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A comparison analysis of the stem lubricant performance for motor operated valve used in nuclear power plants

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원자력발전소에서 사용중인 모터구동밸브 스템 윤활유의 성능 비교 분석

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ABSTRACT

In this study, the performance test was carried out under various operation conditions targeting four representing types of lubricant which are mostly used in nuclear power plants, and mutually compared the characteristic and performance of lubricant. Especially, introducing the concept of the thread friction coefficient (hereinafter, TFC), which makes the friction relation between the stem nut and stem screw dimensionless. The test was performed to compare the lubricant performance for the four kinds of lubricant (Texaco, Alvania, Mobilux, MOVLL). In a test of the room temperature stem, the TFC of MOV Long Life shows the lowest value, next to Alvania EP2, Texaco EP2, and Mobilux EP0 in that order. And in a test of the high temperature stem, the TFC of Texaco EP2 shows the lowest, next to MOV Long Life, Alvania EP2, and Mobilux EP0 in that order. From the test result of the aging condition, three types of lubricant (MOV LL, Texaco EP2, Alvania EP2) show similar patterns up to 36 months, but in 60 months, the TFC of lubricant are increased rapidly.

Key Words : Motor Operated Valve, Lubrication Performance, Thread Friction Coefficient, Aging Condition

1. Introduction

A motor operated valve is one of the most important equipment to relieve an accident in nuclear power plant. After TMI(Three Mile Island) nuclear power plant accident, the U.S. NRC(Nuclear Regulatory Commission) issued a safety evaluation guide(General Letter 89-10) for all safety related motor operated valves in the U.S. nuclear power plants. To fulfill the regulatory requirements, many studies have been conducted by nuclear power utilities and research institute in the U.S.. A lubricant is injected between the stem nut and stem of the motor operated valve, and this plays a role of transferring the output power generated from the actuator to the valve effectively by relieving the mutual friction between the stem nut and stem during the valve operation. For the U.S., the studies in the characteristic and performance analysis of stem lubricant are actively being carried out around EPRI(Electric Power Research Institute). AECL(Atomic Energy of Canada Limited) has carried out the lubricant test about the maturing aging processes under the high temperature condition and recently, a Long-life lubricant has also been developed which can extend the replacement period of the lubricant.

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In this study, the lubricant performance test was carried out under various operation conditions targeting four representing types of lubricants which are mostly used in domestic nuclear power plants, and mutually compared the characteristic and performance of lubricant. Especially, introducing the concept of the thread friction coefficient (hereinafter, TFC), which makes the friction relation between the stem nut and stem screw dimensionless, the effect of lubricant performance on the actuator of the motor operated valve was evaluated quantitatively to recognize its phenomenon and effect simply and easily.

2. Analysis on relation between TFC and lubricant performance

The power transfer mechanism of the motor operated valve is shown in figure 1. The rotational force of the motor is transferred to the stem nut through a helical gear and worm gear and stem nut is connected with a stem to move the stem up and down so that the valve disc shall be actuated. During the process of converting the torque generated at the actuator into stem thrust, the loss of force occurs due to the friction between the stem nut and stem. In order to minimize the loss of force, the formation of proper lubricant film between the stem nut and stem is necessary. If maintained a good lubricant film between the stem nut and stem, the torque generated in the actuator can be transferred to the stem thrust effectivlely. The friction occurred between the stem nut and stem is expressed the dimensionless equation(1).

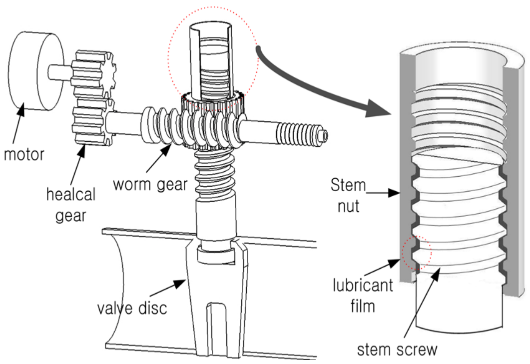

Fig. 1 Structure of motor operated valve stem nut and stem

$$\mathrm{TFC} = 0.046 + \frac{2{,}000\left(\frac{\mathrm{torque}_m}{\mathrm{thrust}_m}\right)\cos\theta - d\cos\theta\tan\alpha}{2{,}000\left(\frac{\mathrm{torque}_m}{\mathrm{thrust}_m}\right)\tan\alpha + d} \qquad (1)$$

Here, TFC : Thread Friction Coefficient

d : stem thread pitch diameter

α : stem thread lead angle(deg)

θ : stem thread pressure angle(deg)

Figure 2 shows the relation between TFC and the thrust of the actuator. If TFC increases from 0.15 to 0.2, the actuator output thrust changes from 1.0 to 0.77. It can be known that the thrust of the actuator suffers a 23% loss. On the other hand, if TFC decreases from 0.15 to 0.08, the actuator output thrust changes from 1.0 to 1.71. So It can be known that the thrust of the actuator force increases by 71%. Therefore, we can conclude in order to obtain a higher output thrust at the same output torque of the motor, reducing TFC is very inportant parameter.

In this study, tests were carried out on four types of lubricants; three types of lubricants being used mostly in domestic nuclear power plants and including MOV Long Life being used in nuclear power plants in the U.S.

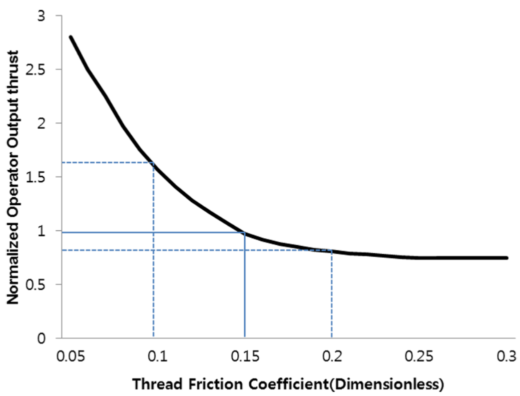

Fig. 2 Sensitivity of thread friction coefficient

3. Test equipment and conditions

3.1 Test equipment

The test equipment is to measure the torque and thrust which is generated between the stem nut and stem of the motor operated valve. It is composed of motor actuator, stem/stem nut, and hydraulic system(Fig. 3). The motor actuator is a Limitorque actuator SMB-00 model which is being used mostly in nuclear power plants. The stem and stem nut were manufactured to disassemble and assemble for easy replacement of the lubricant and stem nut and stem(Fig. 4). A strain gauge sensor is attached on the stem; it can measure the torque and thrust simultaneously(Fig 5). In the hydraulic system, it is designed to maintain a constant load in the cylinder by oil pressure during the stem operation. Using a diagnosis equipment, the current and voltage of the motor, the thrust and torque of the stem, and displacement of the stem are measured. Figure 6 shows the current, torque, and thrust signal acquired through the diagnosis equipment.

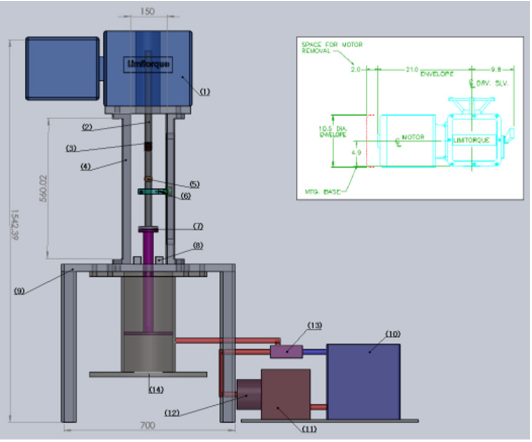

Fig. 3 Test equipment

Fig. 4 Stem & stem nut

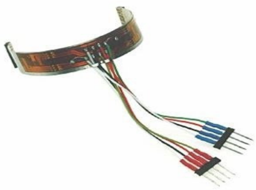

Fig. 5 Strain sensor

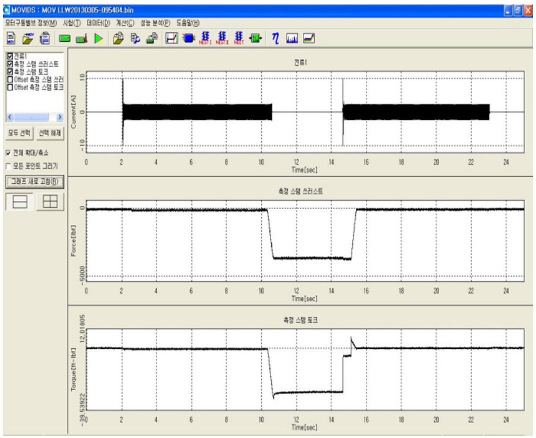

Fig. 6 Test signals (current, torque, thrust)

3.2 Test condition Ⅰ - repetitive loads

When the lubricant which is injected between the stem and stem nut repetitively receives a operation load, the viscosity and chemical characteristic of the lubricant may be changed. Repetitive loads test was performed to analyze how the lubricant affects the TFC on the repetitive load. Conservatively, it is assumed that a safety related motor operated valve installed at the nuclear power plant is operated 24 times per year, and it is operated 240 times in 10 years. Therefore, the test was determined to be repeated 240 times. The test temperature was determined to be two kinds in a case when the fluid passing through the valve is at room temperature (25°C) in general and a case when the temperature of the valve stem is high (average stem temperature 50°C), as the temperature of the fluid is high like a main feed water system and a main steam system.

Table 1 Test conditions of repetitive load

Temperature condition	State of lubricant	No. of test	Max. load
25°C	New	240 times	17,760 N
50°C	New	240 times	17,760 N

3.3 Test condition Ⅱ - aging lubricant

When the lubricant is used for a long period without replacement and exposed to the bad environment, its lubrication performance shall be degraded due to the aging of lubricant. In this test, in order to realize the aging state of the lubricant unchanged for a long period, an Accelerate Lifecycle Test implemented. In order to determine the accelerating time, the '10°C rule' was implemented, which had been developed on the basis of the Arrhenius model. The '10°C rule' is the theory that when the temperature rises by 10°C, the life span is reduced by 50%. Its applicability has been confirmed through the relation graph of time and temperature by the EPRI(Electric Power Research Institute) report. The equation(2) is an Arrhenius equation which shows the relation of the reaction speed constant and temperature.

$$\mathrm{Life} = Ae^{-\Phi/kT} \tag{2}$$

Here, Life : Reaction speed constant

A : Frequency constant

Φ : Activation energy (eV)

k : Boltzman constant ($0.8619\times10^{-5ev/K}$)

T : Absolute temperature (℃)

Currently, as the stem lubricant in domestic nuclear power plants has been generally replaced once every 5 years at the time of complete disassembly of the valve, it was assumed that the aging occurs in 5 years at maximum in room temperature. Types and numbers of the aging test are as shown in Table 2. Figure 7 ∼ 10 show the aging lubricant.

Table 2 Conditions of aging lubricant test

Temp. condition	State of aging	Accelerating temp.	Accelerating hour
25˚C	18months	115˚C	25.6 h
	36months	115˚C	51.3 h
	60months	115˚C	85.5 h

Fig. 7 Texaco EP2 lubricant

Fig. 8 Alvania EP2 lubricant

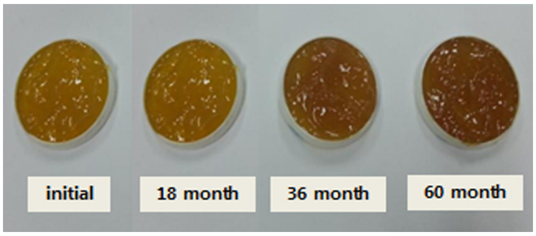

Fig. 9 Mobilux EP0 lubricant

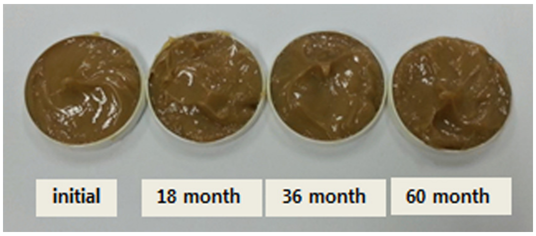

Fig. 10 MOV long life lubricant

4. Test result and analysis

4.1 Test result of repetitive load operation

4.1.1 Analysis on the effect of stem temperature

For each lubricant is tested on room temperature stem(25°C) and high temperature stem(50°C). Figure 11 show the effect of valve stem temperature for four lubricants. Normally, density of lubricant become thin at high temperature codition and lubrication performance gets worse. Alvania EP2, Mobilux EP0 and MOV Long Life, TFC of high temperature stem show high value than that of room temperature stem and the gap of TFC value showed large relatively. For the Texaco EP2, TFC of room temperature stem show high value than that of high temperature stem but the value gap showed small relatively in initial performance and repetitive operation conditions. As a result, Texaco EP2 is relatively stable on the change of stem temperature. But other lubricant is sensitive to stem temperature.

4.1.2 Analysis of lubricant performance on room temperature stem

Figure 12 and Table 3 show the lubrication performance each lubricant during the repetitive operation respectively on a room temperature stem. For the Texaco EP2 lubricant, initial value of TFC was measured as 0.1259, which is the largest among four types of lubricants, but as the

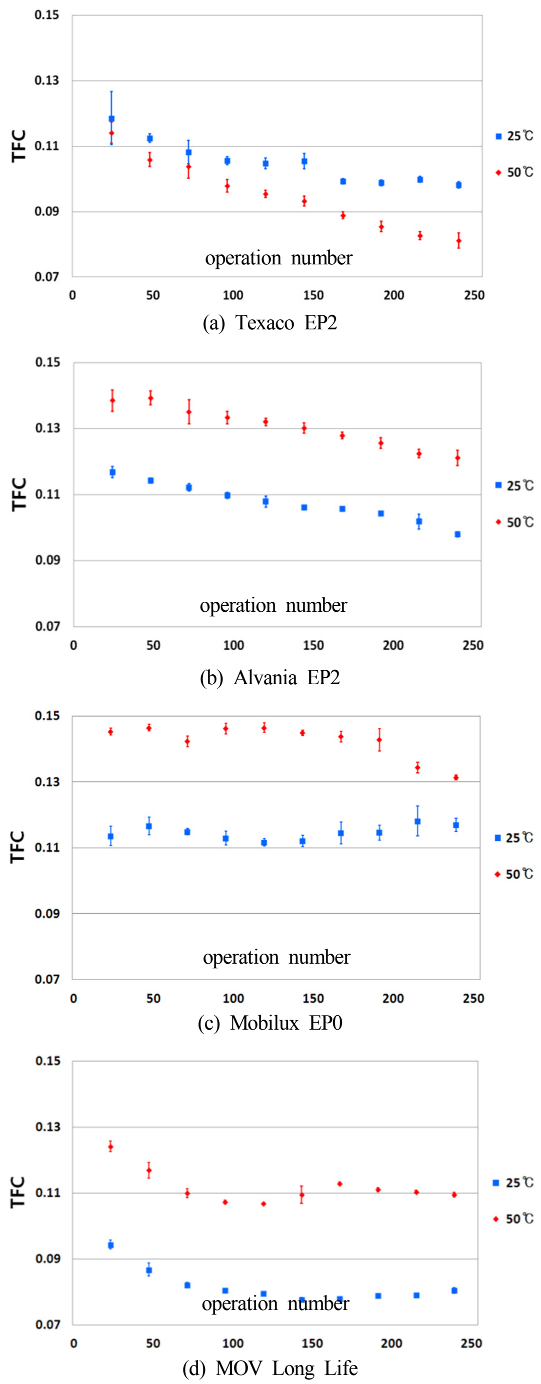

Fig. 11 Lubricant Performance on stem temperature

repetitive operation was carried out, TFC continually dropped and finally TFC decreased to 0.0983. For Alvania EP2, it showed a similar performance as in Texaco EP2.

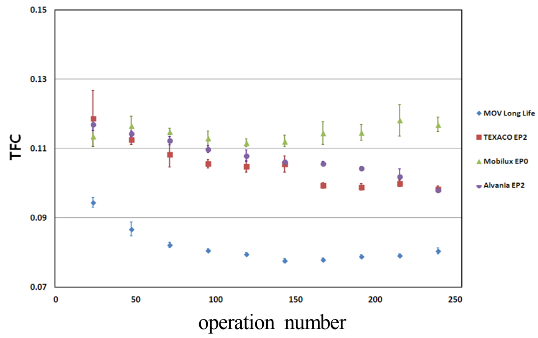

Fig. 12 Lubricant performance at room temperature repetitive operation

Table 3 TFC value of lubricant (at room temperature stem)

Rank	1	2	3	4
Lubricant	MOV LL	Texaco EP2	Alvania EP2	Mobilux EP0
TFC	0.0805	0.0983	0.0980	0.1170

For the Mobilux EP0, the initial value of TFC was 0.1109. After 240 repeated operations, TFC shows 0.1170, which showed little decline of performance, The performance change curve was relatively constant, it is judged that the performance change by the repetitive operation was minor. For the MOV Long Life, the initial value of TFC was 0.0954, and as the repetitive motion was carried out, TFC dropped continuously, and at 145 repeated operations, it dropped to 0.0805 and converged to a similar value until 240 repeated motions. From the result of the test, at the initial period, the performance of MOV Long Life was excellent, and the performance of Texaco EP2 was the worst. However, it showed a trend that the TFC values of MOV Long Life, Texaco EP2 and Alvania EP2 were gradually lowered when the repetitive load was applied. But only Mobilux EP0 showed that there was no greatly change compared to the initial performance.

4.1.3 Analysis of lubricant performance on high temperature stem

Figure 13 and Table 4 show lubricant performance during the repetitive operation on high temperature stem. For Texaco EP2, the initial value of TFC was 0.1151, which showed the lowest among the four lubricants, and as the repetitive operation was carried out, TFC was

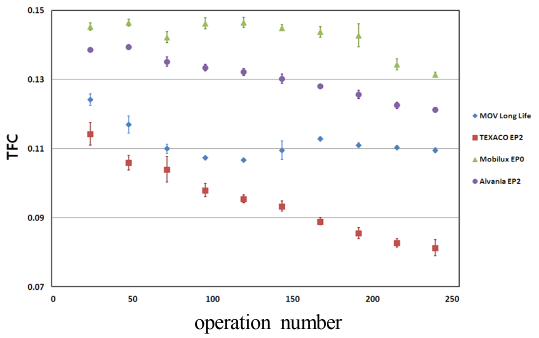

Fig. 13 Lubricant performance at high temperature repetitive operation

Table 4 TFC value of lubricant (at high temperature stem)

Rank	1	2	3	4
Lubricant	Texaco EP2	MOV LL	Alvania EP2	Mobilux EP0
TFC	0.0812	0.1095	0.1212	0.1314

decreased to 0.0812. In case of Alvania EP2, the initial value was 0.1383, and during 240 repeated operations, it decreased to 0.1212. For Mobilux EP0, the initial value was 0.1445, and decreased to 0.1314 during 240 operations. For MOV Long Life, the initial value of TFC was 0.1252, and as the repetitive operation was carried out, TFC dropped and rose again after 120 times, and it converged to 0.1095 during 240 repeated operations. From the result of the test, in the condition of a high temperature stem, TFC of Texaco EP2 showed the lowest, qualifying it for excellent evaluation in the performance of the lubricant. It was judged that in Mobilux EP0 and MOV LL, the deviation of TFC appear relatively low during the initial operation and 240 repeated operations that it may maintain a stable performance of the lubricant in the condition of high temperature.

4.2 Comparison of lubricant performance on aging condition

Figure 14 and Table 5 show the performance of the lubricant in an aging condition. For the MOV LL, TFC with an 18-month aging condition shows a relatively much lower value than that of initial lubricant. The TFC of the lubricant with a 36-month aging condition exceeds the initial TFC, and 60-month aging condition shows

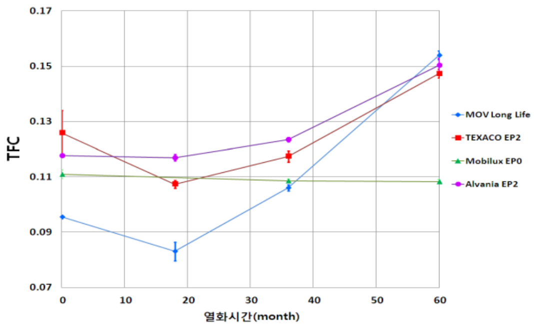

Fig. 14 Lubricant performance on aging condition

Table 5 TFC values of lubricant on aging condition

Rank	1	2	3	4
Lubricant	Mobilux EP0	MOV LL	Texaco EP2	Alvania EP2
TFC (average)	0.1087	0.1307	0.1311	0.1372

rapid elevation. In Texaco EP2, TFCs of 18-month and 36-month aging condition show lower than the initial TFC, and the TFC of 60-month aging condition shows a rapid increase. In Alvania EP2, TFCs of lubricant with an 18-month and 36-month aging condition do not show a greatly increase than the initial TFC, but that of the lubricant with a 60-month aging condition show a greatly increase. In Mobilux EP0, as every TFC of the initial, 36-month, and 60-month show similarity, it is judged that the lubricant is not nearly affected by the aging condition. From the result of the aging condition test, three kinds of lubricant (MOV LL, Texaco EP2, Alvania EP2) show similar patterns, and up to 36 months, they have the similar value as the initial TFC, but in 60 months, it showed that the TFC increases rapidly. Therefore, when the valve is operated in a condition which generates the aging condition easily as the stem lubricant is exposed to the inferior performance decline of lubricant is expected to be greater. It is judged that if possible, replacing the lubricant before 60 months is effective to maintain the performance of the actuator. As the rest of the three types of lubricants show the similar result at the point of aging for 60 months, the rank of Table 5 was determined by the average value from the point of aging 36 months and 60 months.

5. Conclusions

A repetitive operation test and an aging condition test were carried out for four types of stem lubricant, and their results were deduced as follows.

- In case of the repetitive operation (240 times) test with room temperature stem, the TFC of MOV Long Life shows the lowest value, next to Alvania EP2, Texaco EP2, and Mobilux EP0 in that order.
- In case of the repetitive operation (240 times) with high temperature stem, the TFC of Texaco EP2 shows the lowest, next to MOV Long Life, Alvania EP2, and Mobilux EP0 in that order.
- Among four types of lubricant, three types show a lower TFC in a condition of a room temperature stem than that of a high temperature stem. Therefore, it is generally judged that the performance of the stem lubricant worsens in a high temperature stem.
- In case of the aging condition test, three types of lubricant (MOV LL, Texaco EP2, Alvania EP2) show similar patterns, and up to 36 months, they have the similar value as the initial TFC, but in 60 months, the TFC of lubricants are increased rapidly.
- Therefore, the stem lubricant in which the aging condition can be generated easily because of its exposure to an inferior atmosphere with high temperature and humidity, the performance decline of the lubricant is expected to be greater, and thus it is judged that if possible, replacing the lubricant within 60 months is effective to maintain the performance of the actuator.
- It shows that Mobilux EP0 is not nearly affected by the aging condition as it maintains the similar value up to a 60-month aging condition.

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