 year normal dose plus accident dose) is 1.06E8 rads. The MOV's were tested and qualified to 2.04E8 rads under Reference 1.

Per Reference 4, the worse case outside containment 40 year radiation dose is 1.0E6 rads. For 60 years the dose equals 1.5E6 rads. The worse case LOCA dose outside containment is 6.0E6 rads. The Total Integrated dose (60 year normal dose plus accident dose) is 7.5E6 rads. Under B0003 the MOV's were tested and qualified to 2.0E7 rads.

J. **CONCLUSION**:

This calculation has demonstrated that the MOV's are qualified in excess of 60 years for their operating environment. The MOV's were also tested and qualified for the worse case radiation environment.

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