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A Study on the Stem Coefficient of Friction of Motor-Operated Gate/Globe Valves

Rae-Hyuck Jeoung, Sung-Keun Park, Do-Hwan Lee, and Yang-Seok Kim
Korea Electric Power Research Institute
103-6 Munjidong, Yuseung-gu, Daejeon 305-353, Korea
j-r-h@hanmail.net

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Abstract

Stem-stem nut coefficient of friction(COF) in motor-operated gate/globe valves is one of the important factors which determine the performance of the valve/actuators. The COF is affected greatly by the type and condition of the stem-stem nut lubricants, environmental parameters, surface condition of the stem/stem-nuts, and the number of strokes after the lubrication. In this paper, the measured data of the COFs at stem threads of some safety-related motor-operated gate/globe valves in domestic nuclear power plants are presented. In addition, the performance of the lubricants is evaluated by comparing the COFs among those valves. The results show that the measured COF at torque switch trip are higher than the unwedging COF and conservatively applicable to the unwedging COF. It is also shown that the lubricating performance based on the measured COFs varies with the lubricants.

Key Words : motor-operated valve, stem coefficient of friction, probability density function, thread pressure, stem factor, cumulative distribution function, unwedging, torque switch trip

1. Introduction

Motor-operated gate/globe valves are one of the significant components whose main functions are to isolate or control the flow in the pipeline systems. In nuclear power plants, especially, the improper operating or the malfunction of a safety-related motor operated valve (MOV) may affect the safety of the plants. Therefore, the operability of MOVs is very important to guarantee the plant safety during the plant lifetime.

To evaluate the operability of a safety-related MOV under the design basis conditions, the following analysis and diagnostic approach is generally accepted:

(1) Review of design basis conditions of the valve
(2) Confirmation of the proper control switch setting by diagnostic tests
(3) Evaluation of the valve operability under design basis conditions

In the design basis review, the differential pressure across the valve, the required thrust and torque, and the actuator output torque at degraded voltage are reviewed and the weak link analysis is also performed. Based on the results of the design basis review, the diagnostic static testings are made mainly to confirm or adjust the control switch setting under the static condition without flow and system pressure. Also, the dynamic diagnostic tests are performed in the design base condition to obtain the key parameters, such as valve factor and rate of loading effect. Finally, the valve operability under the design basis conditions is evaluated in terms of operability margin between the required thrust and the actuator capability, based on the results of the design basis reviews and diagnostic testings.

The actuator capability is expressed as a thrust converted from the actuator torque at degraded voltage condition, using stem factor whose definition is an actuator output torque divided by valve stem thrust[1]. It can be seen, therefore, that stem factor is one of the key parameters to determine the valve operability.

The Stem factor is mainly affected by stem/stem-nut coefficient of friction(COF) which is dependent greatly on the type and condition of the stem lubricants, environmental parameters, surface condition of the stem and stem-nuts, and the number of strokes after lubrication[2]. In the design basis review, stem factor is generally determined based on 0.15 of COF[3] though the value measured in the static tests is used to evaluate the final valve operability margin. For some gate/globe valves whose stem factor cannot be measured, however, 0.20 of COF is used to calculate the stem factors. 0.20 has been conservatively used to consider the possible poor maintenance on the stem & stem-nut. Thus it is required to verify that 0.20 is conservative value for those valves.

In this paper, the measured data of the COFs at stem threads of some safety-related motor-operated gate/globe valves in domestic nuclear power plants are presented and the distributions of the COFs at closing torque switch trip (TST) and at opening unwedging are compared. In addition, the performance of the lubricants is evaluated by comparing the average COFs among those valves.

2. In-Plant Static Tests and Data Analysis

2-1. Stem/Stem-Nut Coefficient of Friction

The stem factor(SF), depending on the valve stem geometry, stem-nut geometry, and stem/stem-nut coefficient of friction, can be obtained by measuring the actuator output torque and thrust (valve stem torque and thrust) in a static test as follows:

$$SF = \frac{Tq_{measured}}{Th_{measured}} \tag{1}$$

where $Tq_{measured}$ and $Th_{measured}$ are the measured stem torque and thrust, respectively. The COF the means frictional characteristics at contact area between the stem and stem-nut when the actuator torque produced by the motor is converted into stem thrust through the worm gear and stem-nut(See Fig. 1).

From the measured SF in a static test, COF can be determined as follows[1, 2, 5]:

$$COF = \frac{0.96815 \times (24 \times SF - d_{PITCH} \times \tan a)}{24 \times SF \times \tan a + d_{PITCH}} \tag{2}$$

where,

COF = stem/stem-nut coefficient of friction

$d_{PITCH} = Ds - \frac{P_{stem}}{2}$; stem thread pitch diameter[inch]

D_s = stem diameter[inch]

P_{stem} = stem pitch[inch]

$\tan a = \frac{l_{stem}}{\pi \times d_{PITCH}}$

l_{stem} = stem lead[inch]

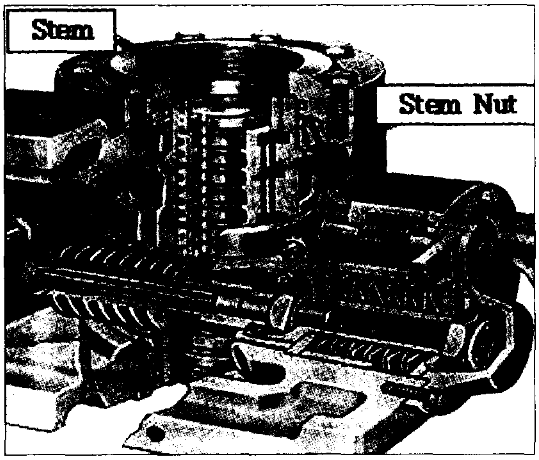


Fig.1. Cutaway View of Limitorque Motor Operator[4]

If the actuator output torque is not well transferred to the stem thrust due to the lubrication degradation, hardening of the lubricant, or frictional wear of the contact surface, valve operating performance will be reduced. In that case, the valves installed on the system to require high thrust may fail to open or close, so that insufficient flow or fluid leakage occurs.

2.2. In-Plant Static Tests

The main objectives of the static test are to find out the valve degradation, to set up the control switch properly, and to measure the packing load, stem factor and actuator inertia. This test is basically performed under no flow and no differential pressure conditions. Diagnostic equipment and sensors utilized in the static test were UDS(Universal Diagnostic System) and ETT(Easy Torque Thrust)/QSS(Quick Stem sensor), respectively.

Figure 2 shows the typical variation of the thrust signals for the opening and closing tests. For opening stroke with the limit switch control, the maximum thrust occurs at unwedging point where the disk escapes from the seat. For closing stroke with the torque switch control, however, the stem thrust at TST , where motor current supply stops, is important though the maximum thrust occurs after the torque switch is tripped. For gate valves, therefore, the assessment of the COF was made using the unwedging thrust/torque in opening stroke and torque switch trip thrust/torque in closing stroke. On the other hand, the COFs for globe valves was assessed only at the torque switch trip thrust/torque in closing stroke because high thrust is not required for valve opening compared to the gate valve.

The lubricants of valves used in the static tests, including information on the plants where the tests were made, are shown in Table 1.

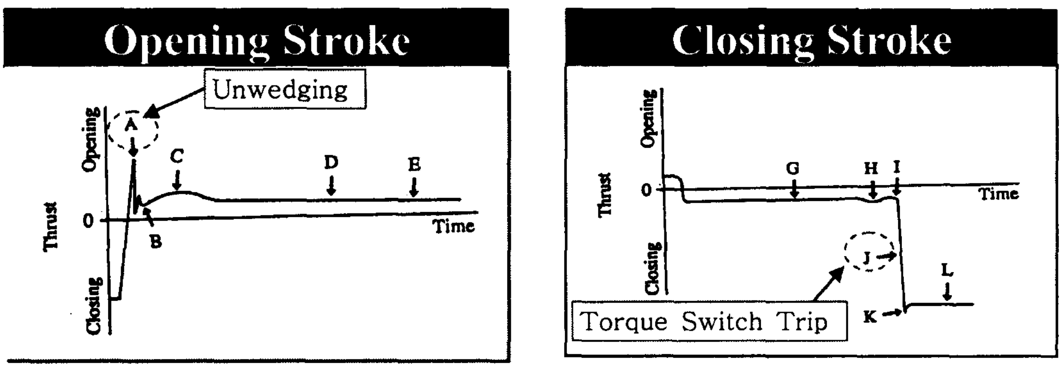


Fig.2. Typical Thrust Change in MOV Strokes

Table 1. The Lubricants of Test Valves

Lubricant	Manufacturer	Gate Valve		Globe Valve	
		# of Valve	Plants	# of Valve	Plants
ALVANIA	Shell Oil Corp.	41	YGN - 6	32	YGN - 6
EXXON NEBULA EP0	EXXON Oil Corp.	34	Kori - 2 YGN - 4	22	Kori - 2 YGN - 4
EXXON NEBULA EP1		7	Kori - 1		
MOBILUX EP0	MOBIL Oil Corp.	102	Kori - 2, 4 YGN - 1, 2, 6	23	Kori - 2, 4 YGN - 1, 2
MULTIFAK EP0	Texaco Corp.	10	UCN - 3	18	UCN - 3
MULTIFAK EP2		33	WSN - 1, 2* YGN - 5	22	WSN - 1, 2* YGN - 5
UNIREX-2	ESSO Oil Corp.	78	Kori - 2 UCN - 1, 2		

*CANDU Plants

2.3. Data Analysis

For total of 442 motor operated gate/globe valves which the diagnostic static tests were completed, the measured COF data were analyzed. The selected gate and globe valves have the disc types of flexible wedge and unbalanced, respectively, and are controlled with the limit switch in opening stroke and torque switch in closing stroke. For valves which both strokes are controlled by the limit switch, it is analyzed only for opening stroke.

Equation 1 is used to determine the COF using the measured steam thrust and torque. The COF of each valve was calculated using the high value of the stem factors measured from the last two stroke tests after setting up the control switch properly. That is, the maximums of the stem factors measured at unwedging and at TST of the last two valve strokes were used to evaluate the unwedging and TST COFs, respectively.

To show the effect of the stem load at the contact area between the stem and stem-nut on the COF, the nominal thread pressure was introduced as follows[5]:

$$TP = \frac{Th_{measured}}{\pi \times \left(D_s - \frac{p_{stem}}{2}\right) \times \frac{p_{stem}}{2}} \tag{3}$$

where TP, $Th_{measured}$, D_s, and p_{stem} are the nominal thread pressure, the measured stem thrust, the outside diameter of the stem, and stem pitch, respectively. Note that the above equation assumes all valves have the standard ACME threads. The thread pressure defined by Eq. 3 is not the true pressure but it is meaningful as a parameter representative of thread load at the stem and stem-nut interface.

The obtained COF data were analyzed for good data within normal data scatter selected by Grubb's method[6]. Grubb's Method is mainly used when dealing with the statistic sample data and has an advantage that the loss of the available data is smaller than the other methods. According to this method, 20 COF data exceeding the bounding values (sample average $\pm 3 \times$ sample standard deviation), called "outlier data", were eliminated and the rest of the data are used to present the results described hereafter. In this study, the bounding values were defined as 95% confidence values (average COF$\pm 2 \times$standard deviation).

3. Results and Discussion

3.1. Distribution of the COFs of Gate Valves

Figure 3 shows the distribution of the unwedging COFs with the thread pressure for the flexible wedge gate valves. It is found that the lower COFs than 0.15 which is assumed for stem factor calculation in the design basis review, bound 90% of the data. This means that the assumption of the COFs of 0.15 in the design basis review for a gate valve is conservative with the 90% confidence. Also most of the COFs are concentrated on the thread pressures less than 10,000 psi and distributed in the wide range. At thread pressure higher than 10,000 psi, however, the range of the distribution with the increase of the thread pressure is narrowed down. This shows consistency with EPRI's COF data for the wedge-type gate valves[7]. However, it can be seen that several COF data higher than 95% confidence value (0.175) is measured. The reason is not clear but these data may come from the increase of the frictional resistance due to the change of the lubricating performance between stem and stem-nut. The lubricating performance is degraded mainly due to the frictional wear at stem and stem-nut and the hardening of the lubricant. A further study is required to invest the reasons.

In Fig. 4, the experimental PDF (Probability Density Function) with the interval of 0.02 for the COFs is compared to the theoretical PDF using the "Gaussian method". This figure shows that the data are distributed normally with the average COF value of 0.096 and the minimum and maximum COFs are 0.01 and 0.22, respectively. It can be also seen that the statistical analysis for the data is meaningful and reliable by comparing the experimental PDF to Gaussian PDF. Figure 5, which shows the probability distribution of the cumulative COF,

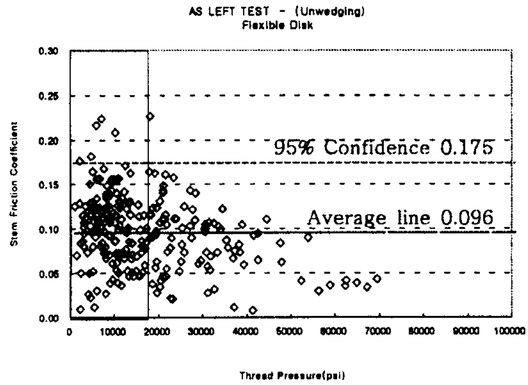


Fig.3. The Distribution of the COFs with Thread Pressure at Unwedging for Gate Valves

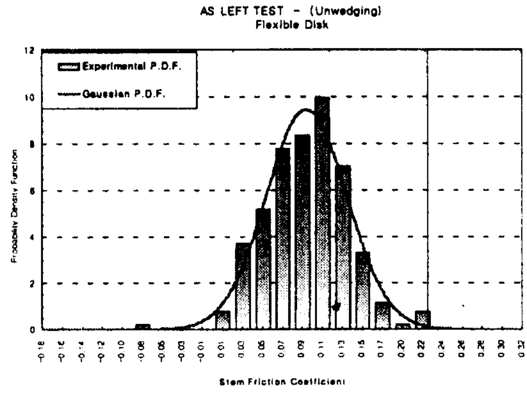


Fig.4. Probability Density Function of the COFs at Unwedging for Gate Valves

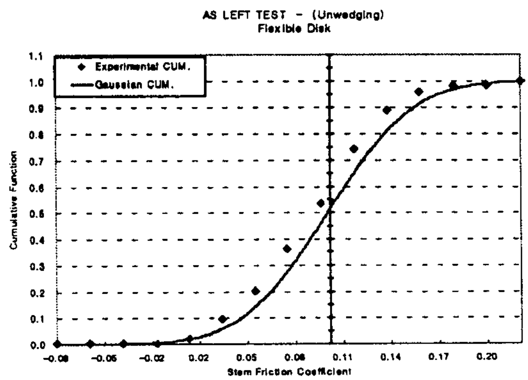


Fig.5. Cumulative Distribution Function of the COFs at Unwedging for Gate Valves

also supports the data reliability.

Figure 6 shows the distribution of the COFs measured at TST in the closing stroke. It is found that the COF data over 0.15 at TST were about 15% of the measured data for the flexible wedge gate valves. This means that there is 85% confidence when 0.15 of COFs for a gate valve is used in the design basis analysis. Unlike the distribution of COFs at unwedging in the opening strokes, the COFs at TST in the closing strokes are mostly distributed in the range of the thread pressure from 10000 to 45000 psi . One of the reasons is thought that the stem thrust at TST is higher than that at unwedging (disk escapes from the seat) in opening stroke after disk is completely wedged in the previous closing stroke.

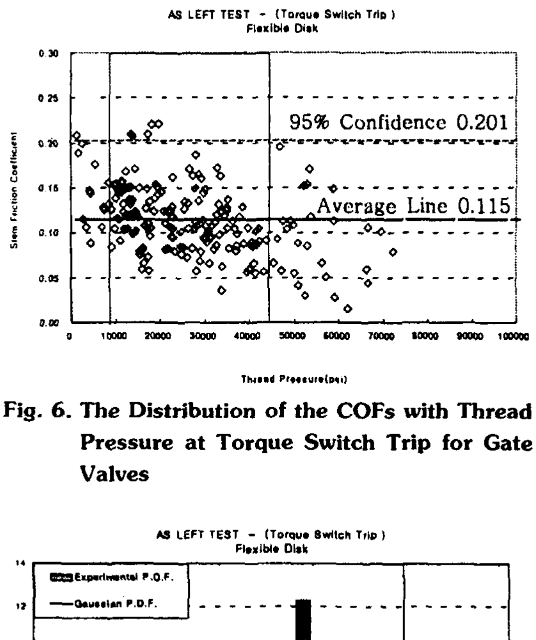


Fig. 6. The Distribution of the COFs with Thread Pressure at Torque Switch Trip for Gate Valves

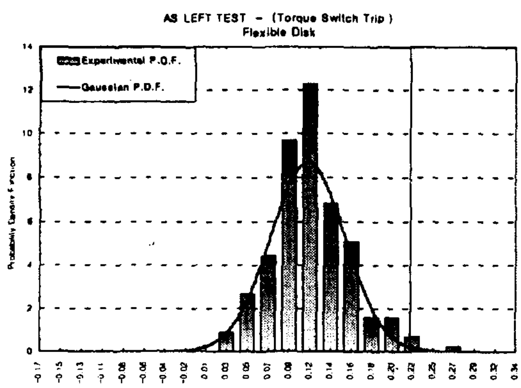


Fig. 7. Probability Density Function of the COFs at Torque Switch Trip for Gate Valves

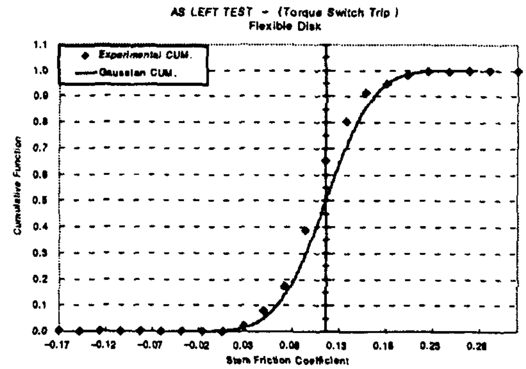


Fig. 8. Cumulative Distribution Function of the COFs at Torque Switch Trip for Gate Valves

When the thread pressure is low, Fig. 6 shows wide distribution of COFs. As the thread pressure is increased, however, the COFs are distributed in the narrow range. This is also found in the distribution of the unwedging COFs in opening direction (see Fig. 3).

The PDF and cumulative probability distribution of the COFs at TST are found in Figs. 7 and 8, respectively. From these figures, it can be found that the distributions are very similar to those at unwedging. The difference of the average COFs between at TST and unwedging was about 0.019. The TST and unwedging COFs with the maximum population are 0.115 and 0.112 , respectively. This means that TST COF are higher than the unwedging COF and applicable to the unwedging COF conservatively

3.2. Distribution of the COFs of Globe Valves

Fig. 9 shows the stem friction coefficients for the unbalanced globe valves at TST. Only 9 valves (7.5%) of 119 valves show the COFs higher than 0.15. Note that 10% and 15% gate valves have the COFs higher than 0.15 at unwedging and at TST, respectively. This indicates that the assumption of 0.15 for COF of the unbalanced globe valve is more conservative than one of the flexible wedge gate valve. It is also evident that all valves with higher COF than 0.15 are in the range of the thread pressure from 10000 to 20000 psi. In addition, there are three valves with higher COFs than the 95% confidence value (0.172), including the highest one with 0.25 which is above two times as the average value. These data may have been caused by the unknown structural problems at the stem to stem-nut contact area rather than the change of the lubricant characteristics.

When the PDF and cumulative probability distribution (see Figs. 10 and 11, respectively) are compared to the gate valve's data, it can be seen that the distribution range of COFs, from 0.0 to 0.23, is very similar but the COFs with maximum population are 0.095 for the globe valves and 0.115 for the gate valves. The difference of 0.02 is expected mainly because the TST stem thrust for the globe valve is smaller than the gate valves.

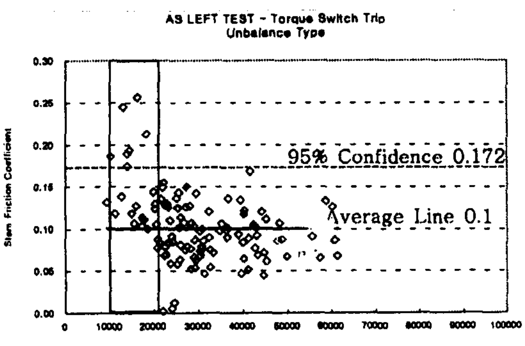


Fig. 9. The Distribution of the COFs with Thread Pressure at Torque Switch Trip for Globe Valves

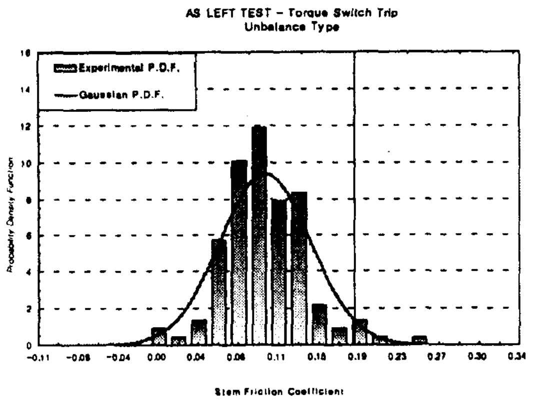


Fig.10. Probability Density Function of the COFs at Torque Switch Trip for Globe Valves

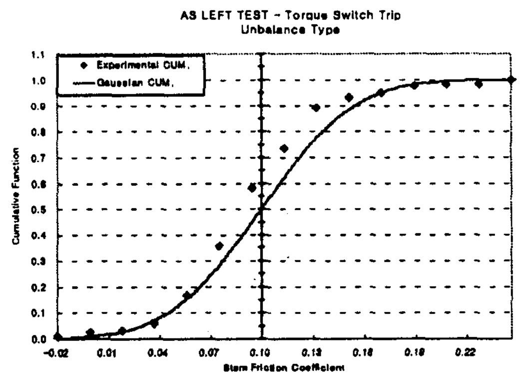


Fig.11. Cumulative Function of the COFs at Torque Switch Trip for Globe Valves

3.3. Comparison of COFs Between the Lubricants

Generally, there may be five main factors that govern the lubricating performance at the stem/stem-nut contact surface[2, 8].

(1) Lubricant type and condition (sealing maintenance and storing period)

(2) Environmental conditions around the valve actuator (i.e., ambient temperature, moisture, and radiation etc.)

(3) Surface condition between stem and stem-nut (surface roughness and frictional wear between stem and stem-nut)
(4) Contact area between stem and stem-nut
(5) Valve stroke number during the lubrication cycle

The main function of lubricants, which consists of the base oil, gelling agent, and additive, is relaxing the frictional force at contact area between stem and stem-nut. Generally, the mineral oil is used as a base oil, and the lithium, calcium, and calcium complex as gelling agent that determines the base properties of the lubricant (i.e., viscosity, heat-resistance, and water-resistance). The additive is adding material based on the environmental factors of a valve such as loading degree, heating environment, frictional wear, pyrolysis, and oxidation dissolution.

In this section, the effect of the lubricants on the measured COFs is presented for the same data described previously. The 7 different lubricants for the gate valves and 5 different lubricants for the globe valves are used as shown in Table1.

For the gate valves, Fig. 12 shows the comparison of the COFs at unwedging with the thread pressure by the lubricant types. As shown in the previous figures, most of the data are distributed below 0.15. For the gate valves using EXXON NEBULA EP0, the average COF was evaluated to be 0.067, which is the lowest among 7 lubricants, so that this lubricant showed a good lubricating performance and small frictional resistance.

Other lubricants, such as EXXON NEBULA EP1, UNIREX-2, and MULTIFAK EP2, also show the average COFs below 0.1. It is difficult to make a conclusion for MULTIFAK EP0 due to insufficient data, however, the average COF was relatively high.

The COFs for the gate valves at TST can be found with the thread pressure by the lubricant types in Fig. 13. The average value for each lubricant was a little higher than average unwedging COF in opening stroke as shown in Fig. 12.

The lowest average value at TST was 0.103 for MULTIFAK EP2 though EXXON NEBULA EP0 showed the lowest average unwedging COF in opening stroke. From the comparison results of the lubricating performance based on the average COFs and the distribution pattern of COFs with the thread pressure, it is concluded that the stem frictional characteristics of the flexible wedge gate valve at TST and at unwedging are very similar.

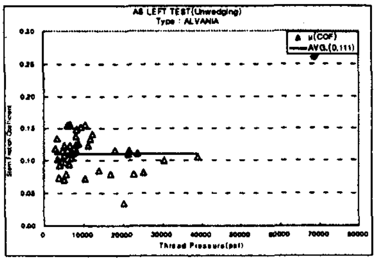
The COF distributions at TST are plotted with the lubricants for the unbalanced globe valves in Fig. 14. The average COFs at TST are found to be lower than those for the gate valves as shown in Fig. 13.

Although MOBILUX EP is evaluated to show the lowest average COF for the globe valves, EXXON NEBULA EP0 is also found to be a good lubricant with the average COF of 0.086, like for the gate valves. Of 5 lubricants used for the globe valves, the lubrication performance of MOBILUX EP0 was excellent though its performance at unwedging and TST for gate valves were poor.

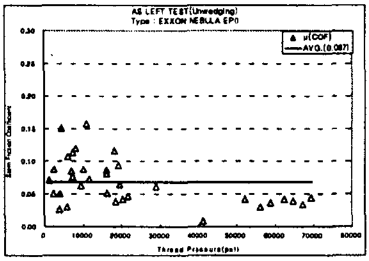
4. Conclusions

From the analysis of the measured COFs between the valve stem and the stem-nut at unwedging in opening stroke(only for flexible wedge gate valves) and at TST in closing stroke(for flexible wedge gate valves and unbalanced globe valves), the following conclusions are made:

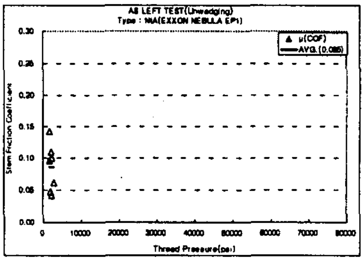
(1) Based on 95% confidence value (0.188) for all measured COF data, it can be seen that for the valve not practical to measure the COF in the static test, the use of 0.2 in determining the design basis stem factor is conservative.
(2) For the gate valves, the unwedging and TST



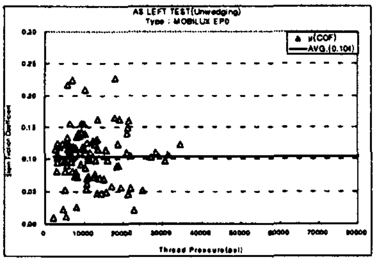
a) ALVANIA



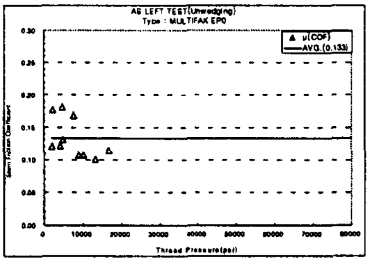
b) EXXON NEBULA EP0



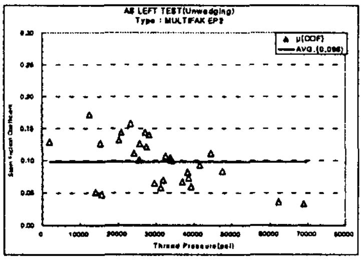
c) EXXON NEBULA EP1



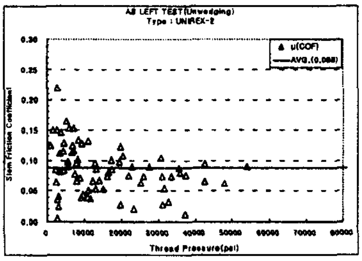
d) MOBILUX EP0



e) MULTIFAK EP0



f) MULTIFAK EP2



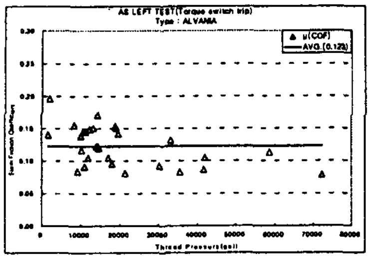
g) UNIREX-2

Fig. 12. The Distribution of the Unwedging COFs with Thread Pressure by Lubricants for Gate Valves

COFs were distributed in the similar range of 0.01~0.23 and the difference of the average COFs between at TST and at unwedging was 0.019. It is concluded, therefore, that the static COF measured at TST is applicable to determine COF at unwedging.

(3) The lubrication performance based on the average COFs is compared among 7 lubricants. From the results, EXXON NEBULA EP0 is recommended for the gate valves and MOBILUX EP0 for the globe valves as stem lubricants. MULTIFAK EP0 is not recommended for both types of valves. EXXON NEBULA EP0 showed also a good lubrication performance for the globe valves.

However, it should be pointed out that the above conclusions were based on the measured stem coefficient of frictions depending on the lubricating performance and geometry of the stem and stem-nut. Therefore, it is recommended that a



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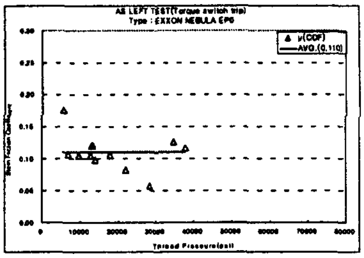
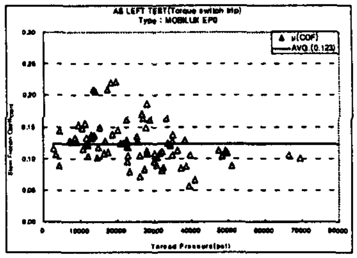
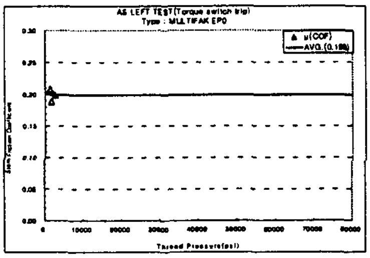


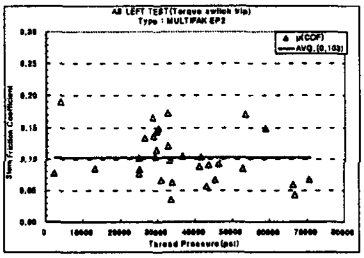
b) EXXON NEBULA EP0



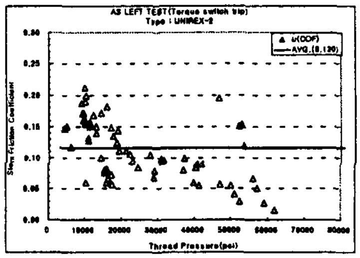
c) MOBILUX EP0



d) MULTIFAK EP0

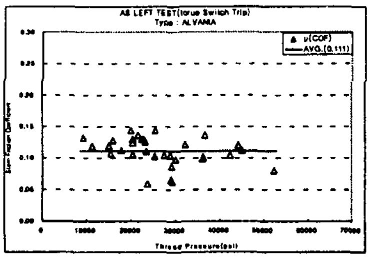


e) MULTIFAK EP2

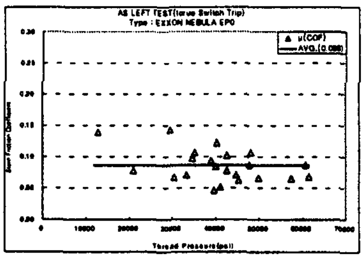


f) UNIREX-2

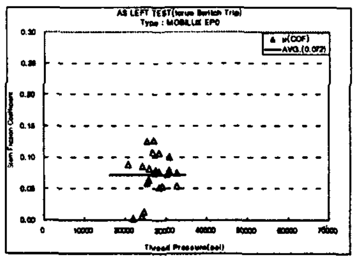
Fig.13. The Distribution of the TST COFs with Thread Pressure by Lubricants for Gate Valves



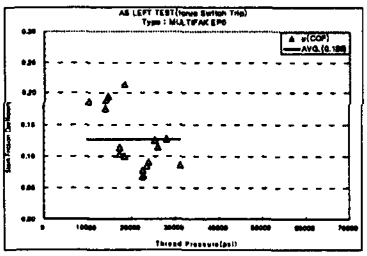
a) ALVANIA



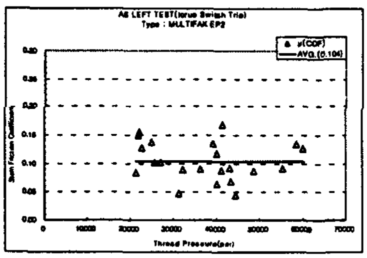
b) EXXON NEBULA EP0



c) MOBILUX EP0



d) MULTIFAK EP0



e) MULTIFAK EP2

Fig.14. The Distribution of the TST COFs with Thread Pressure by Lubricants for Globe Valves

testing program should be initiated to determine the effect of following factors, such as environmental conditions, surface conditions between the stem and stem-nut, lubricating cycle, and number of valve strokes, on the lubricating performance.

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