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MOV Stem Lubricant Aging Research

Idaho National Engineering and Environmental Laboratory

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Office of Nuclear Regulatory Research
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ABSTRACT

This report documents the results of recent tests sponsored by the Nuclear Regulatory Commission (NRC) and performed by the Idaho National Engineering and Environmental Laboratory (INEEL). These tests address the effectiveness of the lubricants used on the threaded portion of the valve stem, where the stem nut turns on the stem. Recent testing indicates that an elevated temperature environment can lead to significant increases in the friction coefficient at the stem/stem-nut interface. Most valve actuator qualification tests are performed at room temperature. Similarly, in-service tests are performed at ambient plant temperatures, usually 70 to 100°F. Since design conditions can lead to valve operating temperatures in the 200 to 300°F range, it is important to know whether a temperature-induced increase in friction at the stem/stem-nut interface will prevent the required operation of critical valves. Lubricant aging is another phenomenon that might have deleterious effects on the thrust output of a valve actuator. Laboratory experience and field experience both indicate that after long periods in elevated temperature environments, the lubricants may lose their lubrication qualities.

This research effort was performed to address the effectiveness of the lubricant used on the threaded portion of the valve stem. The effectiveness of this lubricant can greatly impact the thrust output of the valve actuator and reduce the margin for ensuring motor-operated valve (MOV) performance at design basis. Our analysis looked at the aged performance of two lubricants on one valve stem. It also looked at a new lubricant on one stem to determine its load and end-of-stroke friction behavior, elevated temperature, and aging performance. The following conclusions are based on this work.

- For Chevron SRI and Mobil Mobilgrease 28, lubrication aging does not appear to degrade the performance of stem and stem nut interface. For the single stem tested (Stem 2), the stem and stem nut friction did not increase during the aging period. In some cases, the final friction values for both the hot and cold tests were lower than the initial hot and cold values.

- On the single stem tested, the MOV Long Life lubricant's performance was similar or an improvement over that of other lubricants previously tested. MOV Long Life frictional performance, including end-of-stroke friction behavior, was stable and repeatable over a wide load range. Elevated temperature resulted in a lower friction coefficient than that observed at room temperature but resulted in greater rate-of-loading. Stem nut friction appeared to be stable over the simulated aging period.

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EXECUTIVE SUMMARY

During the past several years, the Nuclear Regulatory Commission (NRC) has supported research addressing the performance of motor-operated valves (MOVs) installed in nuclear power plants. This research included tests and analysis to determine the capability of safety-related MOVs to close (or open) when subjected to the conditions specified in the plants' design documents. For some safety-related MOVs, these design basis conditions include high flow and pressure loads, high temperature, and degraded voltage.

This report documents the results of recent tests sponsored by the NRC and performed by the Idaho National Engineering and Environmental Laboratory (INEEL) to address the effectiveness of the lubricant used on the threaded portion of the valve stem, where the stem nut turns on the stem. The effectiveness of this lubricant can impact the thrust output of the valve actuator and reduce the margin for ensuring the performance of the MOV. Recent testing indicates that an elevated temperature environment can lead to significant increases in the friction coefficient at the stem/stem-nut interface. Lubricant aging is another phenomenon that might have deleterious effects on the thrust output of a valve actuator. Laboratory experience and field experience both indicate that after long periods in elevated temperature environments, the lubricants may lose their lubrication qualities.

The tests described in this report evaluate the effects of lubricant aging on the performance of a stem and stem nut configuration that was typical of that used in U.S. nuclear power plants. The research set out to investigate how the coefficient of friction might change as the lubricant aged, using elevated temperature to accelerate the aging effect on the lubricant. These tests build upon the previous test results to evaluate the effects of lubricant aging and elevated temperature on stem/stem nut performance, and included three lubricants in common use for this application and one stem/stem nut combination. The following tests were performed.

- Additional temperature effects testing was repeated with one stem using an additional lubricant. The Nebula EP1 lubricant used in previous testing has been discontinued by Exxon and the industry is considering replacing it with the MOV Long Life lubricant. Additional temperature effects testing was performed on this MOV Long Life lubricant to provide a baseline for the Aging Effects testing, similar to that already obtained for the other greases.

- Testing of lubricants subjected to accelerated thermal aging was performed. Accelerated aging of three lubricants on a single stem was performed in place. A series of lubricant aging tests, simulating actual MOV operational strokes and flow isolation strokes was performed.

The tests were conducted on the INEEL's motor-operated valve load simulator (MOVLS), an instrumented test stand that provides dynamometer-type testing of valve actuators using load profiles that are very similar to the load profile a valve actuator would experience when closing a valve against a flow load. To support this research, the MOVLS was modified to produce simulated valve strokes with essentially no variation in the stem thrust profile between strokes over the duration of the testing. This allowed us to intermix valve strokes representing design basis conditions with valve strokes representing no or low load quarterly stroke testing and be able to reproduce consistent stem thrust profiles for each type of load.

For elevated temperature testing and accelerated aging of the stem lubricant, the valve actuator was wrapped in heat tape and insulated so as to control the actuator, valve stem threads, and stem nut at the temperature required for testing of the stem nut lubricant. The design configuration allowed operation of the valve actuator without disturbing the heater or insulation.

Test hardware including one valve stem and stem nut and one electric motor actuator. Stem 2 was selected based on its performance in our earlier research documented in NUREG/CR-6100 and NUREG/CR-6750. Our analysis looked at the aged performance of the two lubricants on one valve stem. It also looked at a new lubricant on one stem to determine its load and end-of-stroke friction behavior, elevated temperature, and aging performance. The following conclusions are based on this work.

- For Chevron SRI and Mobil Mobilgrease 28, lubrication aging does not appear to degrade the performance of stem and stem nut interface. For the single stem tested (Stem 2), the stem and stem nut friction did not increase during the aging period. In some cases, the final friction values for both the hot and cold tests were lower than the initial hot and cold values.

On the single stem tested, the MOV Long Life lubricant's performance was similar or an improvement over that of other lubricants previously tested. MOV Long Life frictional performance, including end-of-stroke friction behavior, was stable and repeatable over a wide load range. Elevated temperature resulted in a lower friction coefficient than that observed at room temperature but resulted in greater rate-of-loading. Stem nut friction appeared to be stable over the simulated aging period.

MOV Stem Lubricant Aging Research

1. INTRODUCTION

The effectiveness of the lubricants used in motor-operated valves (MOVs), particularly the lubricant used in the valve stem and stem nut interface, can impact the output of motor actuators and reduce the margin for ensuring the performance of MOVs. Recent test results (Reference 1) indicate that an elevated temperature environment can lead to significant increases in the friction coefficient at the stem/stem nut interface.

Lubricant aging is a phenomena that may have deleterious effects on the output of motor operators. Both laboratory and field experience indicate that after long periods in elevated temperature environments, the lubricants may become caked and lose their lubrication qualities. Caked lubricants will likely be more viscous, which may prevent the lubricants from flowing into the region between the threads of the valve stem and stem nut and result in higher friction coefficients. This may cause a reduction in the thrust available from a motor actuator thus resulting in the inability to either open or close a valve when required. For this reason, it is important to quantify the effects that aging may have on the behavior of lubricants commonly used on the stems and stem nuts of motor-operated valves.

1.1 Background

In rising stem MOVs, the conversion of actuator output torque to a stem thrust occurs at the stem nut, as shown in Figure 1. The ratio of actuator torque to stem thrust is generally referred to as the stem factor. For a specific valve stem and stem nut, the only variable in the conversion of torque to thrust is the coefficient of friction as shown in the following power screw equation.

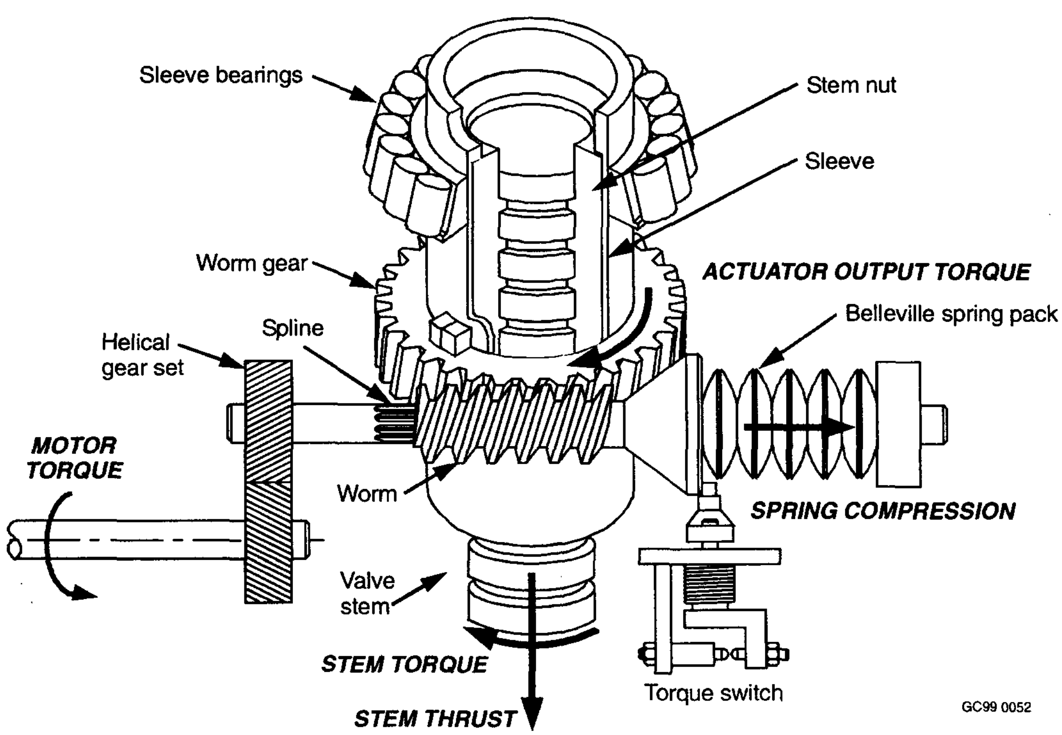

Figure 1. Diagram of the main components inside an actuator gearbox.

$$\frac{T_{output}}{Th_{stem}} = \frac{d(0.96815 \tan\alpha + \mu)}{24(0.96815 - \mu \tan\alpha)} = \text{stem factor} \quad (1)$$

where

T_{output}	=	The output torque of the valve actuator
Th_{stem}	=	The valve stem thrust
d	=	OD_{stem} - ½ Pitch
tan α	=	Lead/(πd)
μ	=	The stem/stem nut coefficient of friction
OD_{stem}	=	The outside diameter of the stem
Pitch	=	The distance from the peak of one thread to the peak of an adjacent thread (inches/thread)
Lead	=	The distance the stem travels in one revolution of the stem nut (inches/revolution)

Equation 1 is written for U.S. Customary units, where torque is in foot-pounds, thrust is in pounds force, and the diameter, pitch, and lead are in inches. The output torque consists of the torque delivered to the stem nut, which is equal to the torque reacted by the valve stem. The valve stem thrust is the thrust applied to the valve stem to move the stem and valve disc. The ratio of torque to thrust is known as the stem factor. The term d represents the mean diameter of the stem in terms of the thread contact area, and the term tan α is the slope of the thread.

1.2 Previous Stem Lubrication Elevated Temperature Testing

Observations during recent testing performed at the INEEL (Reference 1) indicate that significant changes in the coefficients of friction can occur at elevated temperatures. These tests were performed utilizing five lubricants and four different stem/stem nut combinations. Two different Limitorque actuators were used. The lubricants included Exxon Nebula EP1, Chevron SRI, Mobil Mobilgrease 28, SWEPCO Moly 101, and Loctite N5000 anti-seize. The tests included collection of data at room temperature to establish baseline values for the coefficient of friction for each lubricant and stem/stem nut combination. The test apparatus was then insulated and heated to 250°F to simulate accident condition operational temperatures. Additional data were then taken at the elevated temperatures. Increases as high as 40% were observed in the coefficients of friction. The research produced the following conclusions:

- The physical characteristics of each lubricant change with increasing temperature, changing the frictional performance of each stem and stem nut.
- The consistency of the stem/stem nut coefficient of friction from one stroke to another changes significantly with increasing temperature.
- The stem/stem nut coefficient of friction can increase significantly at elevated temperature.
- The end-of-stroke friction behavior is highly dependent on the unique stem/stem nut tested, the lubricant, and temperature.
- Each individual stem and stem nut combination has unique characteristics with regard to variation between strokes, elevated temperature performance, and end-of-stroke friction behavior.

1.3 Previous Stem/Stem Nut Lubricant Aging Tests

Lubricant aging on valve stems has not been extensively tested. One test program was conducted by Atomic Energy of Canada Limited (AECL), who performed tests to evaluate the effects of aging on MOV stem/stem nut lubricants used for MOVs in CANDU and Electricite de France (EdF) nuclear power plants. The results of this testing were presented at the Sixth NRC/ASME Symposium on Valve and Pump Testing (Reference 2). This work was based on a single stem and stem nut and did not consider the effects of different stem/stem nut combinations. A lubricant that is best suited for one type of stem/stem nut configuration may not behave similarly for other stem/stem nut configurations under similar environmental conditions. Also, these tests did not age the lubricant in place on the stem and stem nut. Instead, the lubricant samples were oven aged and then the lubricant was applied to the stem and stem nut to be tested. When applied to a stem in this manner, grease that may have dried out and become hardened or began to separate would remix and regain most of the lubricating qualities that may have been degraded by the aging process. This would not be representative of grease aged in nuclear power plants. Also, most of the operational tests that were performed were conducted at 77°F, essentially room temperature. Limited testing was performed at elevated temperatures, however that data is proprietary.

1.4 Scope of Current Testing

The tests described in this report build upon the previous test results to evaluate the effects of lubricant aging on the performance of motor-operated valve stem and stem nut configurations that are typical of those used in MOVs in U.S. nuclear power plants. The most recent testing performed at the INEEL included three lubricants in common use for this application and one stem/stem nut combination. The scope of testing is comprised of the tasks described below.

Additional temperature effects testing with one additional lubricant. The tests briefly described above were repeated with one stem using an additional lubricant. The Nebula EP1 lubricant used in previous testing has been discontinued by Exxon and the industry is considering replacing it with the MOV Long Life lubricant. Additional temperature effects testing was performed on this MOV Long Life lubricant to provide a baseline for the Aging Effects testing, similar to that already obtained for the other greases.

Testing of lubricants subjected to accelerated thermal aging. Accelerated aging of three lubricants on a single stem was performed in place. A series of lubricant aging tests, simulating actual MOV operational strokes and flow isolation strokes was performed.

2. TEST DESIGN

2.1 Test Equipment

The tests were conducted at the INEEL on the motor-operated valve load simulator (MOVLS), shown in Figure 2. The MOVLS is an instrumented test stand that provides dynamometer-type testing of valve actuators using load profiles that are very similar to the load profile a valve actuator would experience when closing a valve against a flow load. The MOVLS was modified for this test program to produce simulated valve strokes with essentially no variation in the stem thrust profile between strokes and over the duration of the testing. Since several load levels were defined for this research, it was important to be able set the MOVLS to well-defined load levels. This was accomplished by adding a sight glass to the MOVLS accumulator to precisely control the water level at the start of each stroke. The initial pressure in the accumulator was controlled using a pressure gage. The volume of water in the accumulator and the overpressure at the beginning of the stroke determine the load profile during the stroke. With multiple strokes all beginning with the same overpressure and water level in the accumulator, the thrust-versus-position profiles were all essentially the same.

For elevated temperature testing and accelerated aging of the stem lubricant, the valve actuator was wrapped in heat tape and insulated to control the actuator, valve stem threads, and stem nut at the temperature required for testing of the stem nut lubricant. Figure 3 shows the MOVLS during elevated temperature testing. The design configuration allowed operation of the valve actuator without disturbing the heater or insulation.

The following is a list of the major equipment used in the performance of this research.

- Limitorque SMB-0 actuator equipped with a Reliance 25 ft-lb 480V ac motor
- Stem 2, 1.750-inch-diameter, ¼-pitch, ¼-lead valve stem and stem nut

The valve stem and actuator listed above were selected based on their performance in our earlier research (the names match those used in that work) documented in NUREG/CR-6100 (Reference 3). Stem 2 is a single-lead stem that exhibited running coefficients of friction of 0.12 and end-of-stroke friction behavior (ESFB) in the 16% range when tested with the EP-1 lubricant (that is, the coefficient of friction was 16% higher at the end of a high-load stroke, as compared with a low-load stroke).

The results of previous INEEL testing, the testing described above, and accepted methods of achieving accelerated aging of lubricants were used to determine the aging parameters employed for these tests. The most important parameters of influence to be considered were temperature and time of exposure. Care was exercised so that the aging temperature used would at no time exceed the maximum temperature determined during the testing described above, the maximum temperature limit of the motor, or the temperature limits specified by the manufacturer of the lubricant.

A widely used accelerated aging relationship first published by Arrhenius was used to estimate the time and temperature required to accelerate the aging. This relationship is:

$$AT_R = \frac{SA}{Q_{10}^T} \tag{2}$$

where

AT_R = Aging time required (weeks)

SA = Simulated age (weeks)

T = Aging factor (number of degrees Celsius above ambient/10)

Q_{10} = Reaction doubling rate (usually in the range of 1.6 - 2.0)

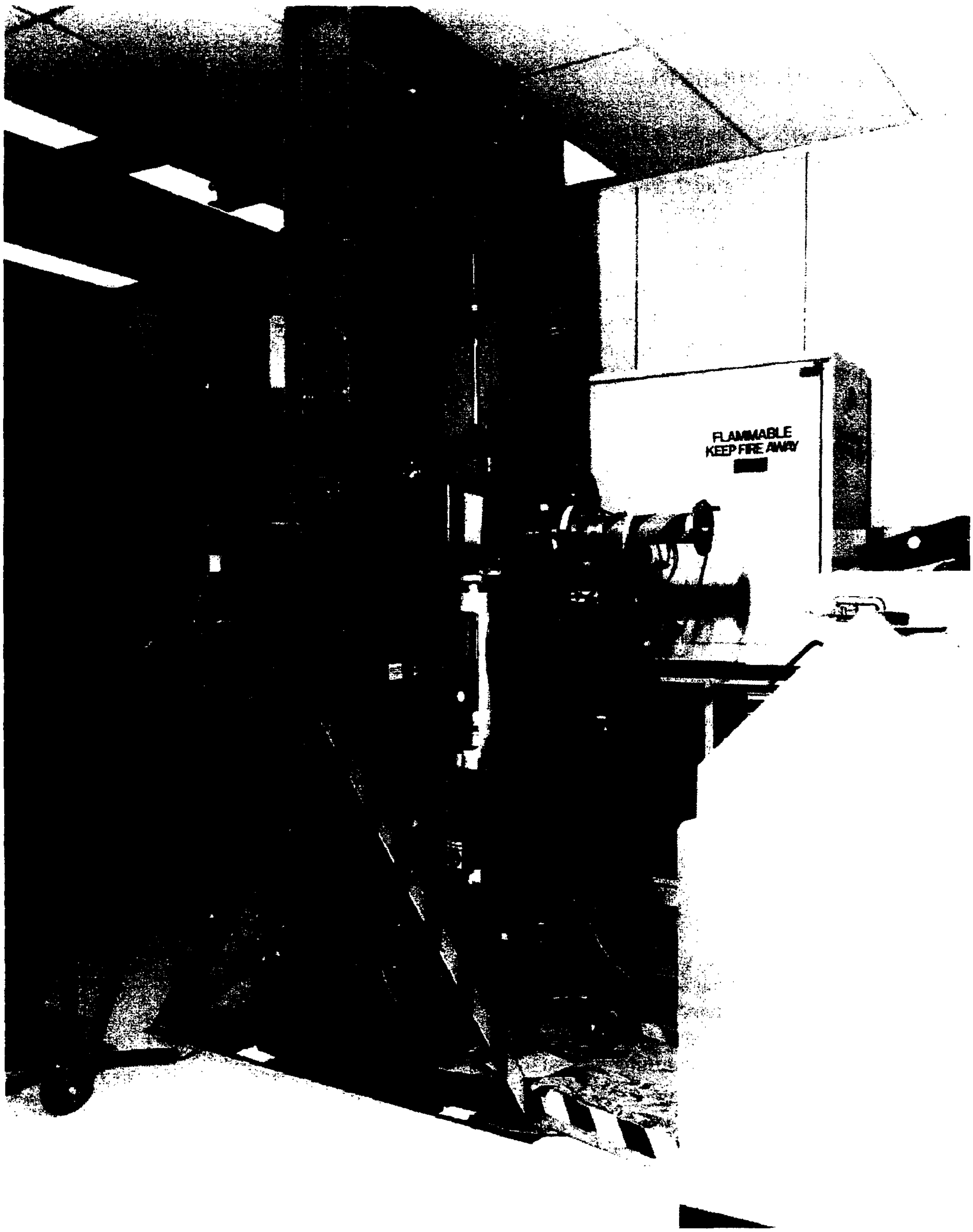

Figure 2. INEEL motor operated valve load simulator (MOVLS).

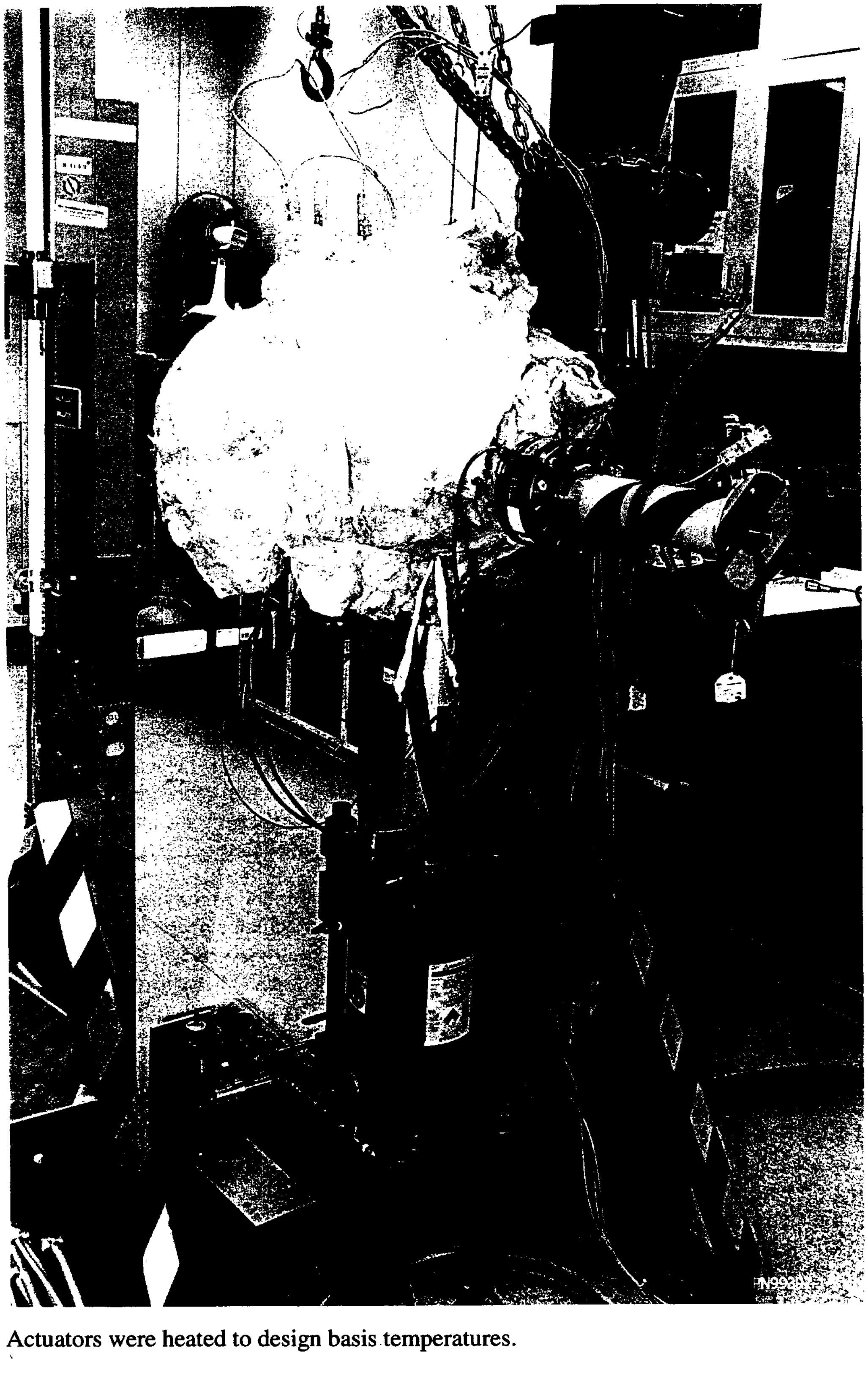

Figure 3. Actuators were heated to design basis temperatures.

Not all reactions follow this rule. Complex reactions, catalytic reactions, and multiple reactions often do not follow this relationship. Lubricant changes over time are complex and often sequential. The reaction doubling rate for each lubricant can only be estimated based on a series of tests at each temperature and over sufficient time periods. Based on the work scope for this testing and recognizing the variables in applying the Arrhenius model, we applied the model as a first-order estimate of the aging rate. A doubling rate of 1.6 was selected for use in estimating the aging rate of the three lubricants tested in this research. This value was found to be consistent with that used in other lubrication research of similar lubricants.

The accelerated aging of the lubricant was performed in place. A fresh quantity of each lubricant was applied to the stem/stem nut combination and then the stem/stem nut combination was installed in the MOVLS valve operator. The operator was then insulated and heated to the selected aging temperature. Additional information on the equipment used to maintain and control heating is provided later in this report.

The series of lubricant aging tests simulated actual MOV operational strokes during the aging period. The test article temperature was continuously recorded and controlled throughout the accelerated aging process. Also, the motor actuators were operated at periodic intervals to simulate quarterly inservice testing or exercising. Following each series of tests the data were evaluated and validated.

For accelerated aging of the stem lubricant, the motor actuator was wrapped in heat tape and insulated to maintain the actuator, valve stem threads, and stem nut at the temperature required for testing of the stem nut lubricant. The design configuration allowed operation of the motor actuator without disturbing the heater or insulation.

A steady-state heat transfer analysis was performed to determine the power necessary to maintain the actuator, stem nut, and stem at a specified temperature. It was assumed that the actuator, stem nut, and stem were perfectly insulated except for the yoke, the motor, and the sensor array. The latter three parts were modeled as cylindrical fins. It was assumed that the insulated parts of the actuator, stem nut, and stem were at the same temperature. Heat is transferred from the yoke, the motor, and the sensor array by convection and by radiation. Figure 4 is the result of the analysis. The minimum power curve was calculated assuming the yoke, the motor, and the sensor array were hollow cylinders. The maximum power limit assumes they are solid cylinders. The ambient temperature for the analysis was assumed to be 70°F.

2.2 Instrumentation

During the testing of each stem/stem-nut combination, the temperature of the MOVLS components were monitored using the instrumentation listed in Table 1. The eight thermocouples were strategically placed to allow monitoring of temperatures at various locations throughout the MOVLS. Each of the measurements was recorded at a rate of 600 samples per second by the data acquisition system whenever the actuator was operated. In addition, a chart recorder was used to track two of the temperature measurements to control the heaters throughout the test period.

Table 2 lists the instrumentation used to monitor actuator operation during the tests. Electrical measurements for the ac motors included the ac line current and voltage for each phase. Motor output torque and speed were measured using a torque cell and tachometer mounted between the motor and the gearbox. A torque arm attached to the valve stem measured the output torque of the gearbox, and an in-line load cell measured valve stem thrust. Other measurements included actuator torque switch trip, torque spring thrust and deflection, and valve stem position. Each of these measurements was recorded at a rate of 600 samples per second by the data acquisition system whenever the actuator was operated. Calibration of the load cells allows a measurement error of ±60 lb. Calibration of the torque arm allows a measurement error of ±4 ft-lb.

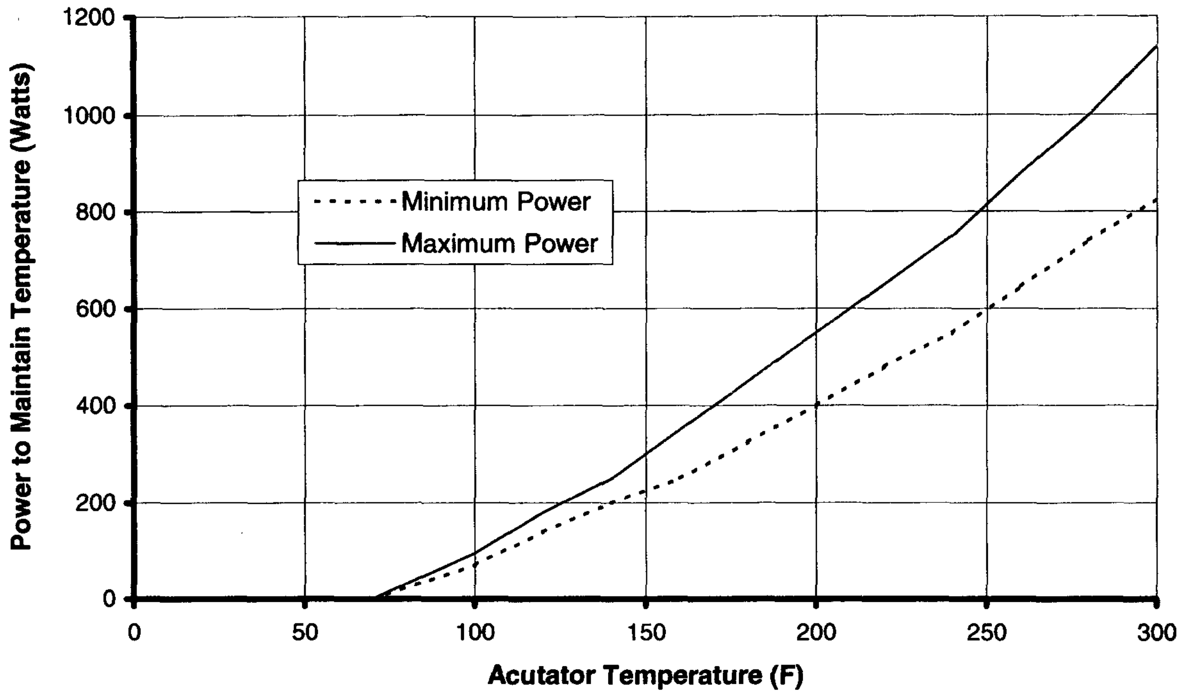

Figure 4. Power requirements to maintain actuator temperature.

Table 1. Temperature instrumentation (600 Hz recording frequency).

TCS Channel No.	Description
0	Thermocouple: Grease temperature - side
1	Thermocouple: Grease temperature - top
2	Thermocouple: Operator housing temperature - limit switch
3	Thermocouple: Operator housing temperature - rear
4	Thermocouple: Valve stem temperature
5	Thermocouple: Stem cover temperature
6	Thermocouple: Spring pack temperature
7	Thermocouple: Spool piece temperature

Table 2. MOV Stroke Instrumentation (600 Hz recording frequency).

TCS Channel No.	Description
48	Motor current - I1 RMS
49	Motor current - I2 RMS
50	Motor current - I3 RMS
56	Motor speed
32	Motor torque
51	Motor voltage - V1-2 RMS
52	Motor voltage - V2-3 RMS
57	Valve stem position
40	Valve stem torque
41	Valve stem torque
33	Valve stem thrust
58	Actuator torque spring deflection
34	Actuator torque spring thrust
59	Actuator torque switch trip
60	Transformer voltage
35	Accumulator pressure

2.3 Test Matrix

The scope of the testing described above requires several different tests. These tests and the conditions for which the data were used are described in the following paragraphs. The test matrix calls for testing with three lubricants and one stem/stem-nut combination.

2.3.1 Lubricants Tested

Prior to each series of tests, the stem and stem nut were removed from the MOVLS and cleaned using a multi-step procedure to remove all traces of the prior lubricant. A fresh application of the next lubricant to be tested was then applied and the stem and stem nut were reinstalled into the MOVLS. Three lubricants commonly used or planned to be used in nuclear power plant MOVs were selected for testing. Descriptions and uses of each were obtained from information published by each manufacturer and summarized below.

2.3.1.1 Chevron SRI. Chevron SRI is a dark green, high temperature ball and roller bearing grease with a smooth and buttery texture. It is recommended for use in a wide range of automotive and industrial applications for use in anti-friction bearings operating at high speeds (10,000 rpm and greater). It is also recommended for use where the operating temperatures are on the order of 302°F (150°C) and higher where there is a likelihood that fresh water or salt water will get into the bearings. It performs satisfactorily in bearings at temperatures as low as -22°F (-30°C).

Chevron SRI is formulated with ISOSYNTM base stocks, a synthetic polyurea ashless organic thickener, and high performance rust and oxidation inhibitors. Major bearing manufacturers, along with a number of electric motor manufacturers, recommend or use Chevron SRI. Chevron SRI will outperform most other greases in unsealed electric motor bearings operating in moist conditions, applications where silent operations are called for; also, as a "life-pack" lubricant by manufacturers of automotive generators, alternators, and starters.

2.3.1.2 Mobil Mobilgrease 28. Mobilgrease 28 is a red synthetic grease with a mild odor. It is designed for the lubrication of plain and rolling bearings at low to high speeds, and splines, screws, worm gears, and other mechanisms where high friction reduction, low wear, and low lubricant friction losses are required. It provides minimum resistance to starting at extreme low temperatures, down to -65°F (-54°C), as well as low running torque.

Mobilgrease 28 prevents friction oxidation (fretting) and lubricates rolling element bearings under conditions of high speeds and temperatures. It has also shown superior ability to lubricate heavily loaded sliding mechanisms, such as wing flap screwjacks.

Mobilgrease 28 is also recommended for industrial lubrication, including sealed or repackable ball and roller bearings wherever extreme temperature conditions, high speeds, or water-washing resistance are factors. Typical applications include conveyor bearings, small alternator bearings operating at temperatures near 350°F (177°C), high-speed miniature ball bearings, and bearing situations where oscillatory motion, vibration, and fretting create problems. Advantages include:

- Improved friction reduction, low wear rates, and low lubricant drag,
- Wide temperature range with high thermal stability,
- Compatibility with mineral-oil-based greases,
- Extreme-pressure characteristics, and
- High resistance to water washing.

2.3.1.3 MOV Long Life (Grade 1). MOV Long Life is a tan-colored calcium sulphonate grease with a mild petroleum odor. It is designed specifically for use in MOV actuators. The nuclear industry's MOV Users Group (MUG) has preliminary recommendations that MOV Long Life could be used as the direct replacement for the discontinued ExxonMobil Nebula EP grease in the gearbox portion of Limitorque actuators, the limit switch gearbox, and at the valve stem (Reference 4). These preliminary recommendations are based on indirect testing, other than testing on an MOV actuator. This research provides some data on the use of MOV Long Life as a stem thread lubricant. Its use in the limit switch gearbox and actuator gearbox was not within the scope of this research.

2.3.2 Baseline Tests

The baseline tests provided data from MOVLS setup strokes and test strokes with the lubricant at ambient temperature. No-load/low-load baseline tests are intended to represent typical in-service tests conducted in the power plants. Data from these tests were used to determine the stability of the stem/stem-nut coefficient of friction at these load levels and to establish the ambient temperature baseline values.

For the high-load baseline tests, the actuator torque switch was set to produce a final stem force near the maximum allowed for the valve stem, the actuator, or the stem thrust and torque instrumentation, whichever was the limiting case. The level and pressure in the MOVLS accumulator was determined during the initial setup so that the running load was sufficient to produce a stem thread pressure that exceeded 10,000 psi by the end of the stroke. A stem thread pressure threshold of 10,000 psi is needed for the friction coefficient to stabilize. Stem thread pressure is determined using the measured thrust and an approximate thread area based on one stem thread revolution.

2.3.3 Elevated Temperature Tests

Two groups of elevated temperature tests were performed with Stem 2 and MOV Long Life. In the first group of tests, data at elevated temperature conditions of 250°F were collected for comparison with the baseline data. Following the 250°F tests, the actuator was allowed to cool down, and a final set of tests was performed at ambient temperature (70°F).

The second group of elevated temperature tests was performed to investigate the temperature sensitivity of the MOV Long Life lubricant by roughly identifying the temperature threshold at which the coefficient of friction departs from the baseline. This second group of tests was conducted by raising the valve actuator temperature in steps and performing five loaded strokes to acquire data at each step. The baseline tests described above provided data at ambient temperature (~70°F). The elevated temperature tests described here collected data at three temperature steps: 130, 190, and 250°F. Following the 250°F tests, the actuator was allowed to cool down, and a final set of tests was performed at ambient temperature (70°F).

Table 3 summarizes the test sequence. The sequence listed in Table 3 was performed on Stem 2 with the MOV Long Life lubricant. These steps for the Chevron SRI and Mobil Mobilgrease 28 were performed during earlier testing (Reference 1). The cold-hot-cold elevated temperature test was repeated with the Chevron SRI and the Mobil Mobilgrease 28 at the end of the aging tests for comparison with the earlier testing.

2.3.4 Accelerated Aging Tests

Operational Tests. The operational tests were included as part of the accelerated thermal aging series. The tests were performed at simulated aging intervals of 0 months, 1 year, 2 years 6 months, 4 years, and 5 years based on the desired equivalent aging of the stem nut lubricant. This test represents one full valve cycle from fully open to fully closed and back to fully open. The MOVLS accumulator settings matched those used for the baseline testing so as to produce stem thrust traces that are essentially identical to the baseline tests.

Inservice Tests. The inservice tests were included as part of the accelerated thermal aging series. The tests were performed at simulated 3-month intervals based on the desired equivalent aging of the stem nut lubricant. This test represents one full valve cycle from fully open to fully closed and back to fully open. The level and pressure in the MOVLS accumulator were the same for all the inservice testing cycles and represented either an unloaded valve or a valve operating against a very small load.

Final Tests. These tests were included as part of the accelerated thermal aging series. After the completion of the final operational test, a series of tests similar to the earlier baseline testing was performed. The purpose of these tests was to determine if any observed stem nut coefficient of friction changes remain after the return to baseline conditions. Unloaded strokes were performed to determine if the stem nut coefficient of friction returned to the baseline values and several loaded strokes were performed to determine the stability of the coefficient of friction.

Table 3. Elevated temperature test sequence.

Test Type	Description
Elevated Temperature Tests	
Setup tests	Various loads, ambient temperature (multiple strokes)
Baseline tests	High load, ambient temperature (five strokes)
Hot tests	High load, elevated temperature, 250°F (five strokes)
Final tests	High load, ambient temperature (five strokes)
Elevated Temperature Step Tests	
Baseline tests	High load, ambient temperature (five strokes)
Step 1 tests	High load, elevated temperature, 130°F (five strokes)
Step 2 tests	High load, elevated temperature, 190°F (five strokes)
Step 3 tests	High load, elevated temperature, 250°F (five strokes)
Final tests	High load, ambient temperature (five strokes)

Table 4 shows the test steps performed on each of the valve stem/stem nut and lubricant combinations during the accelerated thermal aging test series. The date reference in Table 4 (i.e. "3 month inservice test...") describes the rough equivalent aged time at room temperature, based on Equation 2 and the assumed doubling rate of 1.6. Because of the many variables for each lubricant, the aging equivalent cannot be considered exact, but rather a very rough estimate. This represents the case where an MOV's service environment is at room temperature, approximately 70°F. The aging should be considered real time for MOVs seeing service temperatures of 250°F.

Table 4. Stem nut lubrication aging test matrix.

Test Type	Data ID	Description
Baseline		Actuator setup and switch setting
		Repeat 3 no-load strokes at ambient conditions
	-BO1 - B05	Repeat 5 loaded strokes at ambient conditions
		Repeat 3 no-load strokes at temperature
	-BO6 - B10	Repeat 5 loaded strokes at temperature
		Repeat 3 no-load strokes at temperature
	-B11	1 Baseline loaded stroke at temperature
Inservice and Operation	-IS03	3 month inservice test at temperature
	-IS06	6 month inservice test at temperature
	-IS09	9 month inservice test at temperature
	-O10	1st-year loaded stroke at temperature
	-IS10	1 year inservice test at temperature
	-IS13	1 year, 3 month inservice test at temperature
	-IS16	1 year, 6 month inservice test at temperature
	-IS19	1 year, 9 month inservice test at temperature
	-IS20	2 year inservice test at temperature
	-IS23	2 year, 3 month inservice test at temperature
	-O26	2-year, 6 month loaded stroke at temperature
	-IS26	2 year, 6 month inservice test at temperature
		End of aging for Chevron SRI and Mobil Mobilgrease 28
	-IS29	2 year, 9 month inservice test at temperature
	-IS30	3 year inservice test at temperature
	-IS33	3 year, 3 month inservice test at temperature
	-IS36	3 year, 6 month inservice test at temperature
	-IS39	3 year, 9 month inservice test at temperature
	-O40	4th -year loaded stroke at temperature
	-IS40	4 year inservice test at temperature
	-IS43	4 year, 3 month inservice test at temperature
	-IS46	4 year, 6 month inservice test at temperature
	-IS49	4 year, 9 month inservice test at temperature
	-O50	5th - year loaded stroke at temperature
	-IS50	5 year inservice test at temperature
		End of aging for MOV Long Life
Final		Repeat 3 no-load strokes at temperature
	-F01 - F05	Repeat 5 loaded strokes at temperature
		Repeat 3 no-load strokes at ambient conditions
	-F06 - F10	Repeat 5 loaded strokes at ambient conditions

3. RESULTS

3.1 Accelerated Aging Tests – Chevron SRI and Mobilgrease 28

Two lubricants were tested on one stem as part of the lubrication aging test series. Chevron SRI and Mobil Mobilgrease 28 were selected based on earlier testing. Each lubricant was applied to Stem 2 and tested for a simulated two-and-a-half-year period. The results from these tests provide an indication of how aging might affect stem and stem nut performance; however, one must keep in mind the limited sample size. Past testing (Reference 1) has shown that lubricants can perform quite differently on different stems. Other stems may perform differently than the following results.

In previous testing we observed that there can be a large variation in the stem nut coefficient of friction between strokes and even within the running portion of a single valve stroke. To make a consistent evaluation of the effects of different stems, lubricants, and temperatures on the friction coefficient, we chose to make this evaluation based on the performance observed at the end of the valve stroke, just prior to full seat contact. For a gate valve, this position is sometimes referred to as "at wedging." This analysis will take a single value for the stem nut coefficient of friction calculated from the average stem thrust and average stem torque based on the 200 data points (about 1/3 second) just prior to full seat contact. This position in a valve's closure stroke produces the highest loads during closure and is consistent with other analyses performed in the past. This portion of the MOVLS stroke also produces the highest stem loads. The figures discussed in the following sections will show these average stem nut friction values, one for each of the valve strokes performed.

3.1.1 Stem 2 with Chevron SRI

Figure 5 shows the stem-nut coefficient of friction performance for the aging tests for Stem 2 with Chevron SRI. The data shown as "Cold Baseline" are the five strokes performed at 70°F at the beginning and at the very end of the aging test. The "Hot Baseline" data are the five strokes performed after initial heatup to 250°F and then again at the end of the aging test, prior to cool down. The "Loaded" tests were performed at the simulated 0, 1, and 2.5-year points and the "IST" or unloaded tests were performed on a simulated three-month interval. For Stem 2 with Chevron SRI, the initial cold test data show an increase in the stem nut coefficient of friction from 0.115 to 0.130 with each successive stroke. Similar to earlier testing, elevated temperature resulted in higher stem nut friction. The test plan called for three zero-load strokes immediately after heatup, resulting in hot baseline friction values even greater than those observed in earlier testing. But with the initial heatup we also see large increases with each successive test, approaching 0.240 by the fourth stroke. Also note that the final hot and final cold tests exhibit stem nut friction values that are better behaved and consistent with the initial cold test values.

Figure 6 contains the same data as Figure 5, but plotted as a function of time. The time scale on the axis shows the actual test dates, but can be related to the simulated 2.5-year aging period. The vertical grid lines represent a simulated six-month interval. The data in Figure 6 show an improvement in stem nut friction over time for both the Loaded and IST strokes. Stem nut friction for Stem 2 with Chevron SRI becomes less as it ages, at least within the simulated 2.5-year period.

At the conclusion of the aging tests the single step elevated temperature test reported in Reference 1 was repeated, without relubrication of the stem. Figure 7 shows the results of that testing. Consistent with the earlier testing, Stem 2 with Chevron SRI shows good repeatability among the five cold strokes, both initial and final. After increasing the temperature, more variability is evident among the five strokes, with the first being the lowest and increasing with each additional stroke. But, contrary to the earlier testing, there is no immediate change in stem nut friction at heatup. The first hot stroke exhibits essentially the same friction value as the prior cold test.

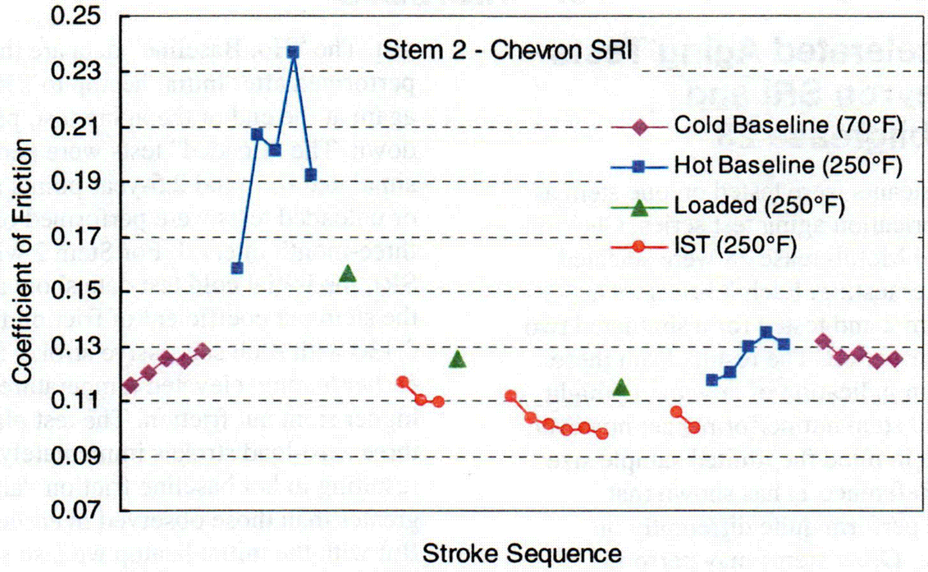

Figure 5. Aging test stroke sequence for Stem 2 with Chevron SRI.

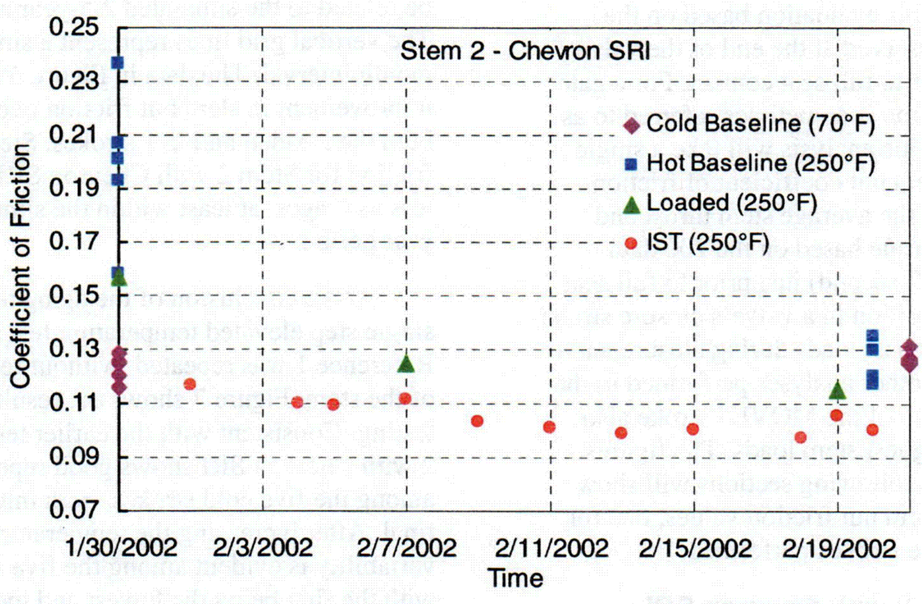

Figure 6. Aging test time line for Stem 2 with Chevron SRI.

C07

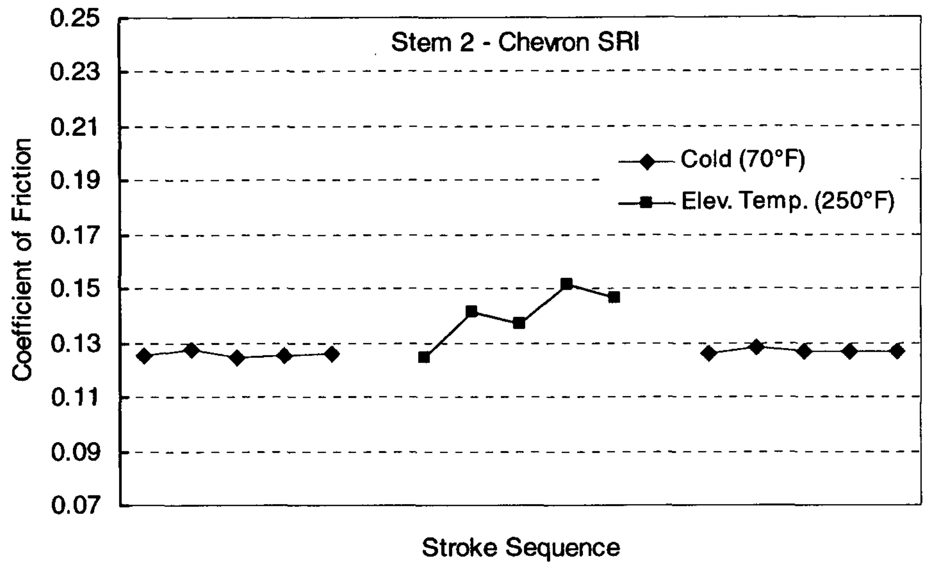

Figure 7. Elevated temperature test for Stem 2 with Chevron SRI.

3.1.2 Stem 2 with Mobil Mobilgrease 28

Figure 8 contains the stem-nut coefficient of friction performance for the aging tests for Stem 2 with Mobil Mobilgrease 28. For this combination, the initial cold test data show very stable friction with no change with each successive stroke. Initial stem nut friction begins at 0.110 in the cold tests and increases with successive strokes in the hot tests. After the aging period, the behavior of the stem nut friction has changed. After aging, both the final hot and final cold friction increases significantly with each repeat stroke.

Figure 9 contains the same data as Figure 8, but plotted as a function of time. Once again, the time scale on the axis shows the actual test dates, but can be related to the simulated 2.5-year aging period and the vertical grid lines represent a simulated six-month interval. The data in Figure 9 show essentially no change in stem nut friction over time for both the Loaded and IST strokes. Stem nut friction for Stem 2 with Mobil Mobilgrease 28 appears to be stable over the simulated 2.5-year period.

The single step elevated temperature test was repeated, without relubrication of the stem. Figure 10 shows the results of that testing.

Consistent with the earlier testing, Stem 2 with Mobil Mobilgrease 28 cold baseline test shows good repeatability among the five strokes. Once again, Stem 2 has more scatter between tests at high temperature and good repeatability during the final cold tests.

3.2 MOV Long Life Testing

The MOV Long Life lubricant, manufactured by Crompton Company, has been identified by the MUG as the preferred grease to replace the discontinued ExxonMobil Nebula EP grease for the gearboxes in Limitorque actuators. The MUG also recommends MOV Long Life for use in the limit switch gearbox and on the valve stems and stem nuts. This lubricant was added to the test program to evaluate its performance under normal conditions, elevated temperature, and aging. One sample of the MOV Long Life (Grade 1) was applied to Stem 2 and several tests were performed. No repeat applications of new MOV Long Life were performed. The results from these tests provide an indication of how aging might affect stem and stem nut performance; however, one must keep in mind the limited sample size. Past testing (Reference 1) has shown that lubricants can perform quite differently on different stems. Other stems may perform differently than the following results.

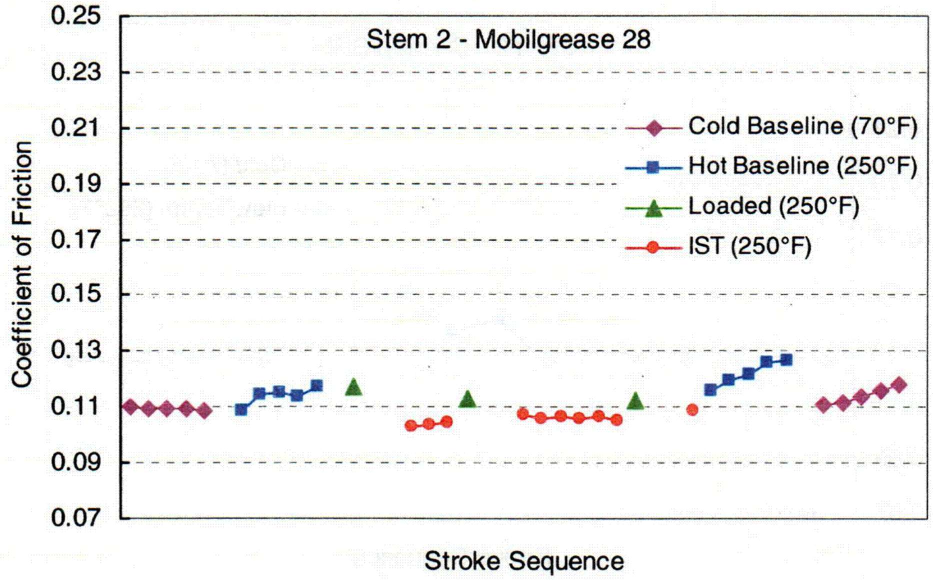

Figure 8. Aging test stroke sequence for Stem 2 with Mobil Mobilgrease 28.

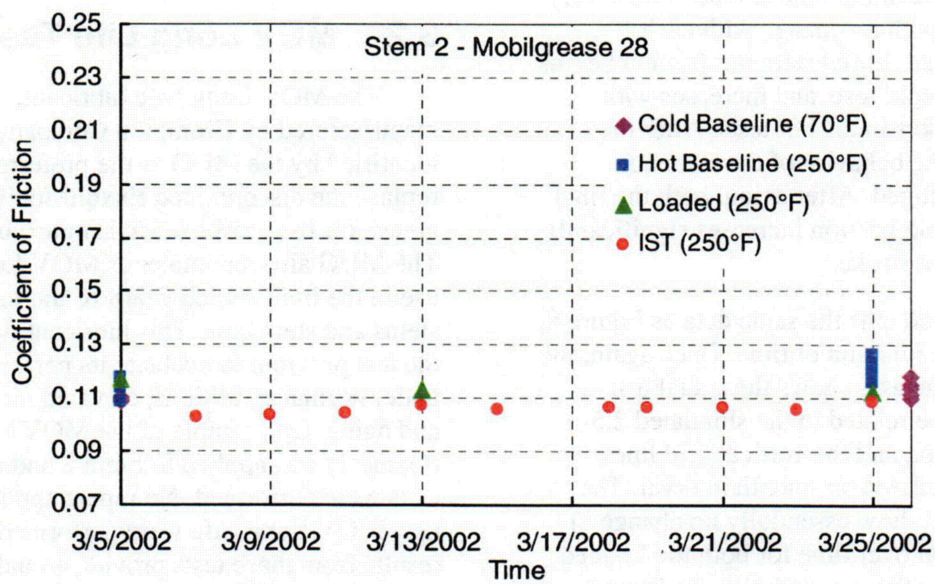

Figure 9. Aging test time line for Stem 2 with Mobil Mobilgrease 28.

C02

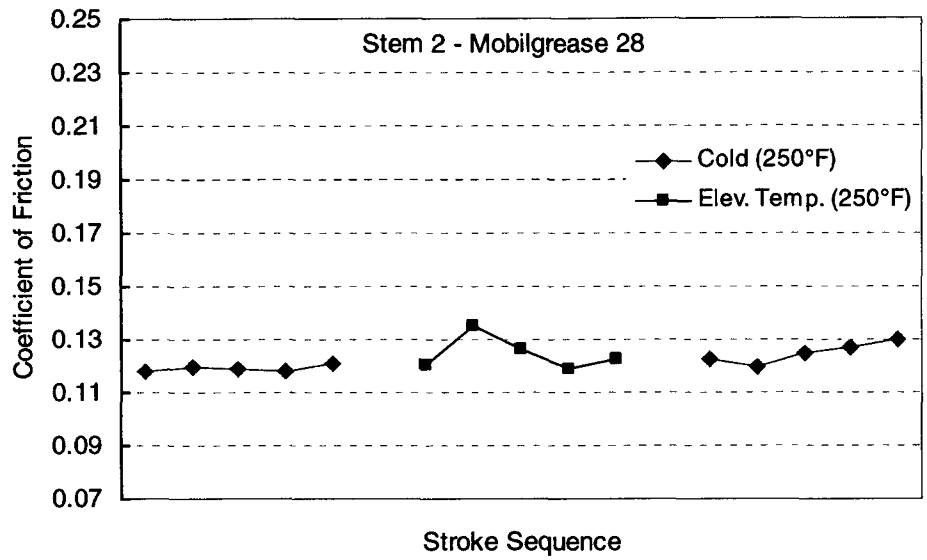

Figure 10. Elevated temperature test for Stem 2 with Mobil Mobilgrease 28.

3.2.1 Stem Nut Friction and End Of Stroke Friction Behavior Tests

A series of tests was performed with Stem 2 and MOV Long Life to characterize the stem nut friction over a range of running loads and to evaluate the end-of-stroke-friction behavior (ESFB). The MOVLS was configured to provide four different load simulations for these tests as follows:

1. Low Load – this setting provides a low running load simulating a valve that has to overcome packing load but essentially no stem rejection load.

2. Medium Load – this setting adds a stem rejection type load to the low load setting, but does not include any flow loads.

3. High Load – this setting adds a moderate flow load simulation to the loads described above. This setting is the same as that used for the "Loaded" tests identified in the aging tests.

4. Maximum Load – this setting simulates a high differential pressure or high flow load.

Figure 11 contains the data from each of these four load simulations. Once again, the analysis uses a single value for the stem nut coefficient of friction calculated from the average stem thrust and average stem torque based on the 200 data points (about 1/3 second) just prior to full seat contact. Figure 11 shows stable and repeatable stem nut friction values between 0.120 and 0.130 for each of the load levels. For Stem 2 with MOV Long Life, the friction value does not vary as loads change.

A significant change in the stem nut coefficient of friction can occur at the end of valve travel when seating or wedging occurs. Most often, the coefficient of friction drops to a very low value making the MOV performance at torque switch trip look overly optimistic. Our evaluation of the change in stem nut friction at the end of valve travel looked at the total change from full seat contact to the final stem position, which we shall refer to as the MOV's end-of-stroke friction behavior (ESFB).

Figure 12 shows the end-of-stroke friction behavior (ESFB) for the same load simulations. The end-of-stroke friction behavior is the overall change in stem nut friction from the point in the valve stroke commonly called hard seat contact

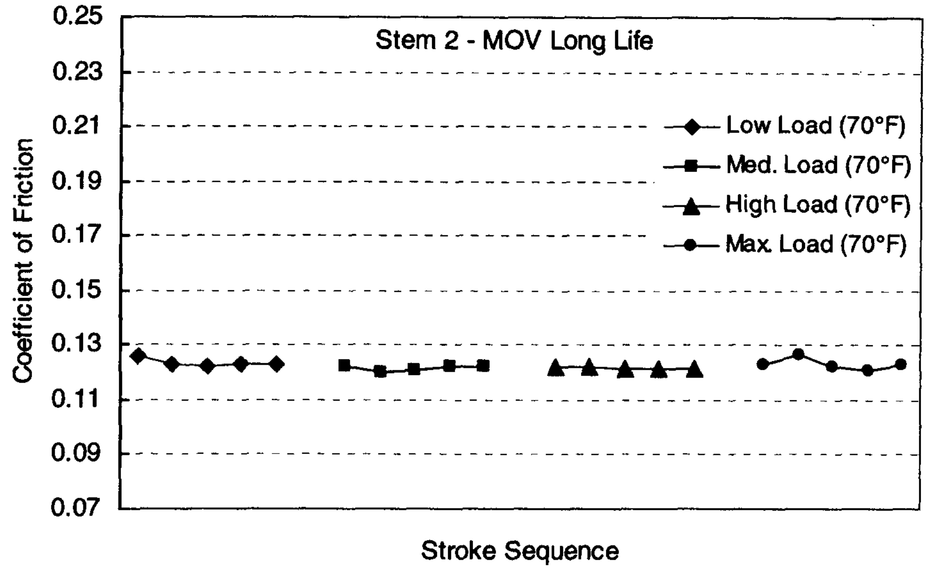

Figure 11. Stem nut friction at various stem loads for Stem 2 with MOV Long Life.

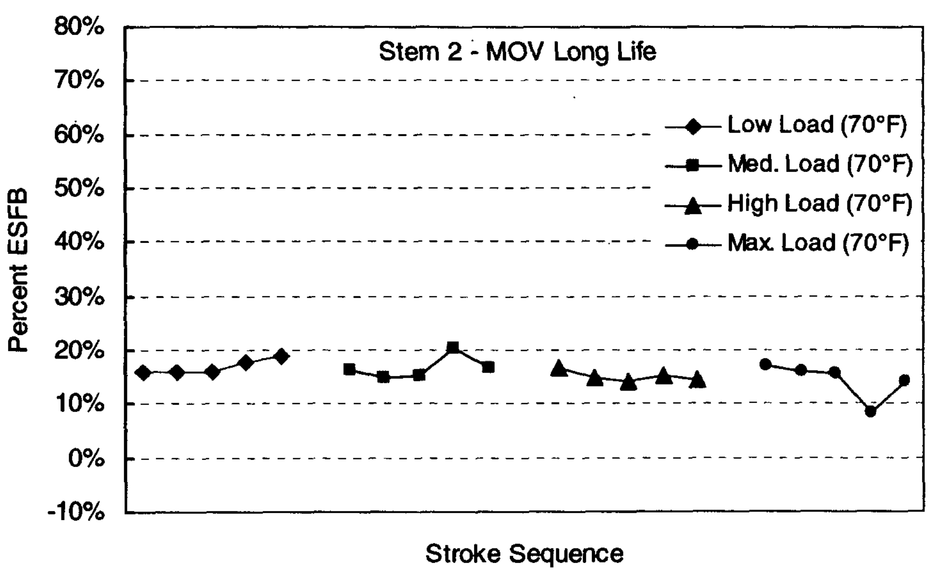

Figure 12. End-of-stroke friction behavior at various loads for Stem 2 with MOV Long Life.

to the final value at the end of valve operation. This is usually slightly larger than the rate-of-loading value that is taken from hard seat contact to torque switch trip. In Figure 12 we see stable ESFB with values running between 15 and 20 percent. The percent change in ESFB is the change in stem nut friction from running to final divided by the running friction. For Stem 2 with MOV Long Life, ESFB did not change as the magnitude of the running load changed.

3.2.2 Elevated Temperature Tests

A series of tests was performed to evaluate the performance of the MOV Long Life lubricant at elevated temperatures. These tests used the same temperatures and test steps used for testing the other lubricants described in Reference 1. This included a single step series (70, 250, and 70°F) and a multiple step series (70, 130, 190, 250, and 70°F).

Stem 2 with MOV Long Life showed excellent repeatability among each set of five strokes, even at elevated temperature, as shown in Figure 13. Figure 13 also shows that the effect of elevated temperature is opposite that seen previously for other lubricants. The stem nut friction drops significantly as the temperatures increase from 70 to 250°F. Little change is seen in the friction value at 130°F.

Figure 14 is similar to Figure 13, but contains the end-of-stroke friction value. This also exhibits a strong temperature influence, again reducing friction values at elevated temperatures. However it is not as extreme as in Figure 13. Figure 15 shows the effect that elevated temperature has on the ESFB performance. Here we see an increase in ESFB at elevated temperature, approaching 40 percent at 250°F. For the MOV Long Life lubricant, ESFB is greater at elevated temperature.

3.2.3 MOV Long Life Aging Tests

Figure 16 contains the stem-nut coefficient of friction performance for the aging tests for Stem 2 with MOV Long Life. For this combination, the initial cold test data show very stable friction with little change with each successive stroke. Initial stem nut friction in the cold baseline test begins at about 0.125 in the cold tests and decreases slightly with successive strokes. The figure shows more scatter in the hot tests (both initial hot and final hot tests) starting at about the same value as the previous cold test, increasing significantly in the second and then dropping with further hot stroking. After the aging period, the behavior of the stem nut friction remains consistent with the initial baseline tests, both hot and cold performance.

Figure 17 contains the same data as Figure 16, but plotted as a function of time. Once again, the time scale on the axis shows the actual test dates, but this time the overall scale relates to a simulated five-year aging period and the vertical grid lines represent a simulated one-year interval. The data in Figure 17 show a slight increase in stem nut friction over the first 2.5 years, but no increase beyond the 2.5 years. This increase over the initial period and later stability is seen in both the Loaded and IST data. Stem nut friction for Stem 2 with MOV Long Life 28 appears to be stable over the simulated 5-year period.

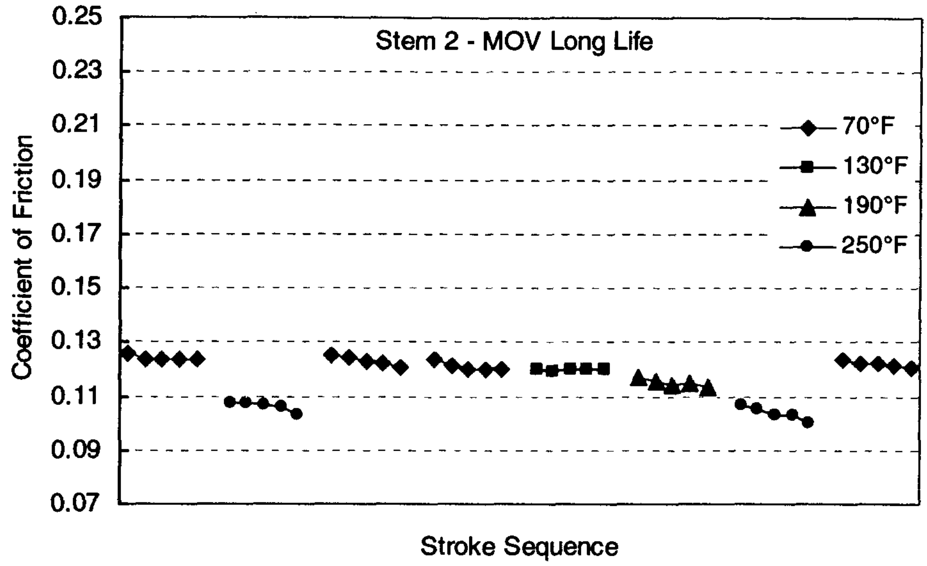

Figure 13. Running stem nut friction at elevated temperature for Stem 2 with MOV Long Life.

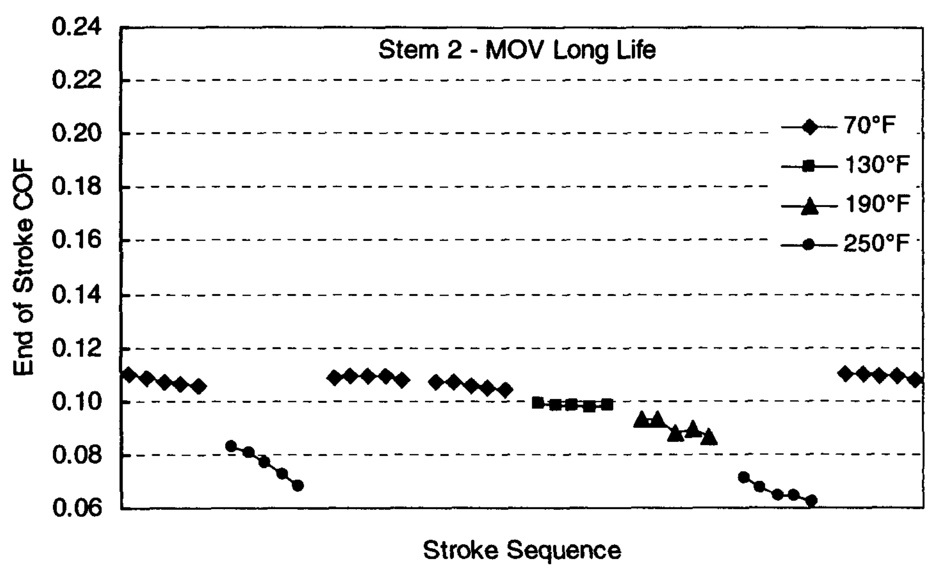

Figure 14. End-of-stroke stem nut friction at elevated temperature for Stem 2 with MOV Long Life.

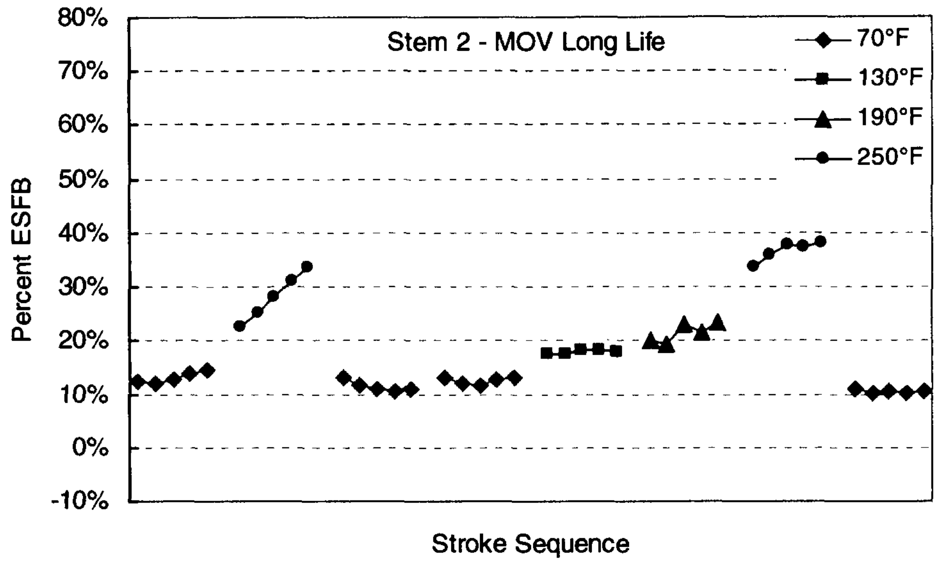

Figure 15. End-of-stroke friction behavior at elevated temperature for Stem 2 with MOV Long Life.

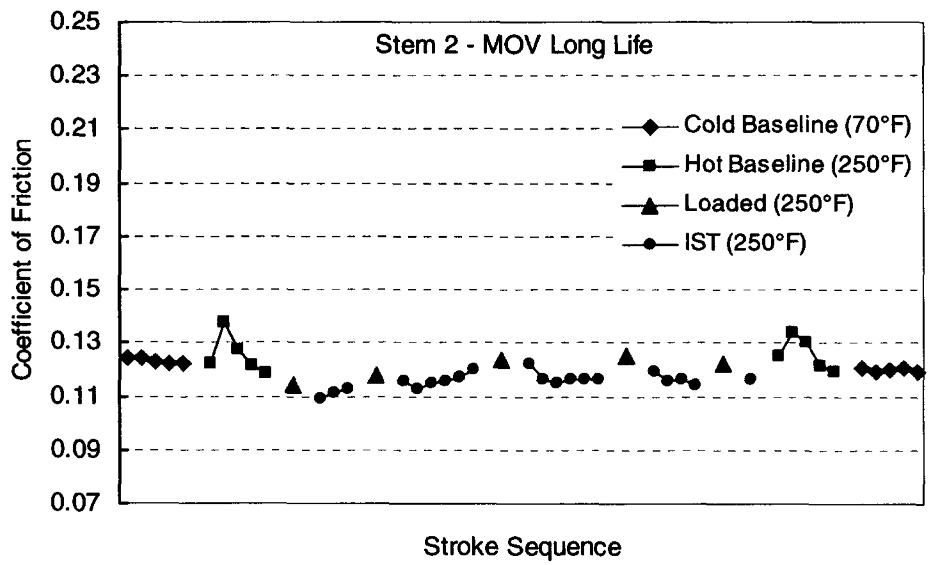

Figure 16. Aging test stroke sequence for Stem 2 with MOV Long Life.

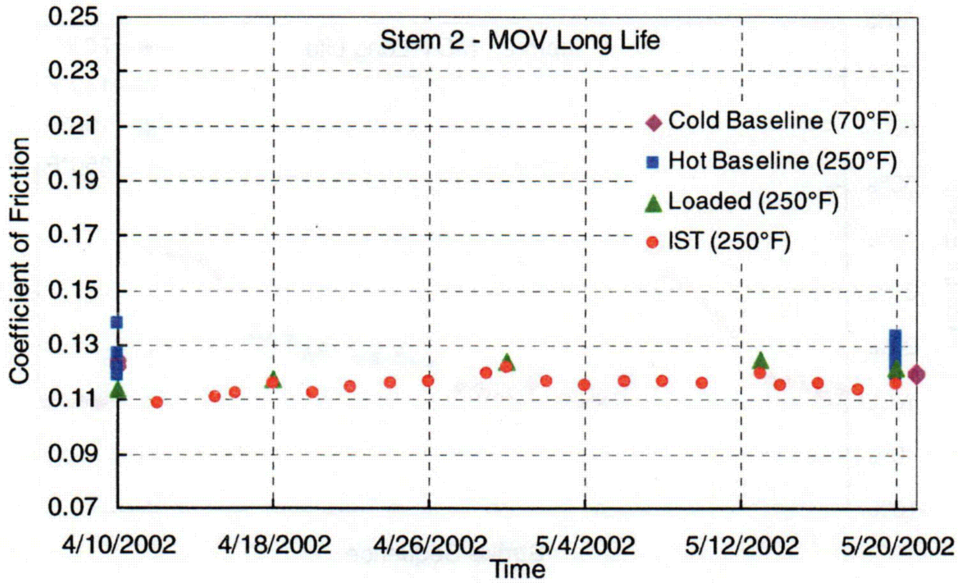

Figure 17. Aging test time line for Stem 2 with MOV Long Life.

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4. CONCLUSIONS

This research effort was performed to address the effectiveness of the lubricant used on the threaded portion of the valve stem. The effectiveness of this lubricant can greatly impact the thrust output of the valve actuator and reduce the margin for ensuring MOV performance at design basis. Our analysis looked at the aged performance of two lubricants on one valve stem. It also looked at a new lubricant on one stem to determine its load and end-of-stroke friction behavior, elevated temperature, and aging performance.

The results of this research provide an indication of how aging might affect stem and stem nut performance: however, one must keep in mind the limited sample size. The research used only one stem and stem nut combination and no repeat tests were performed. Past testing has shown that lubricants can perform quite differently on different stem and stem nut combinations. Also, stem and stem nut performance is not always repeatable with some lubricants. Additional testing with lubricants being applied to several different stem and stem nut combinations would be necessary to make more generic conclusions. Also, the accelerated aging applies to valves that operate in a cold environment. The data must be considered naturally aged for valves in environments near 250°F.

The following conclusions are based on this work.

- For Chevron SRI and Mobil Mobilgrease 28, lubrication aging does not appear to degrade the performance of stem and stem nut interface. For the single stem tested (Stem 2), the stem and stem nut friction did not increase during the aging period. In some cases, the final friction values for both the hot and cold tests were lower than the initial hot and cold values.

- On the single stem tested, the MOV Long Life lubricant's performance was similar or an improvement over that of other lubricants previously tested. MOV Long Life frictional performance, including end-of-stroke friction behavior, was stable and repeatable over a wide load range. Elevated temperature resulted in a lower friction coefficient than that observed at room temperature but resulted in greater rate-of-loading. Stem nut friction appeared to be stable over the simulated aging period.

5. REFERENCES

1. K. G. DeWall, et al, "Performance of MOV Stem Lubricants at Elevated Temperature," NUREG/CR-6750, INEEL/EXT-01-00816, United States Nuclear Regulatory Commission, October 2001.

2. F. M. Guérout, et al, Selection of Greases for Motor-Operated Valve Stem/Stem Nut Lubrication, "Proceedings of the Sixth NRC/ASME Symposium on Valve and Pump Testing," NUREG/CP-0152, Vol. 3, United States Nuclear Regulatory Commission, July 2000.

3. R. Steele, et al, "Gate Valve and Motor-Operator Research Findings," NUREG/CR-6100, INEL-94/0156, United States Nuclear Regulatory Commission, September 1995.

4. E. J. Cavey, "Equivalent Replacement Evaluation For MOV Gearbox Lubricant," MOV Users Group Position Paper, 6 May 2002.

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10. SUPPLEMENTARY NOTES
Jerry E. Jackson, NRC Project Manager

11. ABSTRACT (200 words or less)
This report documents the results of recent tests sponsored by the Nuclear Regulatory Commission (NRC) and performed by the Idaho National Engineering and Environmental Laboratory (INEEL). This research effort was performed to address the effectiveness of the lubricant used on the threaded portion of the valve stem. The effectiveness of this lubricant can greatly impact the thrust output of the valve actuator and reduce the margin for ensuring motor-operated valve (MOV) performance at design basis. The analysis looked at the aged performance of two lubricants on one valve stem. It also looked at a new lubricant on one stem to determine its load and end-of-stroke friction behavior, elevated temperature, and aging performance.

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