LUBRICATION OF THE LIMITORQUE ACTUATORS AT DRESDEN/QUAD CITIES NUCLEAR STATIONS

Prepared for Dresden - Units 2 & 3
and Quad Cities - Units 1 & 2
by the
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1.0 INTRODUCTION

The Limitorque valve actuators installed at Dresden/Quad Cities Nuclear Plants use two types of lubricants: Mobilux EP greases (actuator main gear box lubricant) and Mobilgrease 28 (actuator limit switch gear box lubricant). The main gear boxes were tested and are supplied for in containment applications with EXXON Nebula EPO grease, although Nebula EP1 can be used in place of the EPO. A Limitorque actuator test report (Reference 14) qualified EXXON Nebula EP1 grease (main gear box lubricant) and Beacon 325 grease (limit switch gear box lubricant) for DBA and 30 days of post-accident operation.

The Mobil greases Mobilux EPO, EP1 and EP2 and Mobilgrease 28 were subjected to a test program at Wyle Laboratories for the purpose of evaluating the greases' acceptability for use in Limitorque actuators at the Dresden and Quad Cities Nuclear Power Generating Stations.

It is the purpose of this document to provide a basis for the substitution of Mobilux EP and Mobilgrease 28 greases for the currently used EXXON Nebula EP1 and Beacon 325 greases and also to provide the technical basis for the Maintenance and Surveillance practices at Dresden and Quad Cities Stations.

2.0 LUBRICATION INSPECTION PROCEDURE

2.1 Limitorque Position

Limitorque does not define a specific service life for the lubricating greases. Limitorque Report B0058 (Ref. 5), Section 6.1, states "Life expectancy of the lubricants would be difficult to assess due to the

many variables that would differ from unit to unit located in the same Nuclear Plant. However, if the lubricant is maintained per Limitorque Procedure LC8 and not subjected to contamination, it would have a design life expectancy of 40 years."

2.1.1 Frequency of Lubrication (Per LC8)

The frequency of lubrication inspections should be based upon historical data of the installed equipment. Every operator application has its own effect on lubricants and each facility should pattern its inspections around its particular needs.

The following schedule of lubrication inspection is recommended by Limitorque.

Main Gear Case: Inspect lubrication at approximate intervals of 18 months or 500 cycles - whichever occurs first. Lubricate the Zerk fitting in the housing cover at the same interval.

Geared Limit Switch: Inspect lubrication at approximate intervals of 36 months or 1,000 cycles - whichever occurs first.

2.1.2 Lubricant Substitutes (Per LC8)

The actual greases utilized during Limitorque testing are the EXXON Nebula EP1 and Beacon 325. Mobilux EPO and Mobilgrease 28 are identified as acceptable substitutes for those tested or certified by Limitorque.

2.2 Nuclear Utility Group on Equipment Qualification (NUGEQ) Position

NUGEQ Report 03-89 (Reference 10) is a clarification of the Limitorque's test experience in light of recent industry attention to the environmental qualification of Limitorque actuators. Lubricants that can be

used in Limitorque actuators are identified in Form LC8 (Reference 6). The actual greases utilized during Limitorque testing were the EXXON Nebula EP1 and Beacon 325. Mobilux EP0 was identified as a substitute for those tested or certified by Limitorque. However, testing, analysis and qualification of the substitute lubricant was to be established by the user. The main gear boxes were tested and are supplied for in containment applications with EXXON Nebula EP0 grease, although Nebula EP1 can be used in place of the EP0. Limitorque warns against the mixing of lubricants with different soap bases. Since EXXON Nebula EP0 and EP1 have the same soap base, mixing, though not desirable, is acceptable.

Limitorque has tested and supplied Beacon 325 and Mobil 28 greases for the limit switch gear housing and cartridge assembly. Limitorque noted that the Beacon and Mobil greases should not be mixed. Finally, Limitorque recommends that the Mobil 28 be used in application when normal operating temperatures are greater than 150^{o}F.

2.3 INPO Position

INPO Report 83-037 (Reference 9) described the results of its investigation of approximately 600 Limitorque actuator failures or operational problems reported in LERs and NPRDs summaries. These failures were investigated with respect to failure - rate and age. This information was statistically analyzed by INPO to determine possible causes of valve operator inoperability. Several important observations with respect to identification of potential problems or maintenance requirements were made.

One failure mode that was identified that can be attributed to grease is the failure of the limit switch to perform its function due to one or more of the following

- degradation of the lubricants due to high temperatures (greater than 150^{o}F). The Dresden/Quad maximum bulk temperature is below 150^{o}F.

- lack of replenishment and/or changeout of the lubricant. The present maintenance and surveillance procedure measures grease levels.

- lubricant degradation due to moisture intrusion. Moisture intrusion is not expected in Limitorque actuators at Dresden/Quad Cities since they are installed in low humidity normal environment.

- improper replacement lubricant. Lubricants that are in use are acceptable replacement and are qualified to the specified conditions.

INPO also investigated specific hardware and personnel-related causes of failure by performing engineering evaluations of selected Limitorque actuator failures. The findings of this qualitative investigation with respect to actuator failures tended to support the statistically observed failure patterns, and enabled INPO to conclude that a 2 - 3 year maintenance and surveillance interval was appropriate for Limitorque actuators in nuclear safety related service. Based on INPO's review of nuclear industry operating experience, it is reasonable that the inspection period can be extended from the 18 month period recommended by Limitorque Corp. to a maximum of 36 months.

INPO Report 83-037 qualitatively discussed the importance of periodic maintenance, including general maintenance action recommendations. The study; however, did not investigate the level or frequency of maintenance performed on the actuators which formed the study data base. An implication of the study was that few preventive maintenance actions were performed for the Limitorque population reviewed by INPO. Therefore, it is likely that the maintenance and surveillance interval could be extended beyond 36 months if justified with plant-specific maintenance and operational experience data.

2.4 Current Requirements at Dresden/Quad Cities Nuclear Stations

The following are the current lubrication maintenance and surveillance requirements at Dresden/Quad Cities Nuclear Stations (References 1 and 2).

a. Routine maintenance and surveillance actions are to be performed every other refueling outage (approximately 3 years). These actions include external and internal inspections, operability checks, and lubrication checks.

b. Routine lubrication of the main gear case every other refueling outage (approximately 3 years).

c. Periodic cycling of the valve actuators, not less than twice a year except in a few cases which are cycled only during every outage.

3.0 GREASE QUALIFICATION

Mobilux EP greases and Mobilgrease 28 were subjected to an environmental qualification test as documented in Wyle Test Report 17019-01 (Reference 15). Reference 3 qualifies these greases for a minimum of 38.6 years and a Design Basis Event at Dresden/Quad Cities Nuclear Stations.

3.1 Similarity Analysis

3.1.1 Mobilux EP0/EP1/EP2 Against EXXON Nebula EP1:

Limitorque Lubrication Data Form LC8 (Reference 6) indicates that Mobilux EP0 grease is an acceptable substitute for "EXXON" Nebula EP1 because of many similar properties. Both greases have similar operating temperature range for -20°F (-29°C) to 250°F (121°C) (Reference 11 (i) and (ii)). Refer to reference 12 for additional information.

Per Bechtel Corporation letter (Reference 13 and Attachment 2), Mobilux EP1 and EP2 are compared to the properties of Nebula EP1 and found to be similar and acceptable for use in Limitorque operators. The major

difference between the three greases are the lower dropping points (point at which the grease begins to pass from a semisolid to a liquid state) of Mobil products (340°F and 350°F versus greater than 500°F for Nebula EP1). The lower dropping point is acceptable based upon the following:

- The normal operating temperature (150°F) is significantly less than the dropping point temperature.

- The peak accident temperature does reach the dropping point temperature, however, because of its transient nature and short duration it is doubtful that the grease would reach this temperature.

- The post accident temperature is below the dropping point temperature.

- The Limitorque gear boxes are sealed, so if liquefaction does occur, the grease would be contained ensuring sufficient lubricant is available to lubricate the gears. This was shown by testing (Ref. 15) wherein the liquified greases did not leak out of the gear boxes up to the conclusion of the test.

3.1.2 Mobilgrease 28 Against Beacon 325:

The Limitorque Lubrication Data Form LC8 (Reference 6) also indicated that Mobilgrease 28 is an acceptable substitute for Beacon 325 grease. Mobilgrease 28 can be used for performance temperatures up to 350°F (Reference 11 (iii)). Mobilgrease 28 has a temperature rating superior to Beacon 325 (Reference 11 (iv)).

3.1.3 Mobilux EP0, EP1 and EP2:

Per Ref. 22, Mobilux EP0, EP1 and EP2 are unleaded, multi-service extreme pressure greases compounded with a lithium 12-hydroxystearate soap base and a combination of mineral oils. These three greases are identical in composition, with the exception of the relative amounts of base

oil and soap thickener. The amounts and types of additives are identical, and the types and ratio of base oils are identical. Mobilux EP0 contains less lithium 12-hydroxystearate thickener and more base oil than Mobilux EP1. Mobilux EP1 in turn contains less thickener and more base oil than Mobilux EP2. Following exposure to identical environmental conditions which produce thermal or radiation - induced stresses, the extent of degradation of the three greases is essentially equivalent.

IR scan data from the Wyle Lab EQ Program (Reference 15) indicates that a similar degree of chemical change occurred in Mobilux EP0 and Mobilux EP2. Visual inspection conducted at the conclusion of the environmental tests further substantiate the above statement, both Mobilux EP0 and EP2 grease samples showed no evidence of separation but both have shown evidence of grease lumping.

3.2 Life Evaluation

For the purpose of evaluating the acceptability of using the Mobilgreases in Limitorque actuators at the Dresden and Quad Cities Nuclear Stations, Mobilux EP0, 1, 2 and Mobilgrease 28 were subjected to a test program which consisted of:

- Radiation Exposure: Total integrated dose of 13.2 megarads
- Thermal Aging: 300 Days at 250^{o}F (except EP0)
  100 Days at 250^{o}F (EP0)
- Cycle Aging: The greases were installed in actuators and then the actuators were cycle tested to simulate at least 120 full strokes and return cycles

- Accident Simulation: 349°F for 30 minutes
  287°F for 40 minutes

CQD-042827 (Ref. 3) calculates the qualified life of the subject greases to be 38.6 years at 150°F using the 10°C Rule.

4.0 JUSTIFICATION FOR USING THE 10-DEGREE CENTIGRADE RULE

4.1 The 10°C Methodology

The "10 - Degree Rule" is an approximate relationship which describes the rate of a temperature-dependent reaction. It is an empirical rule which has historically been found to reasonably fit the observed data. Another method of correlating the time temperature relation is the Arrhenius model. The Arrhenius model has a theoretical basis, whereas the "10 - Degree Rule" does not. The method utilized is acceptable only if its predictions are consistent with actual experience.

The "10 - Degree Rule" basically states that life is reduced by one-half for each increase in temperature of 10°C.

4.2 Basis for the 10-Degree Rule Approach

4.2.1 EPRI Document No. NP-4916 - "Lubrication Guide", January 1987

This document illustrates the interaction of temperature, time and irradiation on high quality lubricant under stress. The figure in this document shows how time, temperature and irradiation relate to lubricant life (point at which change-out is necessary). The vertical scale is logarithmic and gives lubricant life in hours. The horizontal scale is the inverse of absolute temperature. Inside this figure is a band, the slope of which represents an approximate doubling of life for every 10°C (18°F) temperature decrease. This decrease is expected for chemical reactions.

Chemical reaction rate approximately doubles with each increase of $10^{o}C$ ($18^{o}F$) in temperature. If the reaction rate is very low, there is not as much effect on life. If the reaction rate is appreciable, doubling has a discernible effect.

It was noted that at $66^{o}C$ ($150^{o}F$) lubricant life would be extended and off the chart at 300 months. Of course, lubricant life cannot be extended indefinitely - contamination from dirt, wear debris, etc., may dictate a shorter change out interval.

4.2.2 EPRI Document No. NP-4735 - "Radiation Effects on Lubricants", August 1986

This document presents test data on the effect of temperature and radiation on bearing performance of a grease by creating an Arrhenius plot (log bearing life versus a function of inverse absolute temperature). In regards to this plot the document states that the bearing life is cut in half with each $10^{o}C$ rise in temperature. It further notes that the scatter of test data points is indicative of the imprecision of tests of this sort and is typical of chemical reactions in general.

4.2.3 Journal of the American Society of Lubrication Engineers - Lubrication Engineering, November 1974

This publication illustrates a general pattern for estimating grease life for ball bearings in industrial equipment, such as electric motors.

It states that with most greases operating in the neighborhood of $100^{o}C$ ($212^{o}F$) bearing temperature, life in laboratory tests drops by a factor of about 1.5 for each $10^{o}C$ ($18^{o}F$) rise. This implies that the $10^{o}C$ Rule, which states that life drops by a factor of 2 with each $10^{o}C$ rise, is very conservative.

4.2.4 NRC Information Notice No. 88-12 - April 12, 1988

A portion of this 1E Notice correlates the grease life to bearing temperature. It states "A rule of thumb, based on certain manufacturers tests, is that grease life is halved for every 25°F increase in temperature and is doubled for every 25°F decrease in temperature." The 10-Degree Rule, which states that the grease life is halved for every 10°C (18°F) increase in temperature is a refined approach by EPRI Document No. NP-4735 and NP-4916 after considerable research.

4.2.5 Bearing Manufacturers Manuals

A number of bearing manufacturers, in their evaluation of bearing life in relation to the lubricant used, support the principle of the 10-Degree Rule. The following are the positions taken by certain bearing manufacturers.

- Rollway Bearing Division - Lubrication Manual RED 83-2, Feb. 1987.

  "Grease is subject to the general rule that, above a critical temperature, each 15°F of rise in temperature cuts the oxidation life of lubricant in half."

- Fafnir Bearings Division of the Torrington Co. - Lubrication Guide Form FA-515, 2nd Edition.

  "It is estimated that the life of an oil will be decreased 50% for every 18°F temperature rise and increased 50% for reductions in temperature of 18°F."

- SKF Bearing Industries Co. - Bearing Installation and Maintenance Guide 140-710, Aug. 1988.

  "The demand of oil by the bearing depends of course, on operating conditions - particularly that of temperature since

a temperature rise of 8^{o} to $11^{o}C$ (14^{o} to $20^{o}F$) can double the rate of oxidation."

4.3 Evaluation

The determination of when a grease is no longer capable of satisfactory accomplishing its lubricating function is difficult to define. Many factors affect the life of grease including type of grease, operating environment, load and application. To properly simulate these factors, the Mobilux EP0, EP1, EP2 and Mobilgrease 28 greases were subjected to the postulated environmental conditions at Dresden/Quad while installed in a prototype Limitorque gear box. This test demonstrated the suitability of the subject greases to the Limitorque operators. The life of the grease was determined using the $10^{o}C$ rule which correlated the accelerated thermal aging testing performed to the normal operating temperature.

The above documents and publications clearly manifest the industry's acceptance of the 10-Degree Rule as a reasonable model relating to the lubricants physical and chemical behavior to thermal stresses.

The qualification test program on Mobil greases (Ref. 15) subjected Mobilux EP0, EP1, EP2, and Mobilgrease 28 to a 40 year equivalent thermal life at the service temperature of $150^{o}F$. Therefore, the recommended lubrication check interval of 36 months is conservative and is largely dictated by the possible grease deterioration due to other factors such as dirt, dust, wear debris, moisture, etc. The gear boxes of the Limitorque actuators are sealed for use in all orientations to prevent entry of dirt and dust.

5.0 CONCLUSION AND RECOMMENDATIONS

Based on the above discussion, the following positions taken by Dresden/Quad Cities Nuclear Stations are deemed acceptable.

- The use of the $10^{o}C$ Rule in the grease qualification.

- The use of Mobilux EP greases and Mobilgrease 28 in lieu of EXXON Nebula EP1 grease and Beacon 325 grease.

- A three-year maintenance and surveillance interval which would ensure that the consistency, quality, and quantity of the grease are sufficiently maintained for proper operation of the actuators.

6.0 REFERENCES

1. CQD-017511, CQD-017504, CQD-017510, CQD-017512 and CQD-017509, Environmental Qualification of Limitorque Actuators, Dresden Units 2 and 3.

2. CQD-017515, CQD-017517, CQD-017514, CQD-017516 and CQD-017513, Environmental Qualification of Limitorque Actuators, Quad Cities Units 1 and 2.

3. CQD-042827 "Qualification of Mobile Oil Co. Greases Mobilux EP-0, EP-1, EP-2 and Mobilgrease 28 Dresden/Quad Cities Nuclear Stations," Rev. 01. 09-27-89. **

4. NRC Information Notice No. 88-12 - April 12, 1988. *

5. Limitorque Corporation Qualification Test Report B0058. Limitorque Valve Actuator Qualification for Nuclear Power Station Service Tests Conducted for IEEE 382(72), 323(74), and 344(75), dated 06-11-80.

6. Limitorque Corporation Appendix A to B0058, Lubrication Data Form LC8, 10-13-79, Lubrication Inspection Procedure and Data. *

7. Limitorque Corporation Appendix A to B0058, Limitorque Maintenance Procedure Form LC9, 06-21-77. *

8. Limitorque Corporation, Limitorque type SMB, Instruction and Maintenance Manual Bulletin SBMI-82B, 1982. *

9. Assessment of Motor Operated Valve Failures INPO Report 83-037, 10-83.

10. NUGEQ, 03-89, "Clarification of Information Related to the Environmental Qualification of Limitorque Motorized Valve Operators."

11. Technical data Sheets for (i) EXXON Nubula EP (03-14-83), (ii) for Mobilux EP0, 1, 2 (iii) Mobilgrease 28, (iv) NRC Information Notice No. 79-03 of 02-09-79 for Beacon 325 Lubricant. *

12. Comparison Between Physical Properties of Mobilux EP0 and Nebula EP1 Lubricants (contained as Reference 6 of Bechtel Package 31.M391.02D). *

13. Bechtel Letter from L. Lucas to J. Hausman (CECo), 10-21-85 (contained as Reference 7 of Bechtel Package 31.M391.02D). *

14. Limitorque Corporation Report 600376A, May 13, 1976 and Addendum A, Rev. B, 01-23-79.

15. Wyle Report 17019-01, "Nuclear Environmental Qualification Test Program on Mobile Greases for Limitorque Actuators," dated 09-15-89. *

16. EPRI Document No. NP-4916 "Lubrication Guide," 01-87. *

17. EPRI Document No. NP-4735 "Radiation Effect on Lubricants," 08-86. *

18. Journal of the American Society of Lubrication Engineers - Lubrication Engineering, 11-74. *

19. Rollway Bearing Division - Lubrication Manual RED 83-2, Feb. 1987. *

20. Fafnir Bearing Division of the Torrington Co. - Lubrication Guide Form FA-515, 2nd Edition. *

21. SKF Bearing Industries Co. - Bearing Installation and Maintenance Guide 140-710, Aug. 1988. *

22. R. R. Terc (Mobil Oil Corporation) letter to Z. Boxer (CECo), 03-13-89. *

*** Attached to B.L. Siegel and M.J. Kopp copies only**

**** Attached to ALL NRC copies**

1. CQD-017511, CQD-017504, CQD-017510, CQD-017512 and CQD-017509,

Environmental Qualification of Limitorque Actuators, Dresden Units 2 and 3

(not included)

2. CQD-017515, CQD-017517, CQD-017514, CQD-017516 and CQD-017513,

Environmental Qualification of Limitorque Actuators, Quad Cities Units 1 and 2

(not included)

3. CQD-042827, "Qualification of Mobil Oil Company Greases Mobilux EP-0, EP-1, EP-2 and Mobilgrease 28 Dresden/Quad Cities Nuclear Stations", Revision 01 September 29, 1989