White Paper
MOV-WP-101

As-Left Stem/Stem Nut Coefficient of Friction

Revision 2
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Commonwealth Edison Company

Corporate MOV Program Support

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1.0 PURPOSE

This position paper focuses on establishing an appropriate as-left (i.e., well lubricated) stem-to-stem nut coefficient of friction for use in establishing target thrust windows. It also provides actions to improve the coefficient of friction if necessary.

2.0 POSITION

- For MOVs with clean and well-lubricated stem/stem nuts, use of a 0.15 coefficient of friction for establishing the target thrust window is appropriate.

- The methods provided herein for improvement of stem friction factors should be implemented as necessary to improve a measured friction coefficient.

Improvement of Stem Friction Coefficients

Friction coefficients that are larger than expected or desired may be improved by one of the following activities.

a) If possible, use a more accurate means of measuring coefficient of friction. For example, the uncertainty in torque may be reduced by using a tested spring pack (TSP) instead of a generic curve, a VOTES Torque Cartridge (VTC) instead of a TSP, or a stem strain gauge instead of a VTC.

b) For rising and rotating stem valves, lubricate the sliding nut (square, hex, or splined) in the drive sleeve and inspect or lubricate the yoke nut.

c) Check to ensure the stem and anti-rotation device (where applicable) are properly lubricated with approved lubricant. Reclean and apply lubricant, if necessary. Lubricate the sliding friction areas of the anti-rotation devices. Some key style devices can be improved by replacing the keys with a harder key material or polishing the surface finish.

d) Check for bronze filings in the grease (stem and main gear box). If filings found, remove and inspect the stem nut. Replace stem nut and/or grease as necessary.

e) Evaluate the VOTES trace for excessive stem/stem nut clearance, and replace if appropriate.

f) Check the stem alignment by evaluating the following:
   - Is the yoke bent or twisted?

- Is the yoke or yoke clamp loose?
- Is the actuator centered over the yoke?
- Is the packing follower cocked and rubbing against the stem?
- Are the packing loads higher than expected?

g) Slightly loosen the top housing cover bolts to determine if the drive sleeve is pinched. If this improves the thrust, re-shim the drive sleeve. NOTE: This step may create binding on SMB-00 and SMB-000 limit switches, if clearance is excessive.

h) If the actuator is an SMB-000 or SMB-00, check the hand (manual) operation to ensure that it turns freely.

i) Check the worm/worm gear contact to ensure the contact pattern is centered. High or low contact can cause loss of torque.

j) Re-shim the lower bearing cup to correct any contact problems. The upper bearing will also need adjustment if the lower cup is moved.

3.0 BACKGROUND

Generic Letter 89-10 requires reconstruction of the MOV design basis. As such, ComEd has established torque and thrust limits to establish the appropriate MOV setup (i.e., target thrust windows) as described in Reference 2.

The stem factor represents the efficiency of the torque to thrust conversion at the stem to stem nut interface and is critical to MOV margin and setup. The stem factor is a function of the stem coefficient of friction and the stem/stem nut geometry. The coefficient of friction depends on the lubricant type and condition, stem/stem nut surface condition, and the contact couple between the stem and stem nut. The Reference 2 guidance requires an assumption of the as-left coefficient of friction to establish the target thrust window top for torque closed valves.

In order to assess the true coefficient of friction, the most accurate method of measuring stem factor should be used. Additionally, improvement of the stem friction coefficient may be necessary to increase margin.

4.0 JUSTIFICATION

4.1 <u>ComEd Station Specific Data</u>

4.1.1 Analysis

The following is a summary of the lubricants utilized at ComEd stations:

Table 2

Station	Previous Lubricant	Current Lubricant	Comments
LaSalle	FEL-PRO N-5000	FEL-PRO N-5000	
Dresden	FEL-PRO N-5000	FEL-PRO N-5000	
Zion	FEL-PRO N-5000	FEL-PRO N-5000	
Byron	NEOLUBE	NEBULA EP	Initiated change in Jan. 1993, cleaned off old lubricant and relubricated with new lubricant prior to baseline testing
Braidwood	FEL-PRO N-5000	NEBULA EP	
Quad Cities	FEL-PRO N-5000	MOBILUX EP-1	

As-left test data from the Station margin reviews (Reference 3) is used to establish an appropriate "well-lubricated" stem/stem nut coefficient of friction. Both VOTES Torque Cartridge (VTC) and Tested Spring Pack (TSP) data is used to provide a large statistical sample[1]. An analysis of the data is performed for each station identifying the average coefficient of friction and standard deviation. The data is limited to stem coefficients of friction that are bounded by 3 times the standard deviation of the entire population. This results in a stem friction coefficient range of 0.03 to 0.25.

Further review of the data eliminates more valves from the population. These are grouped as follows:

- The methodology in the margin review for calculating stem friction coefficients for rising/rotating valves provides apparent low friction coefficients. As such rising/rotating stem valves are excluded.
- Valves that have known misalignment, stem/stem nut damage, etc. are not considered representative of the general population and are excluded.
- There is a population of Zion valves (select Velan gate valves) that appear to have abnormally high apparent friction coefficients. Upon further investigation by the Station, these valves have stem and stem nuts that have minimal thread engagement. These valves are excluded from this evaluation as they are not representative population.

The results are tabulated in Table 3. The average coefficient of friction ranges from 0.11 to 0.13 across the six stations. This data indicates that the maximum coefficient of friction at a 95% confidence level (1.645 times the standard deviation) is between 0.17 and 0.18 for all stations. Results are the same whether VTC/tested spring pack data or VTC data only is used and do not vary significantly amongst the stations. Attachments 1 and 2 provide the data supporting this evaluation.

[1] Byron data prior to 1993 is excluded because of the lubricant change.

4.1.2 Conclusion

ComEd uses thrust measurements as the primary method for MOV setup. Verification of the thrust at control switch trip ensures MOV capability to produce the required seating thrust without exceeding thrust limits. In most cases a torque measurement at control switch trip is also obtained (i.e., TSP or VTC). As such, the assumed friction coefficient of 0.15 is used only to estimate the corresponding torque output when torque data is not acquired (e.g. generic spring pack data only). If the actual friction coefficient is higher than 0.15 (95% confidence value in Table 3 is 0.18), this would result in a higher than expected torque output. The affected torque components are the motor gearing capacity and actuator torque limit. For the few instances where torque has not been acquired, the 0.15 friction coefficient assumption should be bounding. In addition inaccuracies are included for diagnostic equipment and torque switch repeatability; thereby overtorquing is not a significant concern. Continued use of 0.15 as a well-lubricated coefficient of friction is appropriate for MOV setup.

Table 3

Station	Average COF	Standard Deviation.	Maximum COF (95% Confidence)
Braidwood	.111	.0431	.182
Byron	.115	.0357	.173
Dresden	.116	.0376	.178
LaSalle	.108	.0407	.175
Quad Cities	.128	.0332	.182
Zion	.114	.0393	.179
Total	.115	.0389	.179

4.2 EPRI Stem/Stem Nut Lubrication Test Program

An objective of the EPRI test program (Reference 4) was to assess the friction and wear characteristics of a wide range of lubricants under ambient temperature conditions. The testing was performed using one hardware configuration which was cycled statically four times (preconditioning), cycled against a simulated DP load 500 times, and cycled statically twice.

The results of this program were reviewed for the three lubricants currently used in the ComEd system (See Table 4). Specific conclusions are:

- The initial coefficient of friction is between 0.10 and 0.14.
- The coefficient of friction is relatively constant with increasing load.
- The coefficient of friction improves with stroke number.
- Intermediate to low stem nut wear is expected over 500 strokes.

Table 4

Name	Manufacturer	Initial COF	Final COF	Stem Nut Wear
MOBILUX EP	MOBIL	0.14	0.13	Virtually none
NEBULA EP	EXXON	0.10	0.07	Intermediate, smooth
N-5000	FEL-PRO	0.14	0.08	intermediate, smooth

4.3 Actuator Grease Test Program

Actuator grease testing (Reference 1) was conducted to evaluate the consistency of mixed greases in actuators under harsh environmental and operational conditions. Initial testing also addressed unmixed greases. Of the lubricants used by the ComEd Stations, this initial testing only included NEBULA EP. The testing included thermal aging, radiation and high temperature/humidity. Data shows that thermal aging has no affect on the grease and that harsh environments (i.e. high radiation, temperature and humidity) may result in only a slight softening of the grease.

5.0 REFERENCES

1. Commonwealth Edison Co., "Review of Results from Mixed Grease Test Program," draft dated December 30, 1993.

2. White Paper WP-107, Target Thrust Window Methodology.

3. Margin Reviews

Station	File Name	Bytes	Time	Time
Braidwood	bwd_x.dbf	232233	11/14/94	3:09:00p
	calcd.dbf	277390	11/14/94	3:11:00p
	input.dbf	248959	11/14/94	3:37:00p
Byron	byron_x.dbf	693119	12/28/94	9:45:00a
	calcd.dbf	298250	12/28/94	9:45:12a
	input.dbf	225800	12/28/94	9:53:22a
Dresden	ceco_x.dbf	89152	8/25/94	15:54:14p
	calcd.dbf	247914	8/4/94	3:06:12p
	input.dbf	207508	8/5/94	8:26:28a
LaSalle	las_x.dbf	709339	10/31/94	4:28:38p
	calcd.dbf	441290	11/7/94	4:37:44p
	input.dbf	383732	11/7/94	4:51:42p
Quad Cities	quad_x.dbf	173154	9/2/94	3:42:40p
	calcd.dbf	277754	9/2/94	3:52:48p
	input.dbf	237525	9/2/94	4:04:08p
Zion	zion_x.dbf	260827	10/27/94	2:15:12p
	calcd.dbf	319110	10/27/94	6:19:24p
	input.dbf	342013	10/27/94	10:57:36p

4. EPRI TR-102135, August 1993, EPRI MOV Performance Prediction Program, Stem/Stem Nut Lubrication Test Report.

Attachment 1
As-Left Coefficient of Friction Data
Summary

Coefficient of Friction Based on TSP and VTC Testing

Station					
B[illegible]DWOOD	**TOTAL**	0.1110	Standard Dev.	0.0431
			Maximum COF:	0.1819
BYRON	**TOTAL**	0.1147	Standard Dev.	0.0357
			Maximum COF:	0.1734
DRESDEN	**TOTAL**	0.1156	Standard Dev.	0.0376
			Maximum COF:	0.1775
LASALLE	**TOTAL**	0.1078	Standard Dev.	0.0407
			Maximum COF:	0.1747
QUAD CITIES	**TOTAL**	0.1278	Standard Dev.	0.0332
			Maximum COF:	0.1824
ZION	**TOTAL**	0.1146	Standard Dev.	0.0393
			Maximum COF:	0.1792
All Stations	**TOTAL**	0.1149	Standard Dev.	0.0389
			Maximum COF:	0.1788

ficient of Friction Based on VTC Testing

BRAIDWOOD				
	TOTAL	0.1090	Standard Dev.	0.0432
			Maximum COF:	0.1800
BYRON				
	TOTAL	0.1186	Standard Dev.	0.0357
			Maximum COF:	0.1772
DRESDEN				
	TOTAL	0.1198	Standard Dev.	0.0367
			Maximum COF:	0.1801
LASALLE				
	TOTAL	0.1341	Standard Dev.	0.0260
			Maximum COF:	0.1769
QUAD CITIES				
	TOTAL	0.1234	Standard Dev.	0.0286
			Maximum COF:	0.1705
ZION				
	TOTAL	0.1150	Standard Dev.	0.0399
			Maximum COF:	0.1807
All Stations	**TOTAL**	0.1183	Standard Dev.	0.0367
			Maximum COF:	0.1786

Attachment 2
As-Left Coefficient of Friction Data
Detail

VALVE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
BRAIDWOOD							
1AF006A	STUB	1	1/3	2/3	VTC	T	0.052
1AF017B	STUB	1	1/3	2/3	VTC	T	0.071
1CC685	STANDARD	1.25	1/3	1/3	VTC	L	0.14
1CC9412A	STANDARD	1.5	1/3	2/3	TSP	T	0.113
1CC9412B	STANDARD	1.5	1/3	2/3	TSP	T	0.145
1CC9413A	STANDARD	1.5	1/3	2/3	TSP	T	0.062
1CC9413B	STANDARD	1.5	1/3	2/3	VTC	T	0.081
1CC9415	STANDARD	1.75	1/3	1/3	TSP	T	0.117
1CC9416	STANDARD	1.5	1/3	2/3	TSP	T	0.052
1CS001A	STUB	1.5	1/4	2/4	VTC	T	0.089
[illegible]007A	STUB	1.5	1/3	3/3	TSP	T	0.188
[illegible]09A	STUB	2.25	1/3	3/3	VTC	T	0.083
1CS019A	STANDARD	1	1/5	2/5	VTC	T	0.161
1CS019B	STANDARD	1	1/5	2/5	TSP	T	0.187
1CV112B	STANDARD	1.25	1/3	1/3	VTC	T	0.154
1CV112D	STANDARD	1.25	1/3	1/3	VTC	L	0.107
1CV8104	STANDARD	1.125	1/3	2/3	TSP	T	0.092
1CV8110	STANDARD	1.125	1/3	2/3	TSP	T	0.074
1CV8111	STANDARD	1.125	1/3	2/3	VTC	T	0.078
1CV8355A	STANDARD	1.125	1/3	2/3	TSP	T	0.189
1CV8355B	STANDARD	1.125	1/3	2/3	TSP	T	0.146
1CV8355C	STANDARD	1.125	1/3	2/3	TSP	T	0.185
1CV8355D	STANDARD	1.125	1/3	2/3	VTC	T	0.105
[illegible]610	STANDARD	1.125	1/4	2/4	VTC	T	0.055
1RH611	STANDARD	1.125	1/4	2/4	VTC	T	0.062

[redacted] NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[redacted]RH8701A	STANDARD	3	2/5	4/5	VTC	L	0.162
1RH8702A	STANDARD	3	2/5	4/5	VTC	L	0.125
1RH8702B	STANDARD	3	2/5	4/5	VTC	L	0.144
1RH8716A	STANDARD	1.25	1/3	1/3	VTC	L	0.096
1RH8716B	STANDARD	1.25	1/3	1/3	VTC	L	0.094
1RY8000A	STANDARD	1.25	1/3	1/3	VTC	L	0.088
1SI8807A	STANDARD	1.25	1/3	1/3	VTC	L	0.033
1SI8807B	STANDARD	1.25	1/3	1/3	VTC	L	0.071
1SI8808A	STANDARD	2.5	1/3	2/3	TSP	T	0.121
1SI8808B	STANDARD	2.5	1/3	2/3	VTC	T	0.056
1SI8808C	STANDARD	2.5	1/3	2/3	VTC	T	0.191
1SI8808D	STANDARD	2.5	1/3	2/3	VTC	T	0.058
1S[redacted]809A	STANDARD	2	1/4	2/4	TSP	T	0.08
[redacted]11A	STANDARD	2.5	1/3	2/3	TSP	T	0.158
1SI8811B	STANDARD	2.5	1/3	2/3	VTC	T	0.118
1SI8813	STANDARD	1.125	1/3	2/3	TSP	T	0.085
1SI8814	STANDARD	1.125	1/3	2/3	TSP	T	0.142
1SI8821A	STANDARD	1.25	1/3	1/3	VTC	L	0.067
1SI8923A	STANDARD	1.25	1/3	1/3	VTC	L	0.078
1SI8924	STANDARD	1.25	1/3	1/3	VTC	L	0.113
1WO006F	STUB	1.25	1/4	2/4	TSP	T	0.12
1WO020B	STUB	1.25	1/4	2/4	TSP	T	0.076
1WO056B	STUB	1.25	1/4	2/4	VTC	T	0.231
2AF006A	STUB	1	1/3	2/3	VTC	T	0.172
2AF006B	STUB	1	1/3	2/3	VTC	T	0.066
[redacted]013A	STANDARD	1.375	1/4	1/4	VTC	T	0.139
2AF013B	STANDARD	1.375	1/4	1/4	VTC	T	0.119

[redacted]E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
.AF013C	STANDARD	1.375	1/4	1/4	VTC	T	0.115
2AF013D	STANDARD	1.375	1/4	1/4	VTC	T	0.114
2AF013E	STANDARD	1.375	1/4	1/4	VTC	T	0.174
2AF013F	STANDARD	1.375	1/4	1/4	VTC	T	0.15
2AF013G	STANDARD	1.375	1/4	1/4	VTC	T	0.115
2AF013H	STANDARD	1.375	1/4	1/4	VTC	T	0.135
2AF017B	STUB	1	1/3	2/3	VTC	T	0.134
2CC685	STANDARD	1.375	1/3	2/3	VTC	T	0.088
2CC9413B	STANDARD	1.5	1/3	2/3	VTC	T	0.121
2CC9414	STANDARD	1.5	1/3	2/3	TSP	T	0.136
2CC9415	STANDARD	1.75	1/3	1/3	VTC	T	0.069
2CC9416	STANDARD	1.5	1/3	2/3	VTC	T	0.126
[redacted]001A	STUB	1.5	1/4	2/4	VTC	T	0.079
[redacted]07A	STUB	1.5	1/3	3/3	VTC	T	0.12
2CS007B	STUB	1.5	1/3	3/3	VTC	T	0.161
2CS019A	STANDARD	1	1/5	2/5	VTC	T	0.199
2CV112B	STANDARD	1.25	1/3	1/3	VTC	T	0.073
2CV112C	STANDARD	1.25	1/3	1/3	VTC	T	0.036
2CV112E	STANDARD	1.25	1/3	1/3	VTC	L	0.142
2CV8100	STANDARD	1.125	1/3	2/3	VTC	T	0.157
2CV8105	STANDARD	1.125	1/5	2/5	VTC	L	0.132
2CV8111	STANDARD	1.125	1/3	2/3	VTC	T	0.101
2CV8355A	STANDARD	1.125	1/3	2/3	VTC	T	0.033
2CV8355B	STANDARD	1.125	1/3	2/3	VTC	T	0.177
2CV8355C	STANDARD	1.125	1/3	2/3	VTC	T	0.118
[redacted]8355D	STANDARD	1.125	1/3	2/3	VTC	T	0.136
2CV8804A	STANDARD	1.25	1/3	1/3	VTC	L	0.1

E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
RH610	STANDARD	1.125	1/4	2/4	VTC	T	0.055
2RH8701A	STANDARD	3	2/5	4/5	VTC	L	0.109
2RH8701B	STANDARD	3	2/5	4/5	VTC	L	0.151
2RH8702B	STANDARD	3	2/5	4/5	VTC	L	0.144
2RH8716B	STANDARD	1.25	1/3	1/3	VTC	L	0.107
2RY8000A	STANDARD	1.25	1/3	1/3	VTC	L	0.069
2RY8000B	STANDARD	1.25	1/3	1/3	VTC	L	0.059
2SI8801B	STANDARD	1.25	1/3	1/3	VTC	L	0.096
2SI8807A	STANDARD	1.25	1/3	1/3	VTC	L	0.046
2SI8808A	STANDARD	2.5	1/3	2/3	VTC	T	0.093
2SI8808B	STANDARD	2.5	1/3	2/3	VTC	T	0.088
2SI8808D	STANDARD	2.5	1/3	2/3	VTC	T	0.168
809B	STANDARD	2	1/4	2/4	VTC	T	0.039
811A	STANDARD	2.5	1/3	2/3	TSP	T	0.101
2SI8811B	STANDARD	2.5	1/3	2/3	TSP	T	0.119
2SI8812A	STANDARD	2	1/4	2/4	VTC	T	0.097
2SI8821B	STANDARD	1.25	1/3	1/3	VTC	L	0.05
2SI8835	STANDARD	1.25	1/3	1/3	VTC	T	0.08
2SI8924	STANDARD	1.25	1/3	1/3	VTC	L	0.113
2WO006A	STUB	1.25	1/4	2/4	TSP	T	0.082
2WO006B	STUB	1.25	1/4	2/4	VTC	T	0.138
2WO020A	STUB	1.25	1/4	2/4	TSP	T	0.063
2WO020B	STUB	1.25	1/4	2/4	VTC	T	0.114
2WO056A	STUB	1.25	1/4	2/4	VTC	T	0.144
2WO056B	STUB	1.25	1/4	2/4	VTC	T	0.192
			TOTAL		0.1110	Standard Dev.	0.0431
						Maximum COF:	0.1819

BYRON

…E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
1AF006A	STUB	1	1/3	2/3	VTC	T	0.078
1AF006B	STUB	1	1/3	2/3	VTC	T	0.12
1AF013A	STANDARD	1.375	1/4	1/4	VTC	L	0.119
1AF013B	STANDARD	1.375	1/4	1/4	VTC	L	0.09
1AF013C	STANDARD	1.375	1/4	1/4	VTC	L	0.126
1AF013D	STANDARD	1.375	1/4	1/4	VTC	L	0.148
1AF013E	STANDARD	1.375	1/4	1/4	VTC	L	0.125
1AF013F	STANDARD	1.375	1/4	1/4	VTC	L	0.154
1AF013G	STANDARD	1.375	1/4	1/4	VTC	L	0.143
1AF013H	STANDARD	1.375	1/4	1/4	VTC	L	0.155
1AF017A	STUB	1	1/3	2/3	VTC	T	0.134
1AF017B	STUB	1	1/3	2/3	VTC	T	0.148
…685	STANDARD	1.25	1/3	1/3	TSP	T	0.09
…412A	STANDARD	1.5	1/3	2/3	VTC	T	0.103
1CC9413A	STANDARD	1.5	1/3	2/3	TSP	T	0.145
1CC9413B	STANDARD	1.5	1/3	2/3	TSP	T	0.04
1CC9414	STANDARD	1.5	1/3	2/3	TSP	T	0.145
1CC9416	STANDARD	1.5	1/3	2/3	TSP	T	0.126
1CC9438	STANDARD	1.375	1/3	2/3	TSP	T	0.034
1CC9473A	STANDARD	1.75	1/3	1/3	VTC	T	0.103
1CC9473B	STANDARD	1.75	1/3	1/3	VTC	T	0.09
1CS001A	STUB	1.5	1/4	2/4	TSP	T	0.087
1CS001B	STUB	1.5	1/4	2/4	TSP	T	0.148
1CS007A	STUB	1.5	1/3	3/3	TSP	T	0.116
1CS007B	STUB	1.5	1/3	3/3	TSP	T	0.12
…19A	STANDARD	1	1/5	2/5	TSP	T	0.156
1CV112C	STANDARD	1.25	1/3	1/3	VTC	T	0.092

VALVE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
1CV112D	STANDARD	1.25	1/3	1/3	VTC	L	0.136
1CV112E	STANDARD	1.25	1/3	1/3	VTC	L	0.08
1CV8100	STANDARD	1.125	1/3	2/3	VTC	T	0.193
1CV8104	STANDARD	1.125	1/3	2/3	VTC	T	0.138
1CV8105	STANDARD	1.25	1/3	1/3	VTC	L	0.121
1CV8106	STANDARD	1.25	1/3	1/3	VTC	L	0.132
1CV8111	STANDARD	1.125	1/3	2/3	VTC	T	0.058
1CV8112	STANDARD	1.125	1/3	2/3	TSP	T	0.131
1CV8355A	STANDARD	1.125	1/3	2/3	VTC	T	0.149
1CV8355B	STANDARD	1.125	1/3	2/3	TSP	T	0.164
1CV8355C	STANDARD	1.125	1/3	2/3	VTC	T	0.105
1CV8355D	STANDARD	1.125	1/3	2/3	TSP	T	0.12
1CV8804A	STANDARD	1.25	1/3	1/3	TSP	T	0.071
1RH610	STANDARD	1.125	1/4	2/4	TSP	T	0.038
1RH611	STANDARD	1.125	1/4	2/4	TSP	T	0.1
1RH8701A	STANDARD	3	2/5	4/5	VTC	L	0.119
1RH8702A	STANDARD	3	2/5	4/5	VTC	L	0.151
1RH8716A	STANDARD	1.25	1/3	1/3	VTC	T	0.038
1RH8716A_M	STANDARD	1.25	1/3	1/3	VTC	T	0.038
1RH8716B	STANDARD	1.25	1/3	1/3	VTC	T	0.121
1RH8716B_M	STANDARD	1.25	1/3	1/3	VTC	T	0.121
1RY8000B	STANDARD	1.25	1/3	1/3	VTC	L	0.031
1SI8801A	STANDARD	1.25	1/3	1/3	VTC	L	0.044
1SI8801B	STANDARD	1.25	1/3	1/3	VTC	L	0.08
1SI8802B	STANDARD	1.25	1/3	1/3	VTC	T	0.16
1SI8804B	STANDARD	1.25	1/3	1/3	TSP	T	0.044
1SI8807B	STANDARD	1.25	1/3	1/3	VTC	T	0.1

[illegible]E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]I8808A	STANDARD	2.5	1/3	2/3	VTC	T	0.105
1SI8808B	STANDARD	2.5	1/3	2/3	VTC	T	0.129
1SI8808C	STANDARD	2.5	1/3	2/3	VTC	T	0.144
1SI8808D	STANDARD	2.5	1/3	2/3	TSP	T	0.159
1SI8809A	STANDARD	2	1/4	2/4	TSP	T	0.084
1SI8809B	STANDARD	2	1/4	2/4	TSP	T	0.089
1SI8811A	STANDARD	2.5	1/3	2/3	VTC	T	0.147
1SI8811B	STANDARD	2.5	1/3	2/3	VTC	T	0.107
1SI8813	STANDARD	1.125	1/3	2/3	VTC	T	0.177
1SI8814	STANDARD	1.125	1/3	2/3	TSP	T	0.092
1SI8835	STANDARD	1.25	1/3	1/3	VTC	T	0.092
1SI8920	STANDARD	1.125	1/3	2/3	TSP	T	0.103
[illegible]923A	STANDARD	1.25	1/3	1/3	VTC	L	0.119
[illegible]006A	STUB	1.25	1/4	2/4	TSP	T	0.151
1WO006B	STUB	1.25	1/4	2/4	TSP	T	0.123
1WO020A	STUB	1.25	1/4	2/4	TSP	T	0.108
1WO020B	STUB	1.25	1/4	2/4	TSP	T	0.097
2CC685	STANDARD	1.25	1/3	1/3	VTC	T	0.084
2CC9412A	STANDARD	1.5	1/3	2/3	TSP	T	0.119
2CC9412B	STANDARD	1.5	1/3	2/3	VTC	T	0.15
2CC9413B	STANDARD	1.5	1/3	2/3	TSP	T	0.095
2CC9414	STANDARD	1.5	1/3	2/3	VTC	T	0.147
2CC9415	STANDARD	1.75	1/3	1/3	TSP	T	0.123
2CC9473A	STANDARD	1.75	1/3	1/3	TSP	T	0.14
2CC9473A_M	STANDARD	1.75	1/3	1/3	TSP	T	0.14
[illegible]473B	STANDARD	1.75	1/3	1/3	TSP	T	0.129
2CS001B	STUB	1.5	1/4	2/4	TSP	T	0.112

[illegible]E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]CS009E	STUB	2.25	1/3	3/3	TSP	T	0.057
2CS019A	STANDARD	1	1/5	2/5	TSP	T	0.136
2CS019B	STANDARD	1	1/5	2/5	TSP	T	0.077
2CV8105	STANDARD	1.25	1/3	1/3	VTC	T	0.123
2CV8106	STANDARD	1.25	1/3	1/3	VTC	L	0.136
2CV8110	STANDARD	1.125	1/3	2/3	TSP	T	0.072
2CV8111	STANDARD	1.125	1/3	2/3	TSP	T	0.149
2CV8355A	STANDARD	1.125	1/3	2/3	TSP	T	0.101
2CV8355B	STANDARD	1.125	1/3	2/3	TSP	T	0.131
2CV8355C	STANDARD	1.125	1/3	2/3	TSP	T	0.127
2CV8355D	STANDARD	1.125	1/3	2/3	TSP	T	0.142
2RH610	STANDARD	1.125	1/4	2/4	TSP	T	0.042
2RH611	STANDARD	1.125	1/4	2/4	VTC	T	0.126
[illegible]701B	STANDARD	3	2/5	4/5	VTC	L	0.086
2RH8702B	STANDARD	3	2/5	4/5	VTC	L	0.187
2RH8716A	STANDARD	1.25	1/3	1/3	VTC	T	0.171
2RH8716A_M	STANDARD	1.25	1/3	1/3	VTC	T	0.117
2RH8716B	STANDARD	1.25	1/3	1/3	VTC	T	0.14
2RH8716B_M	STANDARD	1.25	1/3	1/3	VTC	T	0.117
2RY8000A	STANDARD	1.25	1/3	1/3	VTC	L	0.048
2RY8000B	STANDARD	1.25	1/3	1/3	VTC	L	0.082
2SI8802A	STANDARD	1.25	1/3	1/3	TSP	T	0.05
2SI8804B	STANDARD	1.25	1/3	1/3	VTC	T	0.111
2SI8806	STANDARD	1.25	1/3	1/3	VTC	L	0.123
2SI8808A	STANDARD	2.5	1/3	2/3	VTC	T	0.164
[illegible]808C	STANDARD	2.5	1/3	2/3	VTC	T	0.145
2SI8809B	STANDARD	2	1/4	2/4	VTC	T	0.153

[illegible]E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
2SI8811B	STANDARD	2.5	1/3	2/3	VTC	T	0.102
2SI8811B_M	STANDARD	2.5	1/3	2/3	VTC	T	0.102
2SI8812A	STANDARD	2	1/4	2/4	VTC	T	0.156
2SI8813	STANDARD	1.125	1/3	2/3	TSP	T	0.129
2SI8920	STANDARD	1.125	1/3	2/3	TSP	T	0.144
2SI8923B	STANDARD	1.25	1/3	1/3	VTC	L	0.111
2WO0065	STUB	1.25	1/4	2/4	TSP	T	0.133
2WO056-4	STUB	1.25	1/4	2/4	TSP	T	0.127
2WO056B	STUB	1.25	1/4	2/4	TSP	T	0.122
			TOTAL		0.1147	Standard Dev.	0.0357
						Maximum COF:	0.1734

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2-0202-4A	STANDARD	3.5	1/2	2/2	TSP	T	0.118
[illegible]02-5A	STANDARD	3.5	1/2	2/2	VTC	T	0.064
[illegible]05-2	STANDARD	0.875	1/5	1/5	TSP	T	0.128
2-0220-2	STANDARD	1	1/6	1/6	TSP	T	0.095
2-1001-02A	STANDARD	2.375	1/4	2/4	TSP	T	0.117
2-1001-02B	STANDARD	2.375	1/4	2/4	TSP	T	0.122
2-1001-05A	STANDARD	2.375	1/4	2/4	TSP	T	0.132
2-1001-05B	STANDARD	2.375	1/4	2/4	VTC	T	0.139
2-1201-1	STANDARD	1.875	1/4	2/4	TSP	T	0.158
2-1201-2	STANDARD	1.875	1/4	2/4	TSP	T	0.117
2-1201-3	STANDARD	1.875	1/4	2/4	TSP	T	0.146
2-1301-1	STANDARD	2.375	1/3	3/3	VTC	T	0.126
2-1301-2	STANDARD	2.375	1/3	3/3	VTC	T	0.118
2-1301-3	STANDARD	2.125	1/3	3/3	VTC	T	0.085
[illegible]01-4	STANDARD	2.125	1/3	3/3	VTC	T	0.134
2-1402-38A	STANDARD	0.75	1/7	1/7	TSP	T	0.095

[illegible]E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]1402-3A	STANDARD	2.125	1/2	1/2	VTC	T	0.113
2-1402-3B	STANDARD	2.125	1/2	1/2	TSP	T	0.055
2-1501-11A	STANDARD	2.125	1/2	1/2	VTC	T	0.045
2-1501-11B	STANDARD	2.125	1/2	1/2	TSP	T	0.135
2-1501-13A	STANDARD	0.875	1/5	1/5	VTC	T	0.119
2-1501-13B	STANDARD	0.875	1/5	1/5	VTC	T	0.128
2-1501-19A	STANDARD	1.25	1/4	2/4	TSP	T	0.087
2-1501-20A	STANDARD	2.375	1/4	2/4	VTC	T	0.158
2-1501-20B	STANDARD	2.375	1/4	2/4	VTC	T	0.118
2-1501-22A	STANDARD	3	1/4	2/4	VTC	T	0.14
2-1501-22B	STANDARD	3	1/4	2/4	VTC	T	0.151
2-1501-32B	STANDARD	2.125	1/2	1/2	TSP	T	0.09
[illegible]01-38B	STANDARD	3.5	2/7	2/7	TSP	T	0.08
[illegible]1-3A	STANDARD	1	1/4	1/4	VTC	T	0.15
2-1501-3B	STANDARD	1	1/4	1/4	VTC	T	0.15
2-1501-5A	OTHER	1.75	1/3	1/3	TSP	T	0.052
2-1501-5B	OTHER	1.75	1/3	1/3	TSP	T	0.067
2-1501-5C	OTHER	1.75	1/3	1/3	TSP	T	0.054
2-1501-5D	OTHER	1.75	1/3	1/3	TSP	T	0.107
2-2301-10	STUB	3.5	1/5	1/5	VTC	T	0.166
2-2301-15	STANDARD	2.125	1/4	2/4	VTC	T	0.09
2-2301-3	STANDARD	1.875	1/4	2/4	VTC	T	0.064
2-2301-36	STANDARD	2.125	1/2	1/2	TSP	T	0.144
2-2301-4	STANDARD	1.875	1/4	2/4	VTC	T	0.148
2-2301-48	STANDARD	1	1/4	1/4	VTC	T	0.073
[illegible]1-49	STANDARD	1.25	1/4	2/4	TSP	T	0.054
2-2301-5	STANDARD	1.875	1/4	2/4	VTC	T	0.143

E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
2301-6	STANDARD	2.125	1/2	1/2	TSP	T	0.106
2-2301-8	STANDARD	2.375	1/4	2/4	TSP	T	0.118
2-2301-9	STANDARD	2.375	1/4	2/4	TSP	T	0.131
2-3702	STANDARD	1.25	1/4	1/4	TSP	T	0.128
2-3703	STANDARD	1.25	1/4	1/4	TSP	T	0.096
2-3706	STANDARD	1.25	1/4	1/4	TSP	T	0.134
3-0202-4[illegible]	STANDARD	3.5	1/2	2/2	TSP	T	0.084
3-0202-4[illegible]	STANDARD	3.5	1/2	2/2	VTC	T	0.145
3-0205-2[illegible]	STUB	0.75	1/5	1/5	VTC	T	0.133
3-0220-1	STUB	0.625	1/5	1/5	VTC	T	0.058
3-0220-2	STUB	0.625	1/5	1/5	VTC	T	0.165
3-1001-02A	STANDARD	2.375	1/4	2/4	TSP	T	0.071
3-1001-02C	STANDARD	2.375	1/4	2/4	TSP	T	0.119
01-05A	STANDARD	2.375	1/4	2/4	VTC	T	0.145
3-1001-05B	STANDARD	2.375	1/4	2/4	VTC	T	0.139
3-1201-1	STUB	1.75	1/3	2/3	VTC	T	0.092
3-1201-1A	STUB	0.75	1/6	1/6	VTC	T	0.127
3-1201-2	STUB	1.75	1/3	2/3	VTC	T	0.106
3-1301-1	STANDARD	2.375	1/3	3/3	VTC	T	0.136
3-1301-10	STANDARD	1	1/4	1/4	VTC	T	0.117
3-1301-2	STANDARD	2.375	1/3	3/3	VTC	T	0.071
3-1301-3	STANDARD	2.125	1/3	3/3	VTC	T	0.049
3-1301-4	STANDARD	2.125	1/3	3/3	VTC	T	0.154
3-1402-24A	STANDARD	1.875	1/4	2/4	TSP	T	0.128
3-1402-24B	STANDARD	1.875	1/4	2/4	VTC	T	0.101
02-25A	STANDARD	1.875	1/4	2/4	TSP	T	0.092
3-1402-25B	STANDARD	1.875	1/4	2/4	VTC	T	0.127

VALVE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
1402-33B	STANDARD	0.75	1/7	1/7	VTC	T	0.149
3-1402-3A	STANDARD	2.125	1/2	1/2	TSP	T	0.058
3-1402-3B	STANDARD	2.125	1/2	1/2	VTC	T	0.064
3-1402-4A	STANDARD	1.875	2/7	2/7	VTC	T	0.155
3-1402-4B	STANDARD	1.875	2/7	2/7	VTC	T	0.188
3-1501-11A	STANDARD	2.125	1/2	1/2	VTC	T	0.06
3-1501-11B	STANDARD	2.125	1/2	1/2	VTC	T	0.083
3-1501-18A	STANDARD	1.5	1/4	1/4	VTC	T	0.14
3-1501-18B	STANDARD	1.5	1/4	1/4	VTC	T	0.162
3-1501-19A	STANDARD	1.25	1/4	2/4	VTC	T	0.136
3-1501-19B	STANDARD	1.25	1/4	2/4	VTC	T	0.14
3-1501-20A	STANDARD	2.375	1/4	2/4	VTC	T	0.11
3-1501-22A	STANDARD	3	1/4	2/4	VTC	T	0.167
3-1501-22B	STANDARD	3	1/4	2/4	VTC	T	0.213
3-1501-27A	STANDARD	1.625	1/4	2/4	VTC	T	0.072
3-1501-27B	STANDARD	1.625	1/4	2/4	VTC	T	0.063
3-1501-28A	STANDARD	1.625	1/4	2/4	VTC	T	0.113
3-1501-28B	STANDARD	1.625	1/4	2/4	VTC	T	0.068
3-1501-32A	STANDARD	2.125	1/2	1/2	TSP	T	0.103
3-1501-38A	STANDARD	3.5	2/7	2/7	VTC	T	0.088
3-1501-38B	STANDARD	3.5	2/7	2/7	VTC	T	0.143
3-1501-3A	STANDARD	1	1/4	1/4	VTC	T	0.15
3-1501-3B	STANDARD	1	1/4	1/4	VTC	T	0.15
3-1501-5A	OTHER	1.75	1/3	1/3	VTC	T	0.118
3-1501-5B	OTHER	1.75	1/3	1/3	VTC	T	0.125
3-1501-5C	OTHER	1.75	1/3	1/3	VTC	T	0.098
3-1501-5D	OTHER	1.75	1/3	1/3	VTC	T	0.142

[illegible]VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION	
-2301-10	STUB	3.5	1/5	1/5	TSP	T	0.145	
3-2301-1[illegible]	STANDARD	1.5	1/4	1/4	VTC	T	0.125	
3-2301-15	STANDARD	2.125	1/4	2/4	TSP	T	0.226	
3-2301-3	STANDARD	1.875	1/4	2/4	TSP	T	0.065	
3-2301-35	STANDARD	2.125	1/2	1/2	VTC	T	0.151	
3-2301-4	STANDARD	1.875	1/4	2/4	VTC	T	0.119	
3-2301-48	STANDARD	1	1/4	1/4	VTC	T	0.07	
3-2301-49	STANDARD	1.25	1/4	2/4	VTC	T	0.115	
3-2301-5	STANDARD	1.875	1/4	2/4	VTC	T	0.097	
3-2301-6	STANDARD	2.125	1/2	1/2	TSP	T	0.055	
3-2301-8	STANDARD	2.375	1/4	2/4	TSP	T	0.122	
3-2301-9	STANDARD	2.375	1/4	2/4	VTC	T	0.068	
[illegible]03	STANDARD	1.25	1/4	1/4	TSP	T	0.198	
[illegible]06	STANDARD	1.25	1/4	1/4	VTC	T	0.176	
			TOTAL		0.1156	Standard Dev.		0.0376
						Maximum COF:		0.1775

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1B21-F016	STUB	1.125	1/3	1/3	VTC	T	0.132
1B21-F019	STUB	1.125	1/3	1/3	TSP	T	0.069
1B21-F065A	STUB	4	1/3	1/3	VTC	T	0.122
1B21-F067A	STUB	0.75	1/5	1/5	TSP	T	0.055
1B21-F067C	STUB	0.75	1/5	1/5	TSP	T	0.041
1B21-F067D	STUB	0.75	1/5	1/5	TSP	T	0.058
1C41-F001A	STUB	0.875	1/6	1/6	TSP	T	0.204
1C41-F001B	STUB	0.875	1/6	1/6	TSP	T	0.139
1E12-F004A	STUB	2.5	1/3	2/3	TSP	T	0.142
[illegible]2-F004B	STUB	2.5	1/3	2/3	TSP	T	0.051
1E12-F004C	STUB	2	1/3	2/3	TSP	T	0.099

E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
12-F006A	STUB	2	1/3	2/3	TSP	T	0.095
1E12-F006B	STUB	2	1/3	2/3	VTC	T	0.116
1E12-F008	STUB	2.25	1/3	2/3	VTC	T	0.135
1E12-F009	STUB	3.125	1/3	2/3	TSP	T	0.182
1E12-F016A	STUB	1.75	1/3	2/3	TSP	T	0.117
1E12-F016B	STUB	1.75	1/3	2/3	TSP	T	0.057
1E12-F017A	STUB	1.75	1/3	2/3	TSP	T	0.114
1E12-F017B	STUB	1.75	1/3	2/3	TSP	T	0.134
1E12-F021	STUB	3.25	1/3	2/3	TSP	T	0.102
1E12-F023	STANDARD	1.75	1/4	1/4	TSP	T	0.115
1E12-F024A	STUB	3.25	1/3	2/3	TSP	T	0.108
1E12-F024B	STUB	3.25	1/3	2/3	TSP	T	0.105
1E12-F027A	STUB	1.125	1/3	1/3	TSP	T	0.099
-F027B	STUB	1.125	1/3	1/3	TSP	T	0.049
1E12-F042A	STUB	2.25	1/4	2/4	VTC	T	0.145
1E12-F042B	STUB	2.25	1/4	2/4	TSP	T	0.123
1E12-F042C	STUB	2.25	1/4	2/4	TSP	T	0.154
1E12-F047A	STUB	2	1/3	2/3	TSP	T	0.103
1E12-F047B	STUB	2	1/3	2/3	TSP	T	0.14
1E12-F048A	STUB	3.25	1/3	1/3	TSP	T	0.099
1E12-F048B	STUB	3.25	1/3	1/3	TSP	T	0.087
1E12-F049B	STUB	0.875	1/6	2/6	TSP	T	0.087
1E12-F053A	STANDARD	2.75	1/4	1/4	TSP	T	0.119
1E12-F053B	STANDARD	2.75	1/4	1/4	TSP	T	0.122
1E12-F068A	STUB	1.75	1/3	1/3	TSP	T	0.132
-F068B	STUB	1.75	1/3	1/3	VTC	T	0.112
1E12-F093	STUB	1.125	1/3	1/3	TSP	T	0.11

VALVE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]12-F0[illegible]9A	STUB	0.875	1/6	1/6	TSP	T	0.103
1E12-F0[illegible]9B	STUB	0.875	1/6	1/6	TSP	T	0.152
1E12-F312A	STUB	0.625	1/12	1/12	TSP	T	0.077
1E12-F312B	STUB	0.625	1/12	1/12	TSP	T	0.127
1E21-F001	STUB	2	1/3	2/3	TSP	T	0.121
1E21-F005	STUB	2.25	1/4	2/4	TSP	T	0.112
1E21-F0[illegible]2	STUB	2.75	1/3	1/3	TSP	T	0.189
1E22-F0[illegible]4	STUB	2.25	1/3	3/3	TSP	T	0.106
1E22-F0[illegible]2	STUB	1.375	1/3	2/3	VTC	T	0.111
1E22-F0[illegible]5	STUB	1.875	1/3	2/3	TSP	T	0.085
1E22-F023	STUB	3.25	1/3	1/3	TSP	T	0.198
1E32-F001A	STUB	1.125	1/4	1/4	TSP	T	0.102
[illegible]2-F0[illegible]1E	STUB	1.125	1/4	1/4	VTC	T	0.182
[illegible]2-F00[illegible]J	STUB	1.125	1/4	1/4	TSP	T	0.065
1E32-F001N	STUB	1.125	1/4	1/4	TSP	T	0.154
1E32-F002A	STUB	1.125	1/4	1/4	TSP	T	0.037
1E32-F002E	STUB	1.125	1/4	1/4	TSP	T	0.061
1E32-F002J	STUB	1.125	1/4	1/4	TSP	T	0.081
1E32-F003N	STUB	1.125	1/4	1/4	TSP	T	0.044
1E32-F00[illegible]	STUB	1.125	1/4	1/4	TSP	T	0.054
1E32-F007	STUB	1.125	1/4	1/4	TSP	T	0.096
1E32-F009	STUB	0.75	1/5	1/5	TSP	T	0.051
1E51-F008	STUB	1.25	1/3	1/3	TSP	T	0.059
1E51-F010	STUB	1.25	1/3	1/3	TSP	T	0.091
1E51-F013	STUB	1.625	1/3	2/3	TSP	T	0.11
[illegible]1-F022	STUB	0.875	1/6	1/6	TSP	T	0.106
1E51-F031	STUB	1.25	1/3	1/3	TSP	T	0.083

VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
51-F063	STUB	1.75	1/3	3/3	VTC	T	0.133
1E51-F068	STUB	1.5	1/3	2/3	TSP	T	0.067
1E51-F0[illegible]6	STUB	0.625	1/12	1/12	TSP	T	0.123
1G33-F001	STUB	1.5	1/3	1/3	TSP	T	0.109
1G33-F004	STUB	1.5	1/3	1/3	TSP	T	0.1
1G33-F040	STUB	1.375	1/3	1/3	TSP	T	0.143
1HG-001A	STUB	1.125	1/3	1/3	TSP	T	0.123
1HG-001B	STUB	1.125	1/3	1/3	TSP	T	0.044
1HG-003	STUB	1.125	1/4	1/4	TSP	T	0.078
1HG-005A	STUB	1	1/4	1/4	VTC	T	0.167
1HG-005B	STUB	1	1/4	1/4	VTC	T	0.157
1HG-006A	STUB	1	1/4	1/4	VTC	T	0.155
1HG-006B	STUB	1	1/4	1/4	TSP	T	0.081
018	STUB	0.625	1/12	1/12	VTC	T	0.111
1VP-053A	STUB	1.25	1/3	1/3	TSP	T	0.188
1VP-053B	STUB	1.25	1/3	1/3	TSP	T	0.107
1VP-063B	STUB	1.25	1/3	1/3	TSP	T	0.163
1VQ-032	STUB	0.625	1/12	1/12	TSP	T	0.035
1VQ-035	STUB	0.625	1/12	1/12	TSP	T	0.038
1VQ-047	STUB	0.625	1/12	1/12	TSP	T	0.065
1VQ-048	STUB	0.625	1/12	1/12	TSP	T	0.096
1VQ-050	STUB	0.625	1/12	1/12	TSP	T	0.038
1VQ-051	STUB	0.625	1/12	1/12	TSP	T	0.054
1VQ-068	STUB	0.625	1/12	1/12	TSP	T	0.054
1WR-029	STUB	1	1/4	1/4	TSP	T	0.14
-040	STUB	1	1/4	1/4	TSP	T	0.13
1WR-179	STUB	1	1/4	1/4	TSP	T	0.133

...E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
...-180	STUB	1	1/4	1/4	TSP	T	0.042
2B21-F016	STUB	1.125	1/3	1/3	TSP	T	0.139
2B21-F019	STUB	1.125	1/3	1/3	TSP	T	0.062
2B21-F065A	STUB	4	1/3	1/3	TSP	T	0.155
2B21-F065B	STUB	4	1/3	1/3	TSP	T	0.158
2B21-F067A	STUB	0.75	1/5	1/5	TSP	T	0.051
2B21-F067B	STUB	0.75	1/5	1/5	TSP	T	0.104
2B21-F067C	STUB	0.75	1/5	1/5	TSP	T	0.078
2B21-F067D	STUB	0.75	1/5	1/5	TSP	T	0.084
2C41-F001A	STUB	0.875	1/6	1/6	TSP	T	0.103
2C41-F001B	STUB	0.875	1/6	1/6	TSP	T	0.108
2E12-F004C	STUB	2	1/3	2/3	VTC	T	0.107
2E12-F006A	STUB	2	1/3	2/3	TSP	T	0.107
...008	STUB	2.25	1/3	2/3	TSP	T	0.067
2E12-F009	STUB	3.125	1/3	2/3	TSP	T	0.118
2E12-F016A	STUB	1.75	1/3	2/3	TSP	T	0.071
2E12-F016B	STUB	1.75	1/3	2/3	TSP	T	0.145
2E12-F017A	STUB	1.75	1/3	2/3	TSP	T	0.086
2E12-F017B	STUB	1.75	1/3	2/3	VTC	T	0.139
2E12-F021	STUB	3.25	1/3	1/3	TSP	T	0.072
2E12-F023	STANDARD	1.75	1/4	1/4	TSP	T	0.147
2E12-F024A	STUB	3.25	1/3	1/3	TSP	T	0.09
2E12-F024B	STUB	3.25	1/3	1/3	TSP	T	0.113
2E12-F027A	STUB	1.125	1/3	1/3	TSP	T	0.154
2E12-F027B	STUB	1.125	1/3	1/3	TSP	T	0.044
...-F040A	STUB	0.875	1/6	1/6	TSP	T	0.161
2E12-F042A	STUB	2.25	1/4	2/4	TSP	T	0.189

VALVE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
2E12-F042C	STUB	2.25	1/4	2/4	VTC	T	0.145
2E12-F047A	STUB	2	1/3	2/3	VTC	T	0.143
2E12-F047B	STUB	2	1/3	2/3	TSP	T	0.117
2E12-F048A	STUB	3.25	1/3	1/3	TSP	T	0.043
2E12-F048B	STUB	3.25	1/3	1/3	TSP	T	0.049
2E12-F049B	STUB	0.875	1/6	2/6	TSP	T	0.189
2E12-F053A	STANDARD	2.75	1/4	1/4	TSP	T	0.117
2E12-F053B	STANDARD	2.75	1/4	1/4	TSP	T	0.136
2E12-F064B	STUB	1.125	1/3	2/3	TSP	T	0.055
2E12-F064C	STUB	1.125	1/3	2/3	TSP	T	0.055
2E12-F068A	STUB	1.75	1/3	1/3	TSP	T	0.065
2E12-F094	STUB	1.125	1/3	1/3	TSP	T	0.123
2E12-F099A	STUB	0.875	1/6	1/6	TSP	T	0.064
2E12-F099B	STUB	0.875	1/6	1/6	TSP	T	0.081
2E12-F3[illegible]2A	STUB	0.625	1/12	1/12	TSP	T	0.046
2E12-F3[illegible]2B	STUB	0.625	1/12	1/12	VTC	T	0.096
2E21-F0[illegible]	STUB	2	1/3	2/3	VTC	T	0.141
2E21-F01[illegible]	STUB	1.125	1/3	2/3	VTC	T	0.105
2E21-F012	STUB	2.75	1/3	1/3	TSP	T	0.145
2E22-F004	STUB	2.25	1/3	3/3	TSP	T	0.051
2E22-F012	STUB	1.375	1/3	2/3	TSP	T	0.124
2E22-F015	STUB	1.875	1/3	2/3	TSP	T	0.135
2E32-F007	STUB	1.125	1/4	1/4	TSP	T	0.169
2E32-F008	STUB	0.75	1/5	1/5	TSP	T	0.12
2E32-F009	STUB	0.75	1/5	1/5	TSP	T	0.032
2E51-F008	STUB	1.25	1/3	1/3	TSP	T	0.107
2E51-F010	STUB	1.25	1/3	1/3	TSP	T	0.138

[illegible]LVE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]1-F0[illegible]3	STUB	1.625	1/3	2/3	TSP	T	0.102
2E51-F031	STUB	1.25	1/3	1/3	TSP	T	0.071
2E51-F063	STUB	1.75	1/3	3/3	TSP	T	0.13
2E51-F068	STUB	1.5	1/3	2/3	TSP	T	0.106
2E51-F073	STUB	0.625	1/12	1/12	TSP	T	0.111
2G33-F001	STUB	1.5	1/3	1/3	TSP	T	0.127
2G33-F004	STUB	1.5	1/3	1/3	TSP	T	0.135
2G33-F040	STUB	1.375	1/3	1/3	TSP	T	0.12
2HG-001A	STUB	1.125	1/3	1/3	TSP	T	0.077
2HG-001B	STUB	1.125	1/3	1/3	TSP	T	0.051
2HG-002A	STUB	0.875	1/6	1/6	VTC	T	0.103
2HG-002B	STUB	0.875	1/6	1/6	TSP	T	0.078
2HG-005A	STUB	1	1/4	1/4	TSP	T	0.089
[illegible]005B	STUB	1	1/4	1/4	TSP	T	0.108
2HG-006A	STUB	1	1/4	1/4	TSP	T	0.203
2HG-006B	STUB	1	1/4	1/4	VTC	T	0.198
2VP-053A	STUB	1.25	1/3	1/3	TSP	T	0.136
2VP-053B	STUB	1.25	1/3	1/3	TSP	T	0.077
2VP-063A	STUB	1.25	1/3	1/3	TSP	T	0.156
2VQ-032	STUB	0.625	1/12	1/12	TSP	T	0.104
2VQ-035	STUB	0.625	1/12	1/12	TSP	T	0.18
2VQ-047	STUB	0.625	1/12	1/12	TSP	T	0.188
2VQ-048	STUB	0.625	1/12	1/12	TSP	T	0.123
2VQ-050	STUB	0.625	1/12	1/12	TSP	T	0.073
2VQ-051	STUB	0.625	1/12	1/12	TSP	T	0.096
[illegible]Q-068	STUB	0.625	1/12	1/12	TSP	T	0.134
2WR-040	STUB	1	1/4	1/4	VTC	T	0.13

[illegible]VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION	
			TOTAL		0.1078	Standard Dev.		0.0407
						Maximum COF:		0.1747

QUAD CITIES

1-1001-16A	STANDARD	3	2/7	2/7	VTC	T	0.134
1-1001-16B	STANDARD	3	2/7	2/7	TSP	T	0.119
1-1001-135A	STUB	1.5	1/3	1/3	TSP	T	0.159
1-1001-136A	STANDARD	1.625	1/4	1/4	TSP	T	0.173
1-1001-186B	STANDARD	1.625	1/3	1/3	VTC	T	0.145
1-1001-1[illegible]A	STANDARD	0.875	1/5	1/5	VTC	T	0.111
1-1001-1[illegible]B	STANDARD	0.875	1/5	1/5	VTC	T	0.113
1-1001-19A	STANDARD	2.125	1/2	1/2	VTC	T	0.139
1-1001-[illegible]9B	STANDARD	2.125	1/2	1/2	VTC	T	0.159
1-1001-20	STANDARD	0.875	1/5	1/5	TSP	T	0.16
1-1001-23A	STANDARD	1.625	1/3	3/3	VTC	T	0.094
[illegible]1-2[illegible]B	STANDARD	1.625	1/3	3/3	VTC	T	0.136
1-1001-2[illegible]A	STANDARD	1.625	1/3	3/3	TSP	T	0.139
1-1001-2[illegible]B	STANDARD	1.625	1/3	3/3	VTC	T	0.105
1-1001-29A	STANDARD	3	1/4	2/4	VTC	T	0.127
1-1001-29B	STANDARD	3	1/4	2/4	VTC	T	0.141
1-1001-3[illegible]A	STANDARD	2.125	1/2	1/2	VTC	T	0.101
1-1001-3[illegible]B	STANDARD	2.125	1/2	1/2	VTC	T	0.156
1-1001-36A	STANDARD	2	1/4	2/4	TSP	T	0.133
1-1001-3[illegible]B	STANDARD	2	1/4	2/4	TSP	T	0.107
1-1001-37A	STANDARD	1.5	1/4	1/4	VTC	T	0.14
1-1001-37B	STANDARD	1.5	1/4	1/4	VTC	T	0.137
1-1001-43A	OTHER	1.75	1/3	1/3	VTC	T	0.136
[illegible]001-43B	OTHER	1.75	1/3	1/3	VTC	T	0.12
1-1001-43C	OTHER	1.75	1/3	1/3	VTC	T	0.167

VALVE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
001-43D	OTHER	1.75	1/3	1/3	VTC	T	0.139
1-1001-47	STANDARD	3.5	1/3	2/3	TSP	T	0.152
1-1001-4B	STANDARD	2.125	1/2	1/2	VTC	T	0.107
1-1001-50	STANDARD	3.5	1/3	2/3	TSP	T	0.159
1-1001-7A	OTHER	1.75	1/3	1/3	VTC	T	0.134
1-1001-7B	OTHER	1.75	1/3	1/3	VTC	T	0.12
1-1001-7C	OTHER	1.75	1/3	1/3	VTC	T	0.123
1-1001-7D	STANDARD	1.625	1/3	1/3	VTC	T	0.152
1-1201-2	STUB	1.5	1/3	2/3	VTC	T	0.123
1-1201-5	STUB	1.5	1/3	2/3	VTC	T	0.128
1-1301-1[illegible]	STANDARD	1	1/4	2/4	VTC	T	0.098
1-1301-17	STANDARD	1	1/4	2/4	VTC	T	0.127
1-1301-26	STANDARD	1.25	1/4	1/4	VTC	T	0.14
01-48	STANDARD	1.25	1/4	2/4	VTC	T	0.097
1-1301-49	STANDARD	1.25	1/4	1/4	VTC	T	0.176
1-1301-60	STANDARD	1	1/6	1/6	VTC	T	0.083
1-1301-62	STANDARD	1	1/6	1/6	VTC	T	0.073
1-1402-25A	STANDARD	1.875	1/4	2/4	TSP	T	0.057
1-1402-25B	STANDARD	1.875	1/4	2/4	TSP	T	0.072
1-1402-38B	STANDARD	0.75	1/7	1/7	VTC	T	0.105
1-1402-3A	STANDARD	2.125	1/2	1/2	TSP	T	0.235
1-1402-3B	STANDARD	2.125	1/2	1/2	VTC	T	0.129
1-1402-4A	STANDARD	1.5	1/4	1/4	VTC	T	0.148
1-1402-4B	STANDARD	1.5	1/4	1/4	TSP	T	0.178
1-1601-57	STANDARD	0.625	1/8	1/8	VTC	T	0.112
02-5A	STANDARD	3.5	1/2	2/2	TSP	T	0.088
1-202-5B	STANDARD	3.5	1/2	2/2	TSP	T	0.139

[illegible]VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]0-2	STUB	0.75	1/4	1/4	VTC	T	0.12
1-2301-13	STUB	3.5	1/5	1/5	VTC	T	0.182
1-2301-35	STANDARD	2.125	1/2	1/2	VTC	T	0.123
1-2301-36	STANDARD	2.125	1/2	1/2	TSP	T	0.161
1-2301-4	STANDARD	1.875	1/4	2/4	VTC	T	0.15
1-2301-48	STANDARD	1	1/4	1/4	VTC	T	0.125
1-2301-49	STANDARD	1.25	1/4	2/4	VTC	T	0.109
1-2301-5	STANDARD	1.875	1/4	2/4	VTC	T	0.168
1-2301-6	STANDARD	2.125	1/2	1/2	TSP	T	0.16
1-2301-9	STANDARD	2.375	1/3	3/3	TSP	T	0.186
1-2399-40	STANDARD	1	1/5	2/5	VTC	T	0.136
1-2399-41	STANDARD	1	1/5	2/5	VTC	T	0.109
1-3702	STANDARD	1.375	1/4	2/4	VTC	T	0.175
[illegible]3	STANDARD	1.375	1/4	2/4	VTC	T	0.12
2-1001-185A	STANDARD	1.625	1/3	1/3	VTC	T	0.118
2-1001-185B	STUB	1.625	1/3	2/3	VTC	T	0.107
2-1001-186B	STUB	1.5	1/3	1/3	TSP	T	0.113
2-1001-187B	STUB	1.5	1/3	1/3	TSP	T	0.222
2-1001-18A	STANDARD	0.875	1/5	1/5	VTC	T	0.096
2-1001-18B	STANDARD	0.875	1/5	1/5	VTC	T	0.14
2-1001-19A	STANDARD	2.125	1/2	1/2	VTC	T	0.083
2-1001-19B	STANDARD	2.125	1/2	1/2	VTC	T	0.109
2-1001-20	STANDARD	0.875	1/5	1/5	VTC	T	0.119
2-1001-23A	STANDARD	1.625	1/3	3/3	VTC	T	0.142
2-1001-23B	STANDARD	1.625	1/3	3/3	VTC	T	0.097
[illegible]001-26A	STANDARD	1.625	1/3	3/3	VTC	T	0.083
2-1001-26B	STANDARD	1.625	1/3	3/3	VTC	T	0.105

VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
001-29A	STANDARD	3	1/4	2/4	VTC	T	0.143
2-1001-29B	STANDARD	3	1/4	2/4	VTC	T	0.12
2-1001-34A	STANDARD	2.125	1/2	1/2	VTC	T	0.133
2-1001-34B	STANDARD	2.125	1/2	1/2	VTC	T	0.184
2-1001-36A	STANDARD	2.75	1/4	2/4	VTC	T	0.158
2-1001-37A	STANDARD	1.5	1/4	1/4	VTC	T	0.089
2-1001-37B	STANDARD	1.5	1/4	1/4	VTC	T	0.14
2-1001-43A	OTHER	1.75	1/3	1/3	VTC	T	0.165
2-1001-43B	OTHER	1.75	1/3	1/3	VTC	T	0.102
2-1001-43C	OTHER	1.75	1/3	1/3	VTC	T	0.161
2-1001-43D	OTHER	1.75	1/3	1/3	VTC	T	0.136.
2-1001-4A	STANDARD	2.125	1/2	1/2	VTC	T	0.149
2-1001-50	STANDARD	3.5	1/3	2/3	TSP	T	0.175
01-7A	OTHER	1.75	1/3	1/3	TSP	T	0.128
2-1001-7B	OTHER	1.75	1/3	1/3	TSP	T	0.188
2-1001-7C	OTHER	1.75	1/3	1/3	VTC	T	0.147
2-1001-7D	OTHER	1.75	1/3	1/3	VTC	T	0.146
2-1201-2	STUB	1.5	1/3	2/3	VTC	T	0.083
2-1201-5	STUB	1.5	1/3	2/3	VTC	T	0.094
2-1301-16	STANDARD	1	1/4	2/4	VTC	L	0.142
2-1301-17	STANDARD	1	1/4	2/4	TSP	T	0.073
2-1301-2[illegible]	STANDARD	1.25	1/4	1/4	VTC	T	0.067
2-1301-25	STANDARD	1.25	1/4	1/4	VTC	T	0.049
2-1301-49	STANDARD	1.25	1/4	2/4	VTC	T	0.038
2-1301-53	STANDARD	1.5	1/4	1/4	TSP	T	0.138
301-62	STANDARD	1	1/6	1/6	TSP	T	0.162
2-202-5A	STANDARD	3.5	1/2	2/2	TSP	T	0.123

VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION	
2-5B	STANDARD	3.5	1/2	2/2	TSP	T	0.081	
2-220-1	STUB	0.75	1/4	1/4	TSP	T	0.123	
2-2301-10	STUB	3.5	1/5	1/5	TSP	T	0.143	
2-2301-15	STANDARD	2.125	1/4	2/4	TSP	T	0.128	
2-2301-3	STANDARD	1.875	1/4	2/4	VTC	T	0.113	
2-2301-35	STANDARD	2.125	1/2	1/2	TSP	T	0.1	
2-2301-4	STANDARD	1.875	1/4	2/4	VTC	L	0.121	
2-2301-48	STANDARD	1	1/4	1/4	VTC	T	0.104	
2-2301-49	STANDARD	1.25	1/4	2/4	TSP	T	0.081	
2-2301-5	STANDARD	1.875	1/4	2/4	VTC	L	0.09	
2-2301-6	STANDARD	2.125	1/2	1/2	VTC	T	0.083	
2-2301-9	STANDARD	2.375	1/3	3/3	TSP	T	0.148	
2-2399-40	STANDARD	1	1/5	2/5	VTC	T	0.127	
9-4	STANDARD	1	1/5	2/5	TSP	T	0.163	
2-3703	STANDARD	1.375	1/4	2/4	VTC	T	0.139	
2-3706	STANDARD	1.375	1/4	2/4	TSP	T	0.109	
			TOTAL		0.1278	Standard Dev.		0.0332
						Maximum COF:		0.1824
ZION								
1CC0685	STANDARD	1.125	1/3	2/3	TSP	T	0.105	
1CC9412A	STANDARD	1.625	1/3	1/3	TSP	T	0.124	
1CC9412B	STANDARD	1.625	1/3	1/3	TSP	T	0.096	
1CC9413A	STUB	1.5	1/3	2/3	TSP	T	0.087	
1CC9413B	STUB	1.5	1/3	2/3	VTC	T	0.133	
1CC9414	STUB	1.5	1/3	2/3	TSP	T	0.109	
1CC9415	STUB	1.375	1/5	2/5	TSP	T	0.155	
C9438	STANDARD	1.125	1/3	2/3	VTC	T	0.125	
1CS0002	STUB	1.5	1/3	1/3	VTC	T	0.124	

[illegible]VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]S0003	STUB	1.5	1/3	1/3	TSP	T	0.104
1CS0004	STUB	1.5	1/3	1/3	TSP	T	0.121
1CS0005	STUB	1.5	1/3	1/3	TSP	T	0.117
1CS0006	STUB	1.5	1/3	1/3	TSP	T	0.14
1CS0007	STUB	1.5	1/3	1/3	TSP	T	0.125
1CS0008	STUB	1.25	1/3	1/3	VTC	T	0.057
1CS0010	STUB	1.25	1/3	1/3	TSP	T	0.079
1CS0049	STUB	1.875	1/3	1/3	TSP	T	0.192
1CS0050	STUB	1.875	1/3	1/3	TSP	T	0.164
1FW0016	STANDARD	2.25	1/4	2/4	TSP	T	0.129
1FW0017	STANDARD	2.25	1/4	2/4	TSP	T	0.106
1FW0018	STANDARD	2.25	1/4	2/4	TSP	T	0.104
1FW0019	STANDARD	2.25	1/4	2/4	TSP	T	0.121
[illegible]0050	STUB	1.25	1/4	1/4	TSP	T	0.078
1FW0051	STUB	1.25	1/4	1/4	TSP	T	0.096
1FW0052	STUB	1.25	1/4	1/4	TSP	T	0.088
1FW0053	STUB	1.25	1/4	1/4	TSP	T	0.123
1FW0054	STUB	1.25	1/4	1/4	TSP	T	0.113
1FW0055	STUB	1.25	1/4	1/4	TSP	T	0.117
1FW0056	STUB	1.25	1/4	1/4	TSP	T	0.173
1FW0057	STUB	1.25	1/4	1/4	TSP	T	0.094
1FW0074	STANDARD	1.188	1/5	2/5	VTC	T	0.147
1FW0075	STANDARD	1.5	1/4	2/4	TSP	T	0.145
1FW0076	STANDARD	1.188	1/5	2/5	VTC	T	0.159
1MS0005	STANDARD	1.5	1/6	2/6	VTC	T	0.105
[illegible]S0006	STANDARD	1.5	1/6	2/6	VTC	T	0.105
1MS0011	STANDARD	1.5	1/6	2/6	VTC	T	0.111

VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
8000A	STANDARD	1.125	1/3	2/3	VTC	T	0.109
1RC8000B	STANDARD	1.125	1/3	2/3	TSP	T	0.063
1RH8700A	STUB	1.75	1/3	1/3	TSP	T	0.072
1RH8702	STANDARD	2	1/4	1/4	TSP	L	0.07
1RH8716A	STUB	1.375	1/3	2/3	VTC	T	0.055
1RH8716B	STUB	1.375	1/3	2/3	TSP	T	0.054
1RH8716C	STUB	1.375	1/3	2/3	TSP	T	0.131
1RH9000	STUB	1.5	1/3	2/3	TSP	T	0.133
1RHFCV611	STANDARD	1.25	1/5	1/5	TSP	T	0.237
1SI8802	STUB	1.625	1/3	2/3	TSP	T	0.13
1SI8804A	STUB	1.375	1/3	2/3	TSP	T	0.075
1SI8804B	STUB	1.375	1/3	2/3	TSP	T	0.066
1SI8806	STANDARD	1.25	1/3	2/3	VTC	T	0.114
808C	STANDARD	2.5	1/3	2/3	TSP	T	0.151
1SI8809A	STANDARD	2.5	1/3	2/3	TSP	T	0.105
1SI8809B	STANDARD	2.5	1/3	2/3	TSP	T	0.076
1SI8811A	STUB	2	1/3	2/3	TSP	T	0.092
1SI8811B	STUB	2	1/3	2/3	TSP	T	0.036
1SI8812A	STUB	1.5	1/3	2/3	TSP	T	0.09
1SI8812B	STUB	1.5	1/3	2/3	TSP	T	0.211
1SI8813	STANDARD	1.25	1/5	1/5	TSP	T	0.159
1SI8814	STANDARD	1.25	1/5	1/5	VTC	T	0.141
1SI8923A	STANDARD	1.25	1/3	2/3	TSP	T	0.06
1SI8923B	STANDARD	1.25	1/3	2/3	VTC	T	0.058
1SI9010A	STUB	1.625	1/3	2/3	VTC	L	0.118
9011A	STUB	1.625	1/3	2/3	VTC	L	0.15
1SI9011B	STUB	1.625	1/3	2/3	VTC	L	0.084

…E NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
…000.	STUB	1.75	1/5	2/5	VTC	T	0.133
1SW0002	STUB	1.75	1/5	2/5	VTC	T	0.135
1SW0003	STANDARD	2.25	1/2	1/2	VTC	T	0.032
1SW0004	STANDARD	2.25	1/2	1/2	VTC	T	0.047
1SW0006	STANDARD	2.25	1/2	1/2	VTC	T	0.071
1SW0102	STUB	1.25	1/3	1/3	VTC	T	0.134
1SW0106	STANDARD	1.375	1/4	2/4	VTC	T	0.15
1SW0108	STANDARD	1.188	1/5	2/5	VTC	T	0.151
1SW0109	STANDARD	1.188	1/5	2/5	VTC	T	0.112
1SW0110	STANDARD	1.188	1/5	2/5	VTC	T	0.124
1VC112D	STANDARD	1.25	1/3	2/3	VTC	T	0.11
1VC112E	STANDARD	1.25	1/3	2/3	VTC	T	0.124
1VC8100	STUB	1.375	1/3	2/3	VTC	T	0.15
…104	STANDARD	1.25	1/5	1/5	TSP	T	0.169
1VC8105	STANDARD	1.125	1/3	2/3	VTC	T	0.033
1VC8110	STANDARD	1.25	1/5	1/5	TSP	T	0.083
1VC8111	STANDARD	1.25	1/5	1/5	TSP	T	0.159
2CC0685	STANDARD	1.125	1/3	2/3	TSP	T	0.09
2CC9412A	STANDARD	1.625	1/3	1/3	TSP	T	0.116
2CC9412B	STANDARD	1.625	1/3	1/3	TSP	T	0.125
2CC9413A	STUB	1.5	1/3	2/3	VTC	T	0.056
2CC9413B	STUB	1.5	1/3	2/3	VTC	T	0.105
2CC9414	STUB	1.5	1/3	2/3	TSP	T	0.176
2CC9415	STUB	1.375	1/5	2/5	VTC	T	0.1
2CC9438	STANDARD	1.125	1/3	2/3	TSP	T	0.134
…0004	STUB	1.5	1/3	1/3	TSP	T	0.113
2CS0006	STUB	1.5	1/3	1/3	TSP	T	0.083

[illegible]VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]0007	STUB	1.5	1/3	1/3	TSP	T	0.143
2CS0009	STUB	1.25	1/3	1/3	TSP	T	0.051
2CS0010	STUB	1.25	1/3	1/3	TSP	T	0.157
2CS0050	STUB	1.875	1/3	1/3	TSP	T	0.11
2FW0016	STANDARD	2.25	1/4	2/4	TSP	T	0.134
2FW0017	STANDARD	2.25	1/4	2/4	TSP	T	0.176
2FW0018	STANDARD	2.25	1/4	2/4	TSP	T	0.11
2FW0019	STANDARD	2.25	1/4	2/4	TSP	T	0.135
2FW0050	STUB	1.25	1/4	1/4	TSP	T	0.134
2FW0051	STUB	1.25	1/4	1/4	VTC	T	0.138
2FW0052	STUB	1.25	1/4	1/4	TSP	T	0.207
2FW0053	STUB	1.25	1/4	1/4	TSP	T	0.123
2FW0054	STUB	1.25	1/4	1/4	TSP	T	0.101
[illegible]055	STUB	1.25	1/4	1/4	TSP	T	0.169
2FW0056	STUB	1.25	1/4	1/4	TSP	T	0.111
2FW0057	STUB	1.25	1/4	1/4	TSP	T	0.094
2MS0005	STANDARD	1.5	1/6	2/6	VTC	T	0.14
2MS0006	STANDARD	1.5	1/6	2/6	VTC	L	0.137
2MS0011	STANDARD	1.5	1/6	2/6	VTC	L	0.086
2RC8000A	STANDARD	1.125	1/3	2/3	VTC	T	0.177
2RC8000B	STANDARD	1.125	1/3	2/3	TSP	T	0.105
2RH8700B	STUB	1.75	1/3	1/3	TSP	T	0.11
2RH8716A	STUB	1.5	1/3	3/3	TSP	T	0.073
2RH8716B	STUB	1.375	1/3	2/3	TSP	T	0.055
2RH9000	STUB	1.5	1/3	1/3	TSP	T	0.093
[illegible]FCV610	STANDARD	1.25	1/5	1/5	VTC	T	0.167
2RHFCV611	STANDARD	1.25	1/5	1/5	VTC	T	0.111

[illegible]VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
[illegible]8802	STANDARD	1.375	1/3	2/3	TSP	T	0.132
2SI8804A	STUB	1.375	1/3	2/3	VTC	T	0.097
2SI8804B	STUB	1.375	1/3	2/3	VTC	T	0.043
2SI8806	STANDARD	1.25	1/3	2/3	VTC	T	0.146
2SI8809A	STANDARD	2.5	1/3	2/3	TSP	T	0.102
2SI8809B	STANDARD	2.5	1/3	2/3	TSP	T	0.096
2SI8811B	STUB	2	1/3	2/3	TSP	T	0.107
2SI8812B	STUB	1.5	1/3	2/3	TSP	T	0.043
2SI8813	STANDARD	1.25	1/5	1/5	TSP	T	0.145
2SI8814	STANDARD	1.25	1/5	1/5	TSP	T	0.121
2SI8923B	STANDARD	1.125	1/3	2/3	TSP	T	0.105
2SI9010A	STANDARD	1.375	1/3	2/3	VTC	L	0.171
2SI9010B	STANDARD	1.375	1/3	2/3	VTC	L	0.123
[illegible]11A	STUB	1.625	1/3	2/3	TSP	L	0.048
2SW0001	STUB	1.75	1/5	2/5	VTC	T	0.116
2SW0002	STUB	1.75	1/5	2/5	VTC	T	0.139
2SW0003	STANDARD	2.25	1/2	1/2	VTC	T	0.185
2SW0004	STANDARD	2.25	1/2	1/2	VTC	T	0.194
2SW0005	STANDARD	2.25	1/2	1/2	VTC	T	0.08
2SW0007	STANDARD	2.25	1/2	1/2	VTC	T	0.186
2SW0102	STUB	1.25	1/3	1/3	VTC	T	0.126
2VC112D	STANDARD	1.25	1/3	2/3	VTC	T	0.078
2VC112E	STANDARD	1.25	1/3	2/3	VTC	T	0.112
2VC8105	STANDARD	1.125	1/3	2/3	VTC	T	0.094
2VC8106	STANDARD	1.125	1/3	2/3	VTC	T	0.045
[illegible]8110	STANDARD	1.25	1/5	1/5	TSP	T	0.081
			TOTAL		0.1146	Standard Dev.	0.0393
						Maximum COF:	0.1792

VE NO.	THREAD TYPE	STEM DIAM	PITCH	LEAD	TORQUE BASIS	TC/L	COEFFICIENT OF FRICTION
	All Stations		**TOTAL**		0.1149	Standard Dev.	0.0389
						Maximum COF:	0.1788

ATTACHMENT

2

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NOV -8 1994

MPR
ASSOCIATES INC.
ENGINEERS

November 4, 1994

Mr. Paul Dietz
Commonwealth Edison Company
1400 Opus Place
Downers Grove, IL 60515

Subject: Review of CECo WP-156, "AISI Type 1018 Motor Key Pinion Torque Limits and Motor Pinion Key Inspection/Installation Guidelines," Revision C, June 30, 1994.

Dear Mr. Dietz:

Enclosed is a draft report documenting our review of the subject CECo position paper. We have discussed our comments by phone with Mr. John Kelly. Our recommendations are summarized below:

- The mechanism and characteristics of the Kalsi key failures should be documented as part of the justification, to demonstrate that the approach being used addresses the mechanism.

- The method for calculating the load on the key needs to be improved. We understand that CECo is preparing a revised method.

- Torque limits should be calculated only for cycles greater than the number of cycles at which the Kalsi keys failed. We recommend that torque limits for 200 and 2000 cycles be presented in WP-156 and that calculated torque limits at 100 cycles be removed from the paper.

- To the extent possible, the method of the white paper should be assessed against known instances of key failures outside of the Kalsi key failures. Several key failures are described in References 3-11 of the enclosure.

Please call if you have questions or comments regarding the enclosed report.

Sincerely,

Richard O. Vollmer

Richard O. Vollmer

Enclosure

cc: John Kelly, CECo (w/ enclosure)

320 KING STREET ALEXANDRIA, VA 22314-3238 703-519-0200 FAX: 703-519-0224

MPR
ASSOCIATES INC.
ENGINEERS

Enclosure to
MPR Letter Dated
November 4, 1994

REVIEW REPORT FOR REVIEW OF COMMONWEALTH EDISON WP-156

OVERVIEW

This review report documents the approach and conclusions of an independent review of Commonwealth Edison Company White Paper WP-156, "AISI Type 1018 Motor Key Pinion Torque Limits and Motor Pinion Key Inspection/Installation Guidelines." The review was performed using WP-156, Revision C, June 30, 1994, which is included in this report as Attachment A.

SCOPE OF WP-156

The white paper provides torque limits for approximately 180 valve actuators covering 100, 200, and 2000 operational cycles, based on strength limits of AISI Type 1018 motor pinion keys. The torque limit at 2000 cycles is recommended as a criterion for evaluating specific actuators to determine if key replacement is necessary. For actuators in which key replacement is determined to be necessary, the white paper information assists in prioritizing these replacements. The white paper includes guidance on evaluating stall events and provides guidance on installation and inspection of motor pinion keys.

The justification of the white paper position is that for each specific operator, the nominal shear stress in the key due to the operator rated torque is calculated and compared to the nominal shear stress experienced in the Kalsi tests. Standard fatigue curves are used to extrapolate to the shear stress limits at 100 and 2000 operational cycles from the calculated shear stress in the Kalsi tests (which failed at approximately 200 cycles). For each actuator configuration, the shear stress limits are converted to torque limits, expressed as a percent of actuator rated torque.

CONCLUSIONS AND RECOMMENDATIONS

The white paper presents an approach which appears to be appropriate and useful for evaluating actuator configurations with motor pinion keys made of AISI Type 1018 material. However, we conclude that the justification of the detailed approach is not complete and that some features of the method and justification should be revised. Important recommendations in this regard are:

- The mechanism and characteristics of the Kalsi key failures should be documented as part of the justification, to demonstrate that the approach being used addresses the mechanism.

- The method for calculating the load on the key needs to be improved. We understand that CECo is preparing a revised method.

- Torque limits should be calculated only for cycles greater than the number of cycles at which the Kalsi keys failed. We recommend that torque limits for 200 and 2000 cycles be presented in WP-156 and that calculated torque limits at 100 cycles be removed from the paper.

- To the extent possible, the method of the white paper should be assessed against known instances of key failures outside of the Kalsi key failures. Documents describing several key failures are referenced below.

REVIEW APPROACH

The MPR review approach is as follows:

- Review the white paper purpose to ensure that it is clearly and completely stated.

- Review the statement of position to ensure that it:

  - addresses the purpose;
  - is clear and complete;
  - includes all appropriate restrictions and limitations with regard to its use.

- Review the technical justification to ensure that it:

  - logically presents a case which defends the stated position;
  - makes proper technical use of the theory and data which are referenced;
  - adheres to appropriate requirements of codes, standards, and regulations which are referenced;
  - does not exclude references to key data or requirements;
  - provides a sufficient technical basis for the stated position;
  - is written in a way to provide a convincing justification.

As part of the review of the justification, comparisons to other data or approaches (e.g., EPRI data or models) which may not have been considered in writing the justification are made.

DETAILED REVIEW RESULTS

1. <u>Purpose of WP-156</u>

The position paper states:

"This position paper identifies GL 89-10 motor operated valve actuator configurations which could experience stresses at the motor pinion key equal to or in excess of the stresses that failed AISI type 1018 motor pinion keys during the Kalsi Engineering MOV thrust extension testing.

In addition, this position paper provides guidelines on the inspection and installation of motor pinion keys."

1.1 Comment. The content of the white paper goes beyond the stated purpose.

Recommendation. The purpose statement should be revised to address the full scope of the white paper. We suggest the following:

"The purpose of this position paper is to:

(1) Provide a method to identify actuator configurations which could experience stresses in the motor pinion keys equal to or greater than the stresses in keys which failed during Kalsi thrust extension testing. These actuators would be given highest priority for replacement of Type 1018 keys with Type 4140 keys.

(2) Provide a method to identify actuator configurations for which the key stresses are such that key replacement is not necessary.

(3) Provide guidance to prioritize key replacements for actuators for which the key stresses are between items (1) and (2) above.

(4) Provide guidance on evaluation of stall torque limits.

(5) Provide guidance on installation and inspection of motor pinion keys."

2. Technical Position of WP-156

The position provides tables showing the allowable torque loading (expressed as a percent of maximum actuator torque rating) for approximately 180 different actuator configurations, based on AISI Type 1018 motor pinion key strength limits. Separate allowable torques are provided for 100, 200, and 2000 operational loading cycles. A table is provided for gate and butterfly valves and another table is provided for globe valves. The position also provides a worksheet for determining allowable torque loadings for actuator configurations not included in the tables.

The position recommends that motor operated valves for which the existing maximum torque exceeds the 2000 cycle torque limit be given high priority in implementing corrective action (replacing the Type 1018 keys with Type 4140 key material). The position also recommends that stall events be evaluated based on 100 cycle torque limits. Finally, the position provides an attachment which contains guidelines for installation and inspection of motor pinion keys.

2.1 Comment. The position is expressed in a meaningful manner. However, as discussed later in this report, we consider that 100 cycle limits (or any cycle limit below the number of cycles experienced in the Kalsi tests) cannot be technically justified based on the available information.

Recommendation. We suggest that the 100 cycle limits be deleted from the position, and that the disposition of key replacements be restated as follows:

- "Actuator configurations for which the actuator torque rating is less than the 2000 cycle torque limit are not of concern and no key replacements are necessary.
- Actuator configurations for which the actual maximum torque in service is less than the 2000 cycle torque limit are not of concern and no key replacements are necessary.
- Actuator configurations for which the actual maximum torque in service is greater than the 200 cycle torque limit (i.e., key stresses are greater than the key stresses in the Kalsi tests) are of significant concern, and key replacements should be implemented on a high priority basis.
- Actuator configurations for which the actual maximum torque in service is less than the 200 cycle torque limit but greater than the 2000 cycle torque limit are potentially of concern, and key replacements should be performed based on an assigned priority."

Further, we recommend that actuator stall evaluations be performed on the basis of 200 cycle torque limits rather than 100 cycle limits.

3. Technical Justification of WP-156

The white paper provides a method for calculating the "critical stress" in the motor pinion keys of an SMB-0 operator which failed during Kalsi testing (Reference 1). The keys failed after approximately 200 fully reversed cycles at 104% of the operator rated torque. The critical stress is the nominal shear stress in the key, calculated as the load due to the applied torque divided by the shear area of the key. The critical stresses at 100 cycles and 2000 cycles are estimated using the slope of the design fatigue curve for low alloy carbon steel in the ASME Boiler & Pressure Vessel Code.

Using the calculated critical stresses, and including the gear ratio, efficiency and key/keyway geometry of each operator, a torque limit is calculated for each operator at 100, 200, and 2000 cycles. The calculated torque limits are expressed as a percentage of actuator rated torque.

3.1 Comment. As indicated by the fact that the calculated key shear stress is very low, it appears that the actual key loading is not well understood. For example, the loading is likely to include dynamic effects which are not included in the method used in the white paper. Consequently, the method presented in WP-156 to calculate the load on the key based only on the rated actuator output torque (and the static mechanical factors that relate actuator torque to motor torque) does not appear to be well justified.

Recommendation. We understand that CECo is developing a revised method for calculating the load applied to the key.

3.2 Comment. The mechanism and characteristics of the key failures experienced in the Kalsi tests are not documented as part of the technical justification. This information is critical to the validity of the method developed in the white paper. In particular, the method in the white paper depends on the mechanism being low cycle fatigue with shear as the controlling stress.

Recommendation. Document the mechanism and important characteristics of the key failures in the Kalsi tests.

3.3 Comment. The actual stress state in the key is complicated and depends on a number of detailed factors such as the fit of the key in the keyway. Consequently, the nominal shear stress in the key may not be an adequate measure of the fatigue damage of each cycle. Furthermore, at the low number of cycles at which failures have been observed, the fatigue life is related to the amount of cycling of the strain rather than the stress. It is likely that there is plastic deformation during each load cycle, particularly in a relatively soft material such as Type 1018. It is not evident that the amount of plastic deformation of the key is related in a simple fashion to the nominal shear stress.

Recommendation. If the failure of the keys in the Kalsi tests is confirmed to be low cycle fatigue with shear as the controlling stress, and if the load on the key can be adequately calculated, the use of a fitted fatigue curve based on strain attributable to shear is an appropriate method. Because plastic strain is likely involved on each load cycle, the strain is not directly proportional to the stress. The strain is approximately proportional to the amount by which the stress exceeds the yield stress of the material. Accordingly, a change in stress produces a change in strain which is larger than the proportional change in stress. Consequently, extrapolating to numbers of cycles to failure less than that seen in the Kalsi tests (approximately 200 cycles) would be very difficult to justify. However, the method could be justified as conservative for cases in which the cycles to failure exceed 200 (i.e., the stress/strain relationship is less severe than in the Kalsi tests). The conservatism of this approach could be reduced if the load at which plastic deformation is initiated could be established for each actuator, however this would require considerable additional effort which we have not evaluated.

Our recommendation is to develop the method to calculate torque limits for cycles to failure of 200 and 2000, provided that the failure mechanism of the failed keys in the Kalsi tests is confirmed and the actual key loading can be calculated.

3.4 Comment. We are concerned that the use of the slope of the ASME design fatigue curve, rather than actual fatigue curves of failures of appropriate material, could be distorting the extrapolation of the Kalsi results to other numbers of cycles and loads. The ASME curves are for the purposes of design for a wide range of materials and have been modified to provide built-in margins. It would appear more appropriate to base the evaluation on actual low cycle failure data for Type 1018 material.

Recommendation. We have located some low cycle fatigue data for Type 1018 material (Reference 2) which is included in this report as Attachment B. Preliminary comparison of the slope of the fatigue data for Type 1018 material to the slope of the ASME Code design fatigue curve indicates that these curves are similar, but the ASME fatigue curve is non-conservative at cycles greater than 200. Consequently, we recommend that the actual fatigue data for Type 1018 material be used to develop the 2000 cycle torque limit.

3.5 Comment. Because the actual stress state in the key is more complicated than assumed in the WP-156 method, and because the stresses in specific keys may be influenced by differences in clearances (key-to-shaft, key-to-pinion, and shaft-to-pinion), there is potential for significant uncertainty in applying the method based on two failed keys in a single operator to a wide range of operators.

Recommendation. To address this uncertainty, we suggest that the CECo method be applied to other instances of known failures (e.g., References 3-11) to determine whether the method would predict results consistent with the known results. Note that because these are failures in service, successful prediction of the failures by the WP-156 method would provide confidence in the method.

3.6 Comment. The replacement of a relatively soft key material with a harder material inherently increases the potential for damage or failure originating in the mated keyway. There is some information (References 10 and 11) that indicates that the replacement of Type 1018 keys with harder Type 4140 key material may lead to increased keyway damage. Consequently, the possibility of a failure in the motor pinion-to-shaft connection may not be eliminated by the key replacement. For example, in References 10 and 11:

- A motor shaft and key, both of Type 4140 material, were installed in a 100 ft-lbf, SB-3 actuator and cycled approximately 15 times during MOVATS testing. The shaft keyway was significantly deformed, and the key was scored lengthwise. The measured maximum thrust during the tests was 50,000 lbf (as compared to the maximum design thrust of 140,000 lbf for the actuator).

- Inspection of 14 actuators revealed two cracked shafts, minor keyway deformation, and minor to severe key deformation for Type 1018 keys installed in Type 1144 shafts. For Type 4140 keys installed in Type 1140 shafts, the relatively harder keys suffered less damage than the Type 1018 keys. However, the shaft keyways were more severely deformed in the actuators with Type 4140 keys than in the actuators with Type 1018 keys.

From a safety standpoint, replacement of Type 1018 keys with Type 4140 material does not reduce the capacity of the actuator. However, excessive deformation of the shaft keyway could lead to cracking and failure of the shaft.

Recommendation. We recognize that this issue is beyond the scope of WP-156 and we do not recommend that evaluation of this issue be included in the white paper. However, we believe that allowable torque limits for actuators equipped with Type 4140 keys should be established, with specific consideration of the potential for shaft keyway deformation.

MINOR COMMENTS

1. On page 3 of 13 of the white paper, the 200 cycle limit for an SMB-4 actuator with an OAR of 27:1 is identified as 35% MATR. This limit should be 32% MATR (from page 1 of 6 of Attachment A).

2. It would be helpful to include the units for run efficiency and Limitorque torque rating in the tables in Attachments A and B, e.g., "RUN EFF (%)" and "MATR (lbf-in)."

3. Reference 7 of the white paper is identified as "IN 81-08." It appears that this reference should be "IN 88-84."

4. The document listed as "Reference (b)" in Table 1 of WP-156 is identified as "88-44." It appears that this reference should be "88-84."

5. In Item I.d on page 1 of the "Guideline for Installing Motor Pinion gear to Motor Shaft," Type 1018 and Type 4140 materials are identified as acceptable key materials for SMB-000 operators. Since the intent of WP-156 is to eventually replace Type 1018 keys with keys of Type 4140 or equivalent material in actuators which exceed the 2000 cycle torque limit, this procedure should clearly state that Type 4140 or equivalent keys shall be used for all actuators which are candidates for key replacement.

REFERENCES

1. KEI Report No. 1707C, "Thrust Rating Increase of Limitorque SMB-000, SMB-00, SMB-0, and SMB-1 Actuators," Revision 0, November 25, 1991.

2. Metals and Ceramics Information Center, Battelle Columbus Laboratories, "Structural Alloys Handbook," Volume 1, 1988 Edition.

3. IE Information Notice No. 81-08, "Repetitive Failures of Limitorque Operator SMB-4 Motor-to-Shaft Key."

4. NRC Information Notice No. 88-84, "Defective Motor Shaft Keys in Limitorque Motor Actuators."

5. NRC Information Notice No. 90-37, "Sheared Pinion Gear-to-Shaft Keys in Limitorque Operators."

6. NRC Information Notice No. 94-10, "Failure of Motor-Operated Valve Electric Power Train Due to Sheared or Dislodged Motor Pinion Gear Key."

7. Docket No. 50-333, LER No. 92-028-00, "Potential Coolant System Failure Due to Valve Operator Motor Pinion Key Failure."

8. Docket No. 50-461, 10CFR21 Defect 21-93-029, "Potential for Motor Pinion Key Failure in Limitorque Actuators due to Excessive Torque During Valve Backseating and MOVATS Testing."

9. Docket No. 50-390 and Docket No. 50-391, WBRD-50-390/86-64 and WBRD-50-391/87/23 (Final Report), "Failed Motor Pinion Keys and Motor Shaft in Limitorque Operator."

10. Docket No. 50-390 and Docket No. 50-391, WBRD-50-390/86-64 and WBRD-50-391/87/23 (Fifth Interim Report), "Failed Motor Pinion Keys and Motor Shaft in Limitorque Operator."

11. Docket No. 50-390 and Docket No. 50-391, WBRD-50-390/86-64 and WBRD-50-391/87/23 (Third Interim Report), "Failed Motor Pinion Keys and Motor Shaft in Limitorque Operator."

MPR ASSOCIATES INC. ENGINEERS

Attachment A to
MPR Enclosure Dated
November 4, 1994

CECo White Paper WP-156, "AISI Type 1018 Motor Key Pinion Torque Limits and Motor Pinion Key Inspection/Installation Guidelines," Revision C, June 30, 1994.