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January 5, 2001

Mr. Eugene V. Imbro
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Office of Nuclear Reactor Regulation
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Washington, DC 20555

SUBJECT: Response to Questions on Addendum 2 to EPRI Performance Prediction Methodology Software, Version 2.0

Reference: NEI (D.J. Modeen) letter to NRC (E.V. Imbro), dated September 8, 1999, Transmittal of AD-110778 "Addendum 1 to EPRI TR-103237-R2 PPM Version 2.0" and AD-110779 "Addendum 2 to EPRI TR-103237-R2 Thrust Uncertainty Method"

Project Number: 689

Dear Mr. Imbro,

The referenced letter forwarded two reports describing the changes to the EPRI Performance Prediction Program (PPP) included in Version 2.0 of the Performance Prediction Methodology (PPM) software. This information was sent to the staff for its review and endorsement through a supplement(s) to the EPRI PPM SER. The purpose of this letter is to respond to several technical questions on Addendum 2.

The response to the NRC questions on Addendum 2 is included as Enclosure 1. The information in Enclosure 1 is not proprietary.

We believe any NRC staff review of the PPP reports is exempt from the fee recovery provision contained in 10 CFR Part 170. This submittal provides information that might be helpful to NRC staff when evaluating licensee submittals provided in response to Generic Letter 89-10. Such reviews are exempted under §170.21, Schedule of Facility Fees. Footnote 4 to the Special Projects provision of §170.21 states, "Fees will not be assessed for requests/reports submitted to the NRC…[a]s means of exchanging information between industry organizations and the NRC for the purpose of supporting generic regulatory improvements or efforts."

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If you have any questions regarding these enclosures, please contact Mr. John Hosler of EPRI at (650) 855-2785.

The NEI contact for MOV issues is Jim Riley. He can be reached at (202) 739-8137 or jhr@nei.org.

Sincerely,

David J. Modeen

JHR/maa
Enclosure

c: Mr. Thomas G. Scarbrough, U.S. Nuclear Regulatory Commission
Mr. Peter C. Wen, U.S. Nuclear Regulatory Commission
Mr. Leonard Olshan, U.S. Nuclear Regulatory Commission
Mr. John Hosler, EPRI
Mr. Gary Vine, EPRI

Enclosure 1

Responses to NRC Comments on Addendum 2 to EPRI TR-103237-R2

Comment #1

The Electric Power Research Institute (EPRI) indicated during the NRC staff review of the EPRI Motor-Operated Valve (MOV) Performance Prediction Methodology (PPM) that the scope of the valves to be included in the EPRI valve testing program was not intended to constitute a statistical database, but rather was selected to provide a reasonable validation of the EPRI MOV PPM. Explain the basis for applying the Thrust Uncertainty Method described in Addendum 2 of EPRI Topical Report TR-103237 (and the specific test data used in its support) to all gate valves within the scope of the EPRI MOV PPM.

Response to Comment #1

The flow loop test valve population is not a "statistical database" of valve designs; however, it is a significant source of data for Stellite seat coefficients of friction (COFs). Since the Thrust Uncertainty Method accounts for the conservatism in the Stellite COFs in the PPM, use of the method for all gate valves within the scope of the PPM (Stellite seats are a requirement for use of the PPM) is appropriate. In general, there were no observed differences in Stellite COFs between valve designs, except for Borg-Warner gate valves. Borg-Warner gate valves tended to exhibit relatively high Stellite seat COFs, and the Thrust Uncertainty Method is not applicable to these valves. Use of the flow loop test results to determine prediction ratios for use in the method is conservative since the flow loop test valves were preconditioned prior to flow testing. There is additional conservatism in PPM gate valve thrust predictions that is not accounted for in the Thrust Uncertainty Method because the flow loop test valves were preconditioned (and a typical nuclear plant valve would not be preconditioned). See Appendix A for additional discussion on preconditioning of the EPRI flow loop test valves.

Comment #2

Has EPRI evaluated the change in reliability in MOVs that might result from application of the Thrust Uncertainty Method?

Response to Comment #2

Summary

Both the PPM (in EPRI TR-103229 and TR-103231) and the Thrust Uncertainty Method (in Addendum 2 to TR-103237-R2) have been shown to provide predictions of required thrust and minimum allowable thrust at TST, respectively, that ensure reliable MOV operation. Use of the Thrust Uncertainty Method does not diminish the effect of other uncertainties (e.g., torque switch repeatability and diagnostic equipment uncertainty) on the calculated margin for successful valve operation.

Discussion

The PPM has been shown to provide bounding thrust and torque predictions for gate, globe and butterfly valves, and the NRC has accepted the PPM for use as a design standard for ensuring reliable valve operation of safety-related valves. The statistical approach used in the Thrust Uncertainty Method (square-root-sum-of-the-squares) has been used at several plants in calculating minimum allowable thrust at torque switch trip. This approach is also documented in EPRI TR-1034244-R2, which has been accepted by the NRC.

Addendum 2 to EPRI TR-103237-R2 documents that the Thrust Uncertainty Method provides bounding predictions of minimum thrust at torque switch trip for gate valves to ensure reliable valve operation. Table 4 of Appendix C of this report compares the results of validation of the Thrust Uncertainty Method with the results of validation of the PPM. Specifically, Table 4 compares thrust prediction ratios (ratio of measured to predicted thrust) to prediction ratios from validation of the Thrust Uncertainty Method (ratio of measured thrust to expected thrust at torque switch trip based on use of the Thrust Uncertainty Method). The table below (which is based on Table 4 in Appendix C of Addendum 2) summarizes these prediction ratios. For the shaded strokes (15 of 19 strokes), the Thrust Uncertainty Method prediction ratio is less than the thrust prediction ratio, indicating the Thrust Uncertainty Method's prediction of minimum allowable thrust at torque switch trip is more conservative than the PPM's prediction of required stem thrust.

Valve Stroke	Prediction Ratio -- Thrust Uncertainty Method Validation	Thrust Prediction Ratio
01-1-000-713-11	0.67	0.69
03-2-000-1111-11	0.87	0.94
03-4-000-1156-12	0.74	0.82
04-1-000-630-11	0.52	0.55
05-1-000-332-07	0.62	0.66
13-1-000-500-11	0.86	0.77
13-2-000-516-11	0.72	0.76
13-4-D00-544-12	0.76	0.82
14-1-000-711-11	0.63	0.70
24-1-000-890-11	0.78	0.82
24-2-000-1062-13	0.69	0.82
24-4-D00-1090-12	0.79	0.91
25-1-000-627-11	0.71	0.74
30-1-000-987-11	0.63	0.67
30-4-000-1013-12	1.05	1.03
31-1-000-882-11	0.62	0.71
41-1-000-261-11	0.74	0.78
41-1-000-263-13	0.80	0.78
In Situ #21	0.71	0.66

The four strokes for which the Thrust Uncertainty Method prediction ratio is greater than the thrust prediction ratio all exhibited relatively high rate-of-loading (ROL) -- 24.4%, 16.3%, 13.1% and 20.7%, respectively. In three of the four cases, conservatism in the disk-to-seat COF provided sufficient margin to ensure a conservative prediction for the high ROL values (i.e., the Thrust Uncertainty Method prediction ratios are still less than one). For the other stroke (30-4-000-1013-12), both the PPM prediction and the Thrust Uncertainty Method prediction are slightly non-conservative (prediction ratios greater than one). For this stroke, both the ROL (16.3%) and the disk-to-seat COF (0.531 at 530°F, per EPRI TR-103237-R2) were relatively high.

Overall, based on the table above, it is concluded that the Thrust Uncertainty Method provides predictions of minimum allowable thrust at torque switch trip that are at least as conservative as the PPM's predictions of required thrust. Accordingly, setting up MOVs per thrust predictions from the PPM or minimum allowable thrust at TST predictions from the Thrust Uncertainty Method would ensure reliable MOV operation.

During a meeting with the NRC to discuss this comment, the NRC questioned whether use of the Thrust Uncertainty Method would diminish the effect of other uncertainties (e.g., torque switch repeatability and diagnostic equipment uncertainty) on valve margins since these uncertainties are applied to the nominal required thrust rather than the bounding required thrust predicted by the PPM. Although application of these other uncertainties to the nominal required thrust does decrease the magnitude (in pounds) of these uncertainties, it does not affect the calculated percent margin, if the uncertainties are applied correctly. This conclusion is illustrated in the following example.

- Measured thrust at torque switch trip (T_{CST}) = 15,000 pounds
- PPM prediction (T_{PPM}) = 10,000 pounds
- Diagnostic equipment uncertainty (U_{DE}) = 10%

Since U_{DE} is an uncertainty on measured thrust, margin should be calculated by applying U_{DE} to the measured thrust, as follows.

$$\text{Margin (pounds)} = T_{CST}(1 - 0.1) - T_{PPM} = 15{,}000(0.9) - 10{,}000 = 3{,}500 \text{ pounds}$$

$$\text{Margin (\%)} = \frac{T_{CST}(1 - 0.1) - T_{PPM}}{T_{PPM}} = \frac{15{,}000(0.9) - 10{,}000}{10{,}000} = 35\%$$

However, plants typically apply uncertainties to the required thrust so that setup parameters can be easily defined. Since U_{DE} is an uncertainty on measured thrust, if a plant applies this uncertainty to required thrust, U_{DE} must be converted to an uncertainty on required thrust using Equation 4 of Addendum 2 to EPRI TR-103237-R2. This equation is derived below by setting the margin calculated using the converted uncertainty applied to the PPM prediction, equal to the margin calculated using the unconverted uncertainty applied to the measured thrust.

$$\frac{T_{CST} - T_{PPM}(1 + U_{DE-converted})}{T_{PPM}(1 + U_{DE-converted})} = \frac{T_{CST}(1 - U_{DE}) - T_{PPM}}{T_{PPM}}$$

Solving the above equation for $U_{DE\text{-converted}}$ yields Equation 4 of Addendum 2 to EPRI TR-103237-R2. Implementing this equation for the example above yields the following.

$$U_{DE-converted} = \frac{U_{DE}}{1 - U_{DE}} = \frac{0.1}{1 - 0.1} = 0.1111 \text{ or } 11.11\%$$

This value can then be applied to the required thrust, and the margin in percent will be the same as if 10% were applied to the measured thrust even though the margin in pounds is higher. The reason is that even though the margin in pounds is increased, the denominator in the margin equation (minimum allowable thrust at CST) is also increased, as shown below.

$$\text{Margin (pounds)} = T_{CST} - T_{PPM}(1 + 0.1111) = 15{,}000 - 10{,}000(1.1111) = 3{,}889 \text{ pounds}$$

$$\text{Margin (\%)} = \frac{T_{CST} - T_{PPM}(1 + 0.1111)}{T_{PPM}(1 + 0.1111)} = \frac{15{,}000 - 10{,}000(1.1111)}{10{,}000(1.1111)} = 35\%$$

This example illustrates that the effect of an uncertainty on the calculated margin is always the same, as long as the uncertainty is applied correctly, regardless of the magnitude of the required thrust.

The equations below illustrate the effect on margin of an 11.11% uncertainty on predicted thrust (in this example, equivalent to a 10% uncertainty on measured thrust). This uncertainty is applied to both a PPM prediction of 10,000 pound and a nominal thrust prediction, T_{NOM}, (e.g., from the Thrust Uncertainty Method) of 7,000 pounds.

$$\text{Effect on margin (\%)} = \frac{T_{PPM}(0.1111)}{T_{PPM}(1.1111)} = \frac{10{,}000(0.1111)}{10{,}000(1.1111)} = \frac{1{,}111 \text{ pounds}}{11{,}111 \text{ pounds}} = 10\%$$

$$\text{Effect on margin (\%)} = \frac{T_{NOM}(0.1111)}{T_{NOM}(1.1111)} = \frac{7{,}000(0.1111)}{7{,}000(1.1111)} = \frac{777 \text{ pounds}}{7{,}777 \text{ pounds}} = 10\%$$

As shown, the effect on the margin in pounds is less for T_{NOM} (777 pounds versus 1,111 pounds); however, the effect on the margin in percent is the same. Therefore, applying this uncertainty to the nominal required thrust in the Thrust Uncertainty Method does not affect the calculated margin (in percent) for successful valve operation.

Comment #3

The Joint Owners Group (JOG) Program on MOV Periodic Verification references the EPRI MOV PPM in establishing margins and testing schedules for MOVs within the scope of Generic Letter (GL) 96-05, "Periodic Verification of the Design-Basis Capability of Safety-Related Motor-Operated Valves." Has EPRI evaluated whether any changes would be needed to the use of the EPRI MOV PPM in GL 96-05 programs where the Thrust Uncertainty Method is applied?

Response to Comment #3

GL 96-05 references the PPM and states that valves that are set up using the PPM do not need to be considered in a plant's GL 96-05 program, with regard to potential increases in the required thrust or torque. The basis for this position is that PPM thrust predictions include the potential degradation in disk-to-seat COF due to valve stroking. The PPM was shown to appropriately bound data from EPRI testing of valves that had undergone multiple strokes under load to "precondition" the seats (see Appendix A for additional information on preconditioning). The Thrust Uncertainty Method has been shown to appropriately bound the required thrust at torque switch trip from the same data set (see Appendix B). Accordingly, we believe that valves set up per the Thrust Uncertainty Method should not need to be considered in a plant's GL 96-05 program with regard to potential increases in required thrust with stroking.

The JOG PV Program references the PPM only as it relates to the required static test frequency. Specifically, the JOG program document states that valves that are set up based on the PPM can be considered "high margin" valves in the determination of static test frequencies as long as certain conditions are met. One of the conditions is that default friction coefficients are used. Based on the discussion in the previous paragraph, a technical basis exists for maintaining the position that MOVs set up using the EPRI Thrust Uncertainty Method can be considered "high margin" valves. The JOG has the responsibility for determining whether this position will be maintained with respect to valves evaluated using the Thrust Uncertainty Method.

Comment #4

Explain why certain data in Table 1 of Appendix B to EPRI Topical Report TR-103237, Addendum 2, are different from the original test data in previously published EPRI test reports. For example, see the data in EPRI TR-103674-V9P1, "EPRI MOV Performance Prediction Program - High Pressure Cold and Hot Water Blowdown Facility Test Report, Volume 9, Part 1: Test Results for MOV #24."

Response to Comment #4

We assume this comment refers to the term $F_{measured}$ (maximum measured stem thrust) listed in Table 1 of Appendix B of TR-103237-R2, Addendum 2. Values in Table 1 are taken from EPRI TR-103229 and MPR Calculation 140-078-TW14 for solid and flexible wedge gate valves. These values may differ from values presented in the Wyle flow loop test reports (e.g., EPRI TR-103674-V9P1) because of adjustments to account for zero offsets in the data. During the EPRI MOV Program, we performed a detailed analysis of the static test data for each valve to determine if there were zero offsets in the data that should be considered when evaluating the data. For some valves, we found that zero offset adjustments were needed. MPR Calculation 140-81-TW2 determines the zero offsets from the static test data, and MPR Calculation 140-078-TW14 applies the zero offset adjustments to the maximum measured thrust for each valve stroke. The Figure 1, taken from MPR Calculation 140-81-TW2, shows the evaluation of static test data for Valve #24 (strokes performed at Wyle, not at Siemens). As shown, the zero offset for the first static closing stroke performed was 135 pounds, and the zero offset for the last static closing stroke was 257 pounds. Accordingly, in MPR Calculation 140-078-TW1, a zero offset adjustment of 196 pounds (the average of 135 and 257) was used for all Valve #24 strokes performed at Wyle. Therefore, values of measured stem thrust listed in TR-103229 and Addendum 2 to TR-103237-R2 for Valve #24 are 196 pounds higher than shown in TR-103674-V9P1.

Comment #5

EPRI Topical Report TR-103237, Addendum 2, assumes that the EPRI MOV PPM thrust predictions for gate valves are conservative. However, the overall test data obtained by EPRI (including data used to support the Thrust Uncertainty Method) indicate low to moderate friction coefficients for the test valves. Further, low loading conditions applied to the valves during testing might result in significant scatter in the test data. Explain the basis for the assumption that the EPRI test valves were fully preconditioned in light of this information.

Response to Comment #5

The conservatism of the PPM is documented in EPRI TR-103229 (Gate Valve Model Report) and TR-103231 (Assessment Report), and the acceptability of PPM predictions is documented in the NRC Safety Evaluation for the PPM.

Figure E-25 of EPRI TR-103237-R2 is a histogram of apparent disk-to-seat COFs for the flow loop gate valve tests. As shown in this figure most of the COF values were distributed between about 0.3 and 0.75 in a roughly Gaussian distribution, and the mean and 2-sigma values were 0.48 and 0.79, respectively. These results reflect relatively high COFs.

The loading conditions applied to the valves covered the maximum DPs permitted by the pressure class of each valve and are judged high loading conditions.

See Appendix A for a discussion of preconditioning of the EPRI flow loop test valves

Comment #6

Discuss the linear relationship between the prediction ratio (actual required differential-pressure thrust requirement to EPRI MOV PPM differential-pressure thrust prediction) and friction coefficient which suggests that the Thrust Uncertainty Method could become less conservative (and possibly non-conservative) if the friction coefficient increases as the valves age.

Response to Comment #6

Any method used to set up an MOV would become less conservative if the seat COF increases with stroking. Since the Thrust Uncertainty Method is based on a bounding thrust prediction from the PPM, the maximum allowable thrust at torque switch trip predicted by the method would be expected to cover increases in the seat COF with stroking, such that the predictions would not become non-conservative. (See Appendix A for a discussion of preconditioning of the EPRI flow loop test valves.) This conclusion is consistent with the NRC SE for the PPM and GL 96-05.

Comment #7

EPRI Topical Report TR-103237, Addendum 2, indicates that the Thrust Uncertainty Method is intended to be applicable to Aloyco split-wedge gate valves. In a safety evaluation (SE) dated February 20, 1997, the NRC staff stated that users of the EPRI model for Aloyco split-wedge gate valves must justify input of friction coefficients other than EPRI's default friction coefficients. Explain the application of the Thrust Uncertainty Method in light of this concern.

Response to Comment #7

Users are required to justify use of friction coefficients other than the PPM default values for all valve types, including Aloyco split wedge gate valves. Although the Thrust Uncertainty Method does not directly change the friction coefficient used in the method, the effect of implementing the method is to consider a portion of the disk-to-seat friction coefficient as an uncertainty. Applicability of the Thrust Uncertainty Method for Aloyco split wedge and Anchor/Darling double disk gate valves is limited to evaluation of flow isolation only (i.e. the method can only be used if the design basis requirement for the valve is to achieve flow isolation only). As discussed in the response to Comment #1, the key contributor to conservatism in PPM gate valve thrust predictions is the conservatism in the disk-to-seat Stellite COFs. Since disk-to-seat friction is the dominant component of the required thrust to achieve flow isolation for split wedge and double disk gate valves and the EPRI methods for these valve types use the same default COFs used in the PPM software, use of the Thrust Uncertainty Method for flow isolation is judged to be acceptable.

Comment #8

EPRI Topical Report TR-103237, Addendum 2, applies the bounding values for load sensitive behavior derived from the EPRI tests in support of the acceptability of the thrust prediction provided by the Thrust Uncertainty Method. Explain the basis for applying the EPRI load sensitive behavior prediction values rather than the load sensitive behavior of the specific test valves used in support of the Thrust Uncertainty Method.

Response to Comment #8

The key feature of the Thrust Uncertainty Method is that the random component of the PPM thrust uncertainty is combined statistically with other random uncertainties, such as rate-of-loading (ROL). A key constraint in applying the method is that any bias and random uncertainty values included in application of the method (e.g., for ROL) should be appropriate for the valve to which the values are applied (e.g., for ROL, the bias and random uncertainty values should be based on a statistical analysis of test data for the valve population). In validating the Thrust Uncertainty Method against EPRI flow loop test data, the appropriate values to be used as the bias and random uncertainty values for ROL are the values determined by EPRI for the flow loop test population (5.6% bias and 26.4% random uncertainty). For a nuclear power plant, the values used in the Thrust Uncertainty Method should be based on a statistical evaluation of plant test data. Alternatively, the EPRI ROL values could be used since they were approved by the NRC in the SE for the PPM.

Note that if stroke-specific values of ROL had been used in validating the Thrust Uncertainty Method for each of the EPRI flow loop test valves, the ROL values would have been treated as a bias, and the validation would essentially be a comparison of the PPM prediction (bounding, not nominal) to the measured thrust for the flow loop tests. These comparisons were made in validation of the Gate Valve Model and assessment of the PPM.

During a meeting to discuss this comment, the NRC questioned whether ROL values determined from just the 19 validation strokes (6.2% bias and 18.2% random uncertainty) should have been used in implementing the method for validation. Although we consider (as discussed above) that the EPRI ROL values are the appropriate values to use for validation, the additional validation discussed in Appendix B indicates that the conclusions from method validation would be the same if ROL values of 3% bias and 18% random uncertainty were used (these values are less conservative than 6.2%/18.2%). That is, the method predictions would still be bounding for all cold water strokes and three out of four hot water strokes. In fact, the method predictions would have been bounding for all but four strokes (two cold water strokes and two hot water strokes) even if values of 0% had been used for both the bias and random ROL uncertainties.

Comment #9

Describe the basis for the use of the estimated stem rejection load rather than actual valve thrust data in evaluating the Thrust Uncertainty Method.

Response to Comment #9

We calculated the stem rejection load as the product of the upstream pressure and the stem area.

Comment #10

Explain the basis for comparing a prediction ratio based on dynamic thrust predictions from the EPRI MOV PPM to a prediction ratio based on thrust predicted to be delivered at torque switch trip (including random and bias uncertainties) to support the Thrust Uncertainty Method.

Response to Comment #10

We assume this comment refers to Table 4 in Appendix C of Addendum 2 to TR-103237-R2. This table compares thrust prediction ratios (from validation/assessment of the PPM) to prediction ratios for validation of the Thrust Uncertainty Method. As discussed in the response to comment #2, the prediction ratio is a measure of the conservatism in predictions of thrust (from the PPM) or minimum allowable thrust at torque switch trip (from the Thrust Uncertainty Method). The purpose of comparing these prediction ratios is to show that the conservatism in the Thrust Uncertainty Method's predictions of minimum allowable thrust at torque switch trip is similar to (or more than) the conservatism in the PPM's predictions of required thrust.

Appendix B documents additional validation of the Thrust Uncertainty Method against a larger data set, supporting the reliability of method predictions. This additional validation indicates that method predictions would have been bounding for nearly all strokes evaluated, even if values of 0% had been used for both the bias and random ROL uncertainties.

Comment #11

Explain the basis for determining an average prediction ratio for the EPRI MOV PPM to support the Thrust Uncertainty Method rather than evaluating the uncertainty in data obtained from the Stellite separate-effects friction tests conducted by EPRI.

Response to Comment #11

Since the Thrust Uncertainty Method is intended to be used to set up valves in nuclear power plants, our judgement was that valve flow tests were a better source of data than laboratory testing for determining prediction ratios, i.e., COFs measured in valve flow test are more directly applicable to plant valves than friction coefficients measured in a laboratory using small scale test samples. In addition, the friction separate effects testing performed as part of the EPRI MOV program was not designed to provide statistically-representative COF data for fully preconditioned surfaces. The EPRI flow loop test program ensured that each valve was preconditioned prior to testing (See Appendix A).

Note that nominal COFs were determined from the friction separate effects testing in the EPRI MOV program. These nominal COFs are given in MPR Report 1409, Revision 2, "Algorithms for Estimating Friction Coefficients at Sliding Contacts in a Gate Valve," which is Appendix E of EPRI TR-103229. The table below lists the maximum and nominal COFs from MPR-1409 for Stellite-on-Stellite with flat-on-flat contact in water, for stresses up to 10 ksi. The table also calculates the ratio of the nominal to the maximum COF. For comparison purposes, the average prediction ratios (APRs) used in the Thrust Uncertainty Method for each temperature are also shown in the table.

Temperature	5 ksi and below			10 ksi			APR
	Nom COF	Max COF	Ratio	Nom COF	Max COF	Ratio	
65°F and below	0.30	0.61	0.492	0.30	0.61	0.492	0.697
206°F	0.35	0.55	0.636	0.35	0.55	0.636	0.775
310°F	0.37	0.52	0.712	0.32	0.47	0.681	0.775
400°F	0.33	0.50	0.660	0.30	0.47	0.638	0.775
550°F	0.28	0.47	0.596	0.28	0.47	0.596	0.775
650°F	0.21	0.40	0.525	0.21	0.40	0.525	0.775

The APRs in the Thrust Uncertainty Method were determined by dividing the measured DP load by the predicted DP load for EPRI flow loop test strokes. Since DP load is proportional to COF, it is appropriate to compare the APRs in the Thrust

Uncertainty Method to the ratios calculated in the table above. If the APRs are higher than the COF ratios, the APRs are conservative relative to the COF ratios. As shown in the table above, the APRs are higher than the COF ratios in all cases. In other words, if the nominal COFs shown in the table above were used in the Thrust Uncertainty Method, the method would be less conservative.

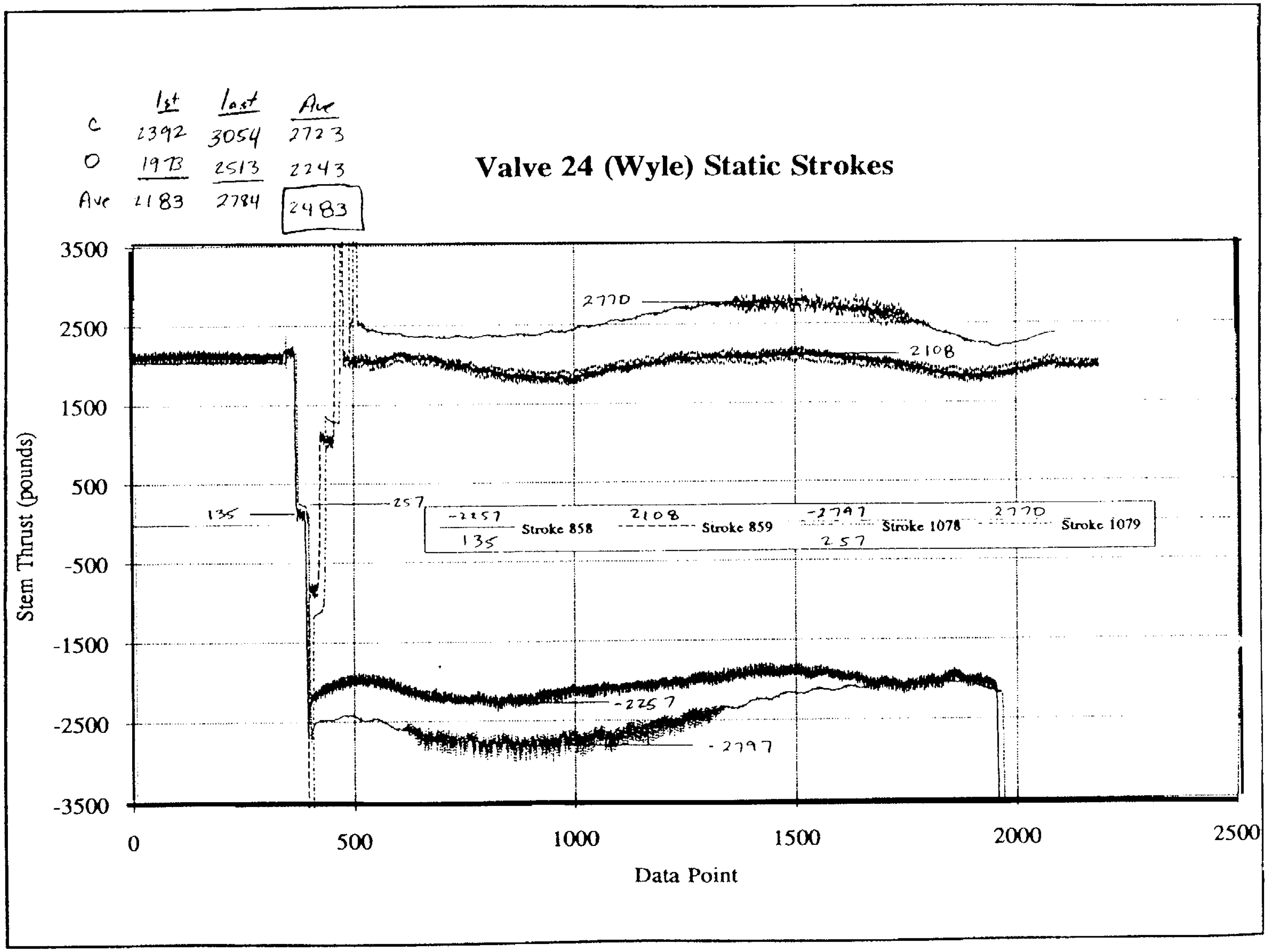


Figure 1. Determination of Zero Offsets for Valve #24

Appendix A: Preconditioning of EPRI Flow Loop Valves

Valve test programs prior to the EPRI MOV Performance Prediction Program identified that the COF between Stellite seats on a gate valve may increase with stroking up to a plateau level. This effect was termed "preconditioning." To help ensure that the performance of the EPRI flow loop test valves represented "preconditioned" behavior, an extensive preconditioning procedure was implemented for each flow loop test valve prior to initiating the ambient water, normal flow test sequence. This procedure involved stroking the valve repeatedly under hydrostatic conditions (full DP but zero flow) until the measured disk-to-seat COF stabilized. The number of preconditioning strokes required to achieve a stable COF ranged up to about 900 strokes for each valve. Steps were then taken to ensure that the preconditioning was not "lost" before performing the test sequence (e.g., the valves were not disassembled).

The Wyle flow loop test reports include plots of measured disk-to-seat COF versus stroke number for the preconditioning strokes (attached) and measured apparent disk-to-seat COF versus stroke number for the valve flow tests. The table below summarizes the information in these plots for the 14 gate valves used to determine the average predictions ratios in the Thrust Uncertainty Method.

Valve	Preconditioning				Cold Water Flow Tests	
	DP (psid)	# Strokes	Initial COF	Final COF	DP (psid)	Range of COFs
MOV #1	740	569	0.10	0.40	740	0.44 - 0.51
MOV #3	1800	900	0.12	0.48	1800	0.45 - 0.65
MOV #4	740	400	0.26	0.30	615	0.31 - 0.46
MOV #6	500	105	0.29	0.58	500	0.24 - 0.34
MOV #13	2600	406	0.25	0.56	2600	0.45 - 0.65(1)
MOV #14	1412	480	0.16	0.42	1800	0.39 - 0.51
MOV #16	1500	690	0.10	0.47	1800	0.44 - 0.68
MOV #17	250	400	0.36	0.41	250	0.49 - 0.60
MOV #18	250	90	0.12	0.18	250	0.24 - 0.35
MOV #23	250	140	0.20	0.35	250	0.36 - 0.60
MOV #24	1800	755	0.32	0.45	1800	0.48 - 0.57
MOV #25	740	495(2)	0.30	0.52	740	0.49 - 0.65
MOV #29	90	8	0.15	0.16	250	0.30 - 0.45
MOV #31	250	788	0.21	0.40	250	0.50 - 0.75(3)

Notes:

1. Only opening preconditioning strokes were performed, and the opening stroke flow test COFs were consistent with the final COF for preconditioning.

2. Forty-five more preconditioning strokes were performed between the first and second test sequences.
3. These high flow test COFs occurred for the opening strokes and were attributed to disc/valve body interference.

The following observations are made from the information in the table above.

- With the exception of MOV #29, each test valve received at least 90 preconditioning strokes (and most received more than 400). It is unlikely that many nuclear plant MOVs have been stroke as many as 90 times with DP or flow.

- For all valves except MOV #6, the range of COFs for the flow tests was consistent with the final precondition COF. This observation supports the conclusion that the seat preconditioning was maintained between the preconditioning strokes and the flow tests. Only two strokes of MOV #6 (both cold water) were used in determining average prediction ratios. If these two strokes were eliminated from this evaluation, the average prediction ratio for cold water strokes would increase from 0.697 to 0.704. This difference is judged negligible. Note that in most cases, the range of apparent COFs for the flow tests is higher than the final COF for preconditioning. This result is expected for two reasons. First, the preconditioning strokes were performed at 100% DP and some of the flow loop tests were performed at lower DPs; Stellite COF is typically higher at low DPs. Second, there are affects other than seat friction that may be included in the apparent COFs for the flow tests, for example, stem bending and the Bernoulli effect for opening strokes.

As further evidence of the preconditioning of the EPRI flow loop test valves, a comparison was made to the COFs measured for gate valves in the JOG PV program. The table below summarizes the measured COFs for closing strokes of gate valve tested in flow loops in the EPRI MOV program. Values are taken from Table E-14 of EPRI TR-103227 and are for the ambient water, normal flow (15 ft/sec) test sequences.

Valve	COF			Notes
	Low DP Test	High DP Test	Average	
MOV #1	0.504	0.432	0.468	
MOV #2	0.163	0.139	0.151	
MOV #3	0.615	0.508	0.562	
MOV #4	0.385	0.361	0.373	
MOV #5	0.465	0.394	0.430	
MOV #6	0.343	0.310	0.327	
MOVs #7-10	---	---	---	Not included because Borg-Warner valves are excluded from Thrust Uncertainty Method
MOV #13	0.484	0.457	0.471	
MOV #14	0.419	0.415	0.417	

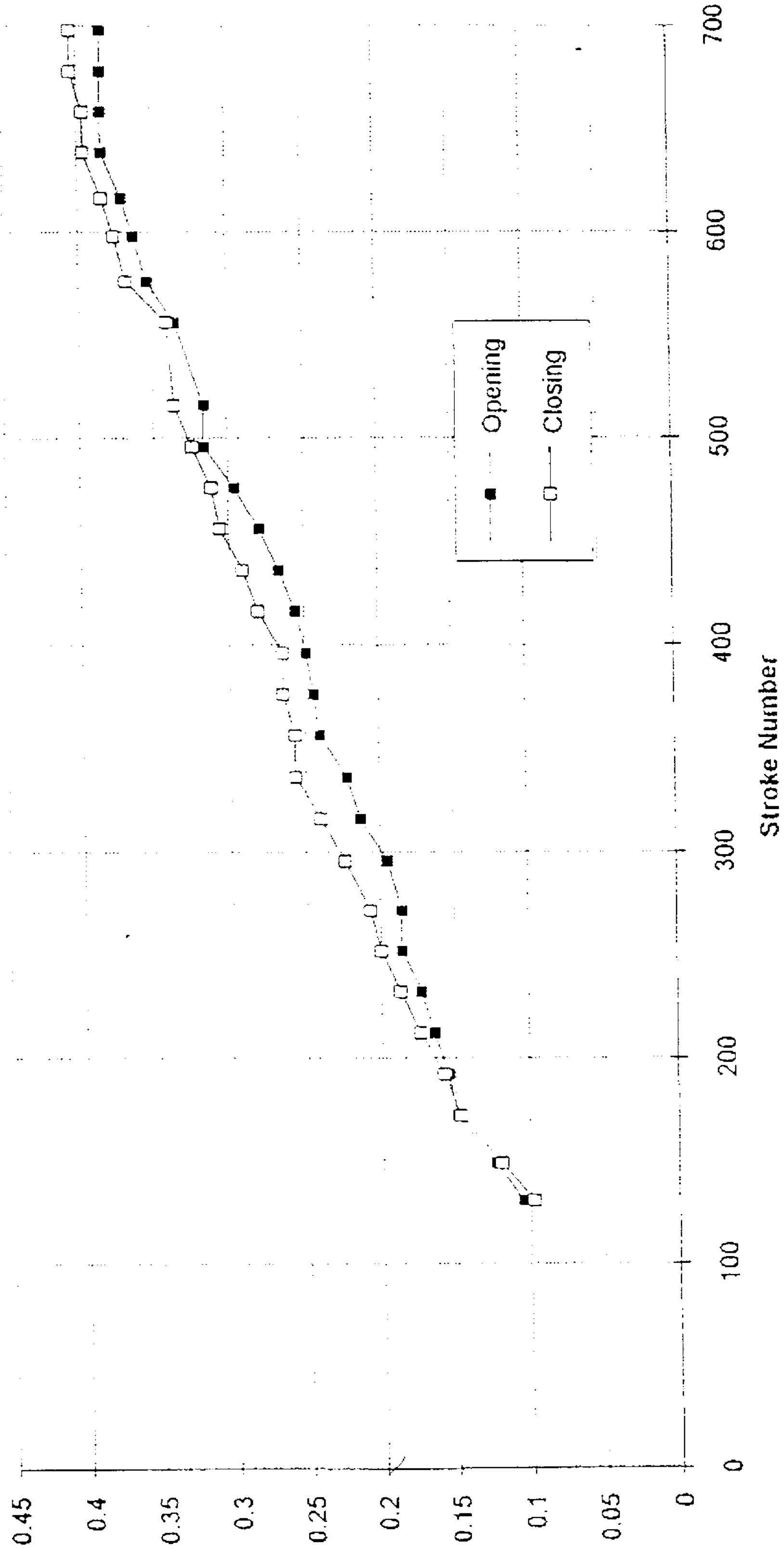
Valve	COF			Notes
	Low DP Test	High DP Test	Average	
MOV #15	0.225	0.171	0.198	Split wedge valve: value at flow isolation is used for low DP test. No value for flow isolation available for high DP test
MOV #16	0.620	0.442	0.531	
MOV #17	0.546	0.489	0.518	
MOV #18	0.361	0.276	0.319	
MOV #23	0.374	0.391	0.383	
MOV #24	0.567	0.493	0.530	
MOV #25	0.544	0.529	0.537	
MOV #29	0.452	0.398	0.425	
MOV #30	0.287	0.399	0.343	
MOV #31	0.497	0.478	0.488	
MOV #34	0.319	---	0.319	No value for high DP test available.
MOV #41	0.469	0.436	0.453	Double disk valve: values at flow isolation are used.
MOV #43	0.584	0.363	0.474	Split wedge gate valve: values at flow isolation are used.
MOV #61	0.589	0.553	0.571	
Average:	---	---	0.422	

The average COF of 0.422 is consistent with the APR used in the thrust uncertainty for cold water strokes (0.697) multiplied by the low stress (#10 ksi), cold water COF used in the PPM (0.61) -- 0.697 * 0.61 = 0.425.

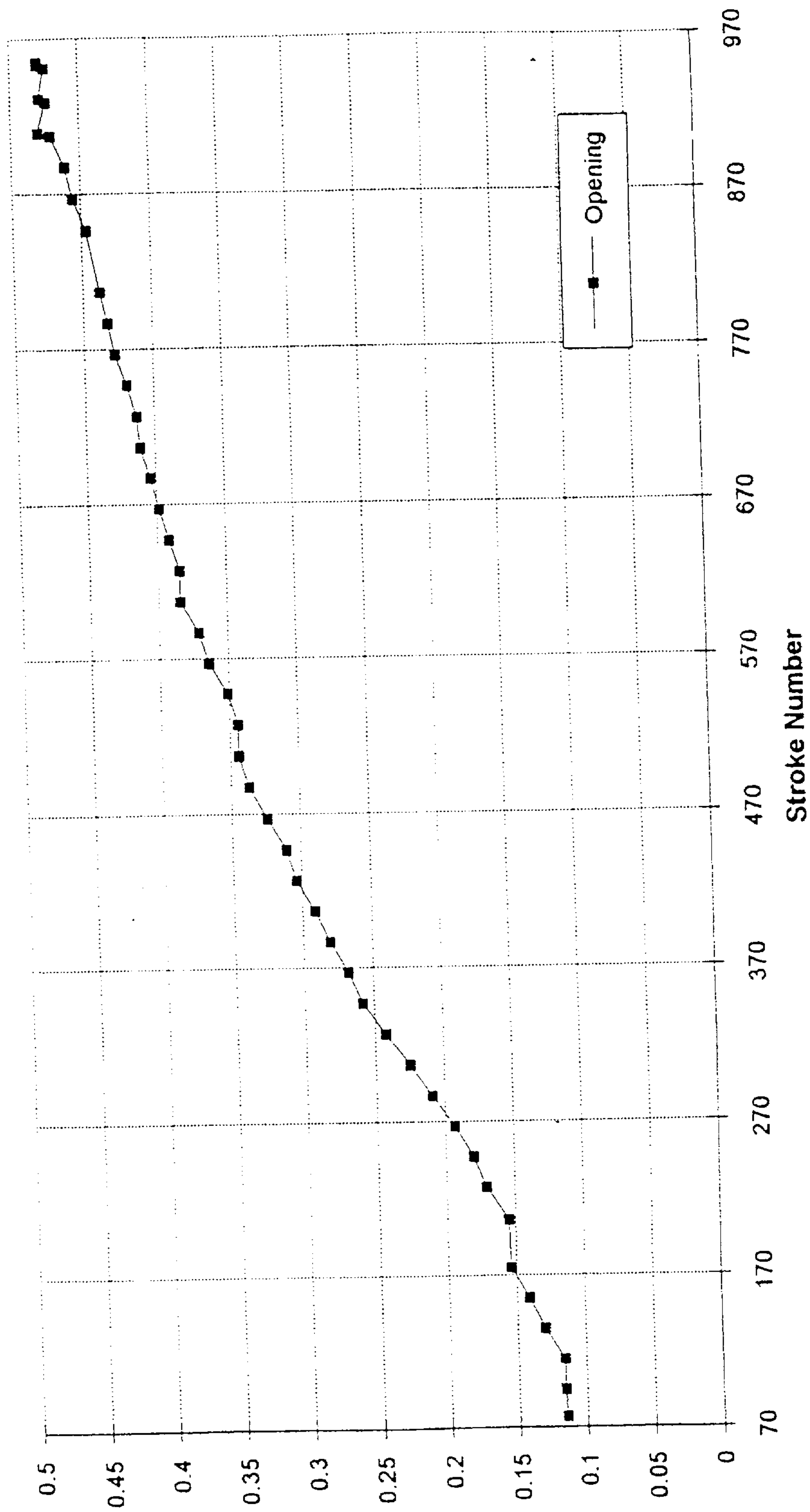
Although measured COF values in the JOG PV program are proprietary, the JOG agreed to allow EPRI access to the JOG PV data to answer the following question.

> For the set of JOG gate valves with self-mated Stellite at the disk-to-seat interface stroked closed at temperatures below 120°F (excluding Borg-Warner gate valves), is the mean apparent disk-to-seat friction coefficient for closing (determined as described below) less than 0.42?

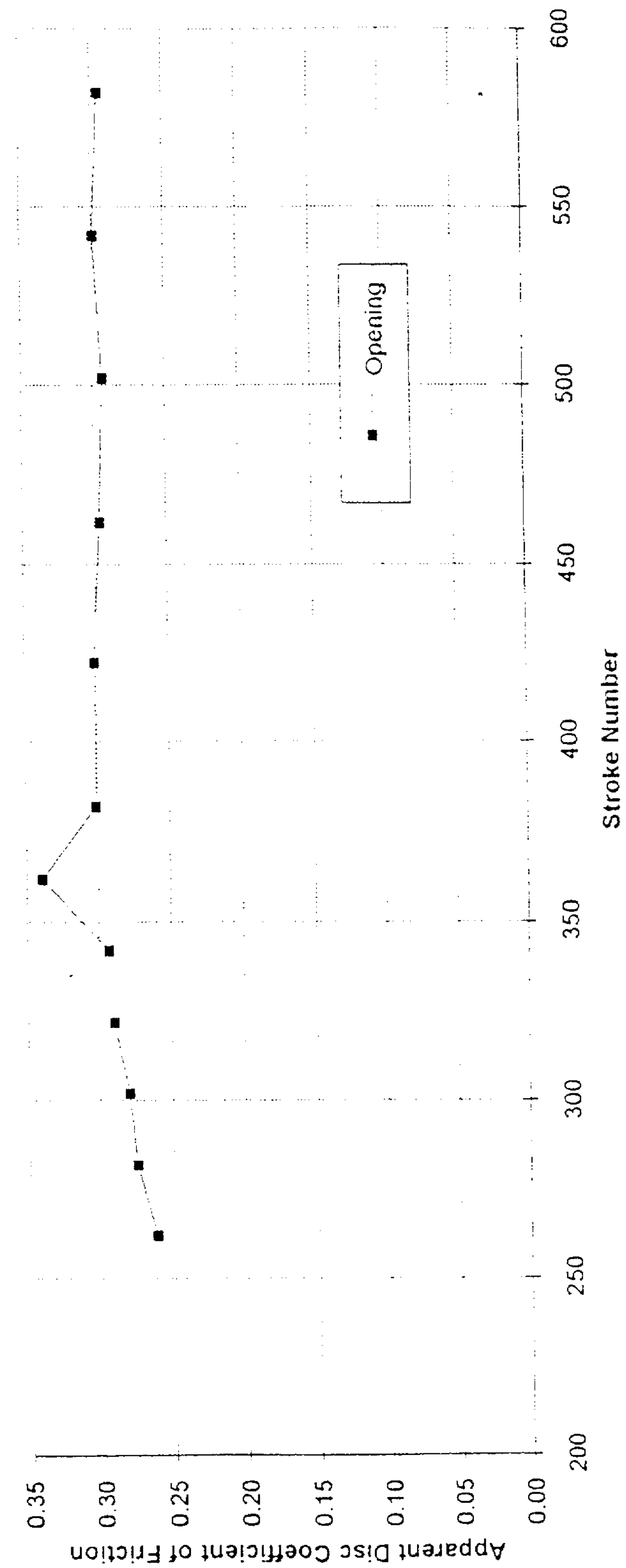
As shown in the attached letter, the response to this question was "yes." This result supports the conclusion that the EPRI flow loop test valves were preconditioned prior to testing more than a typical valve installed in a nuclear power plant.



Preconditioning Plot for Valve #1



Preconditioning Plot for Valve #3



Preconditioning Plot for Valve #4

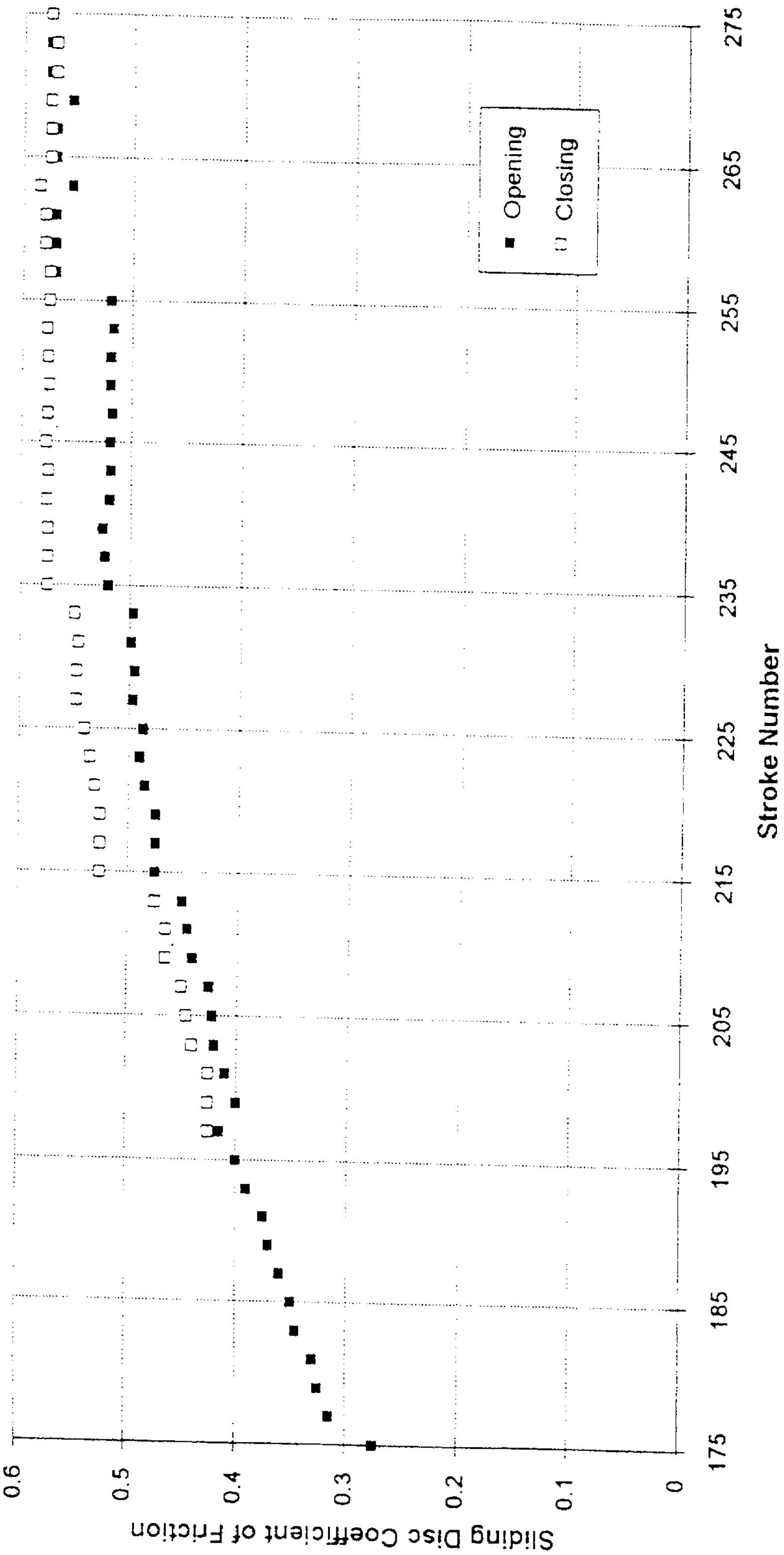
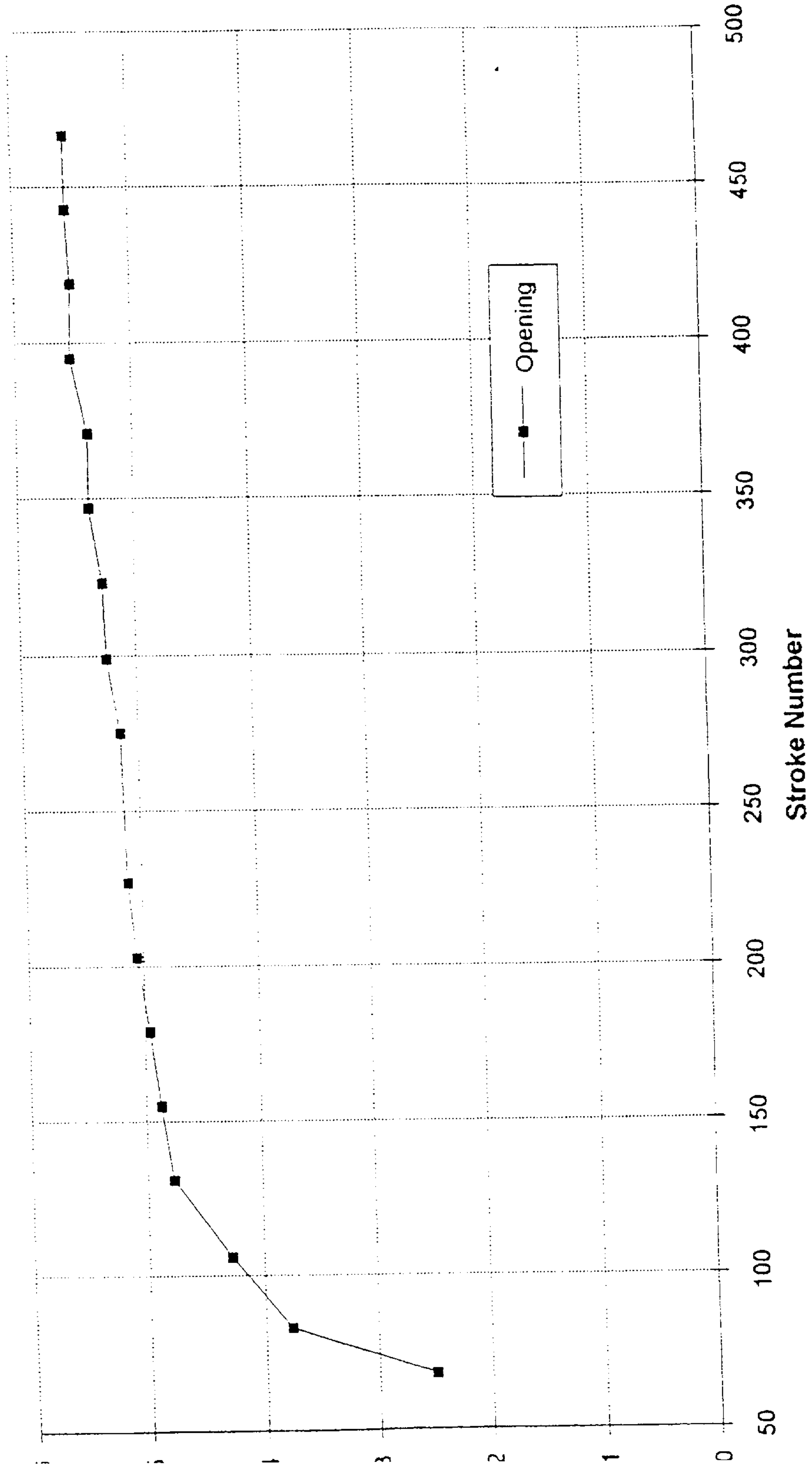


Figure 6-1 Valve Seat Preconditioning Results

Preconditioning Plot for Valve #6



Preconditioning Plot for Valve #13

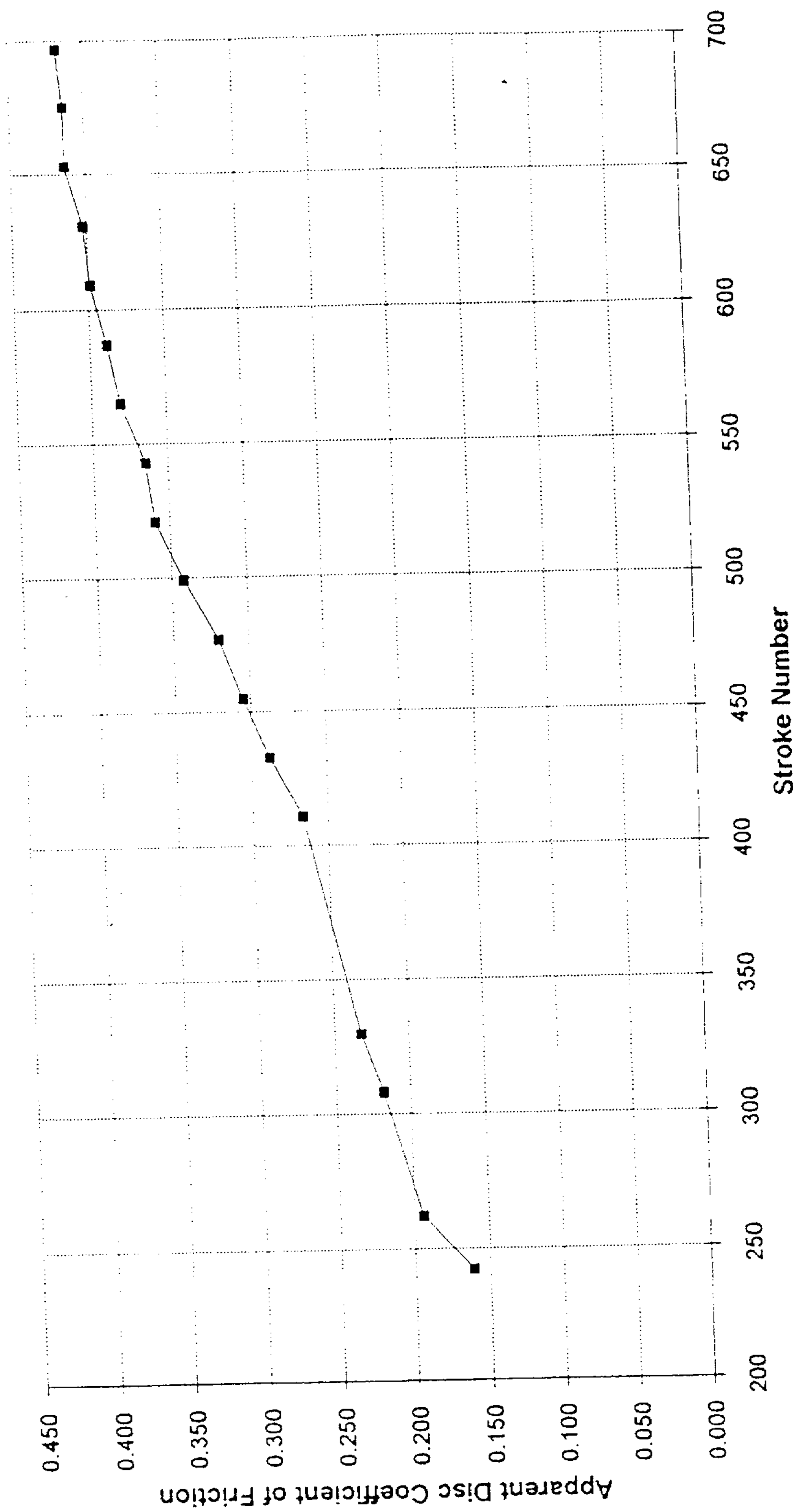


Figure 6-1 Valve Seat Preconditioning Results

Preconditioning Plot for Valve #14

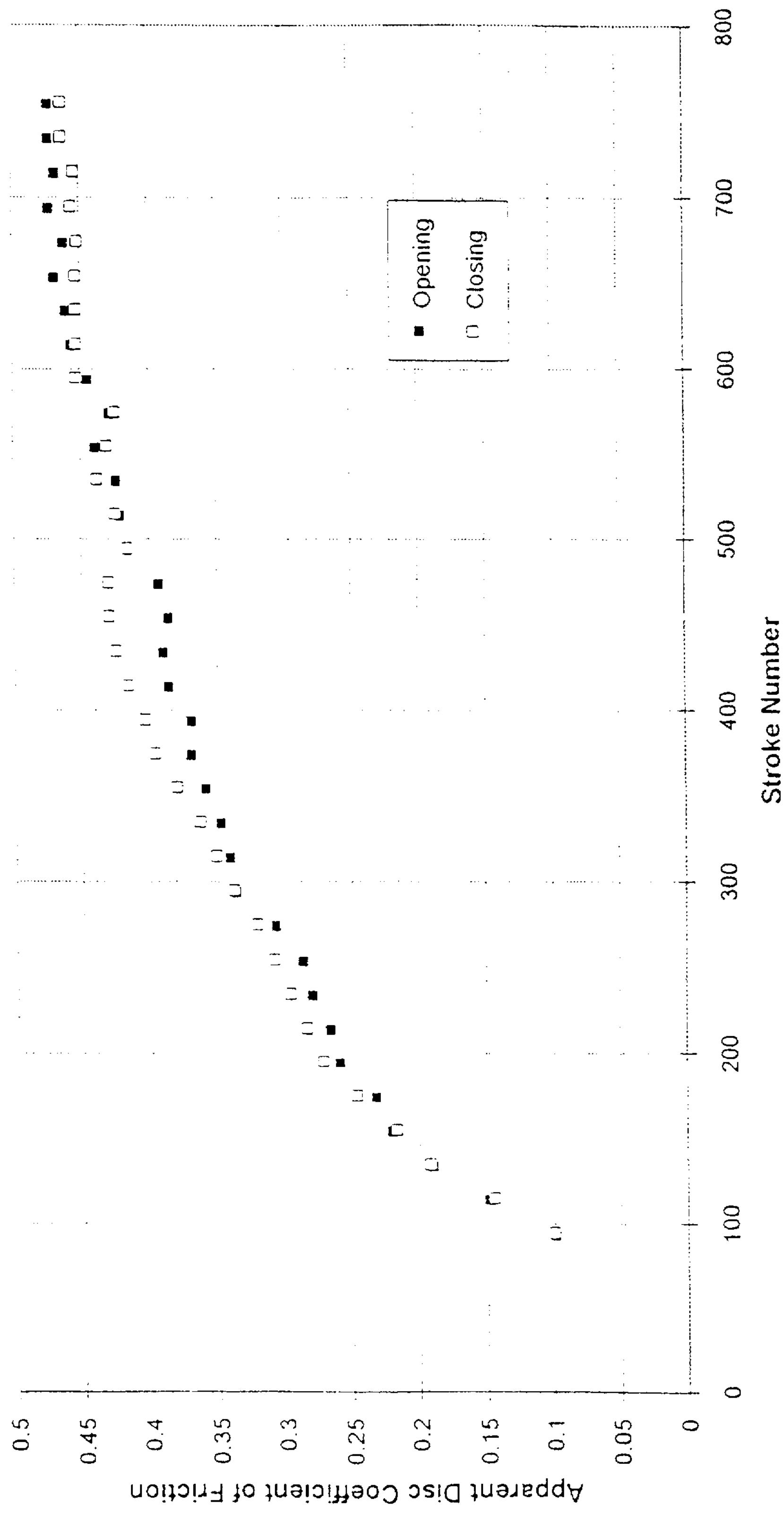


Figure 6-1 Valve Seat Preconditioning Results

Preconditioning Plot for Valve #16

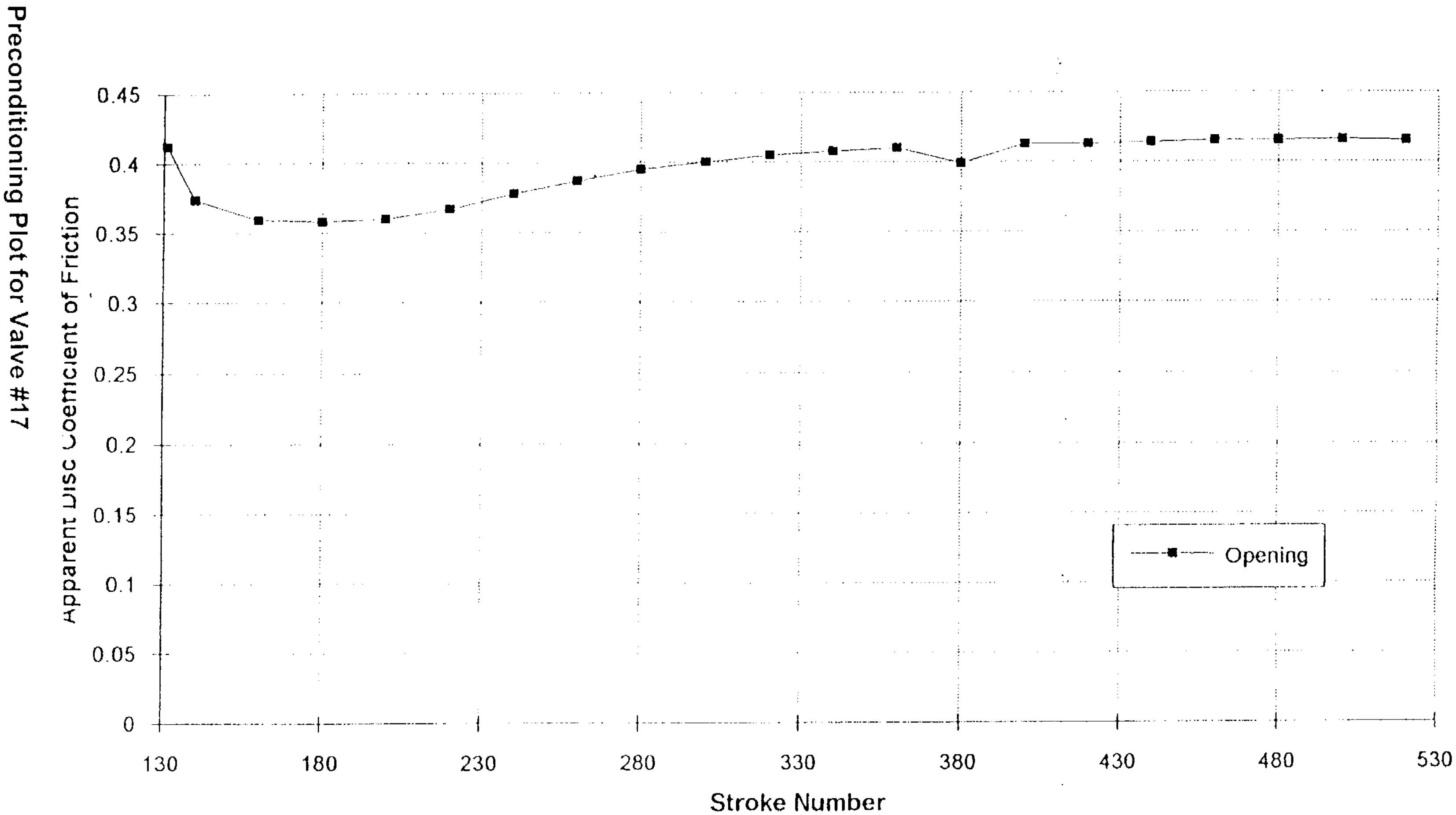


Figure 6-1 Valve Seat Preconditioning Results

Preconditioning Plot for Valve #18

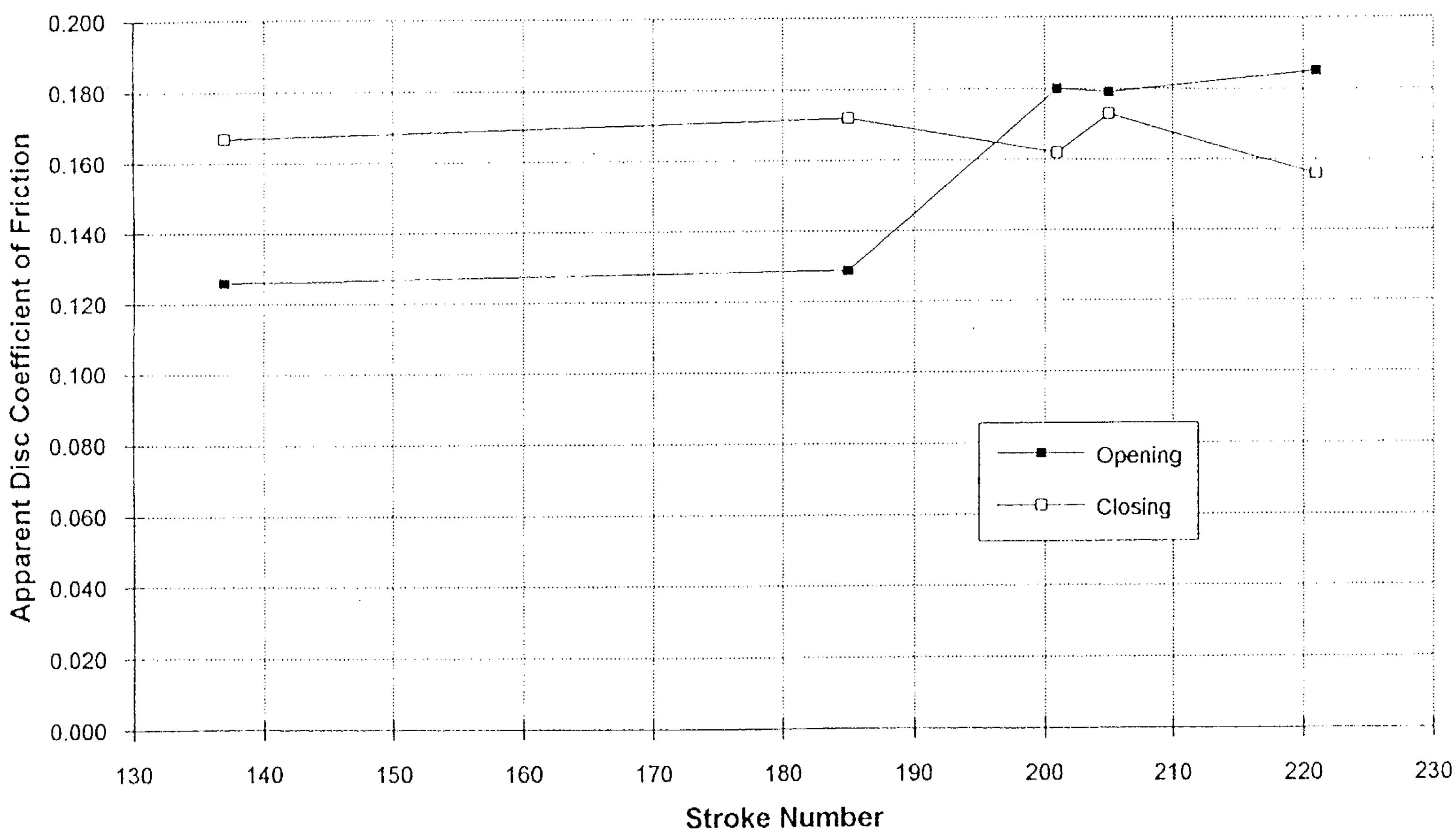
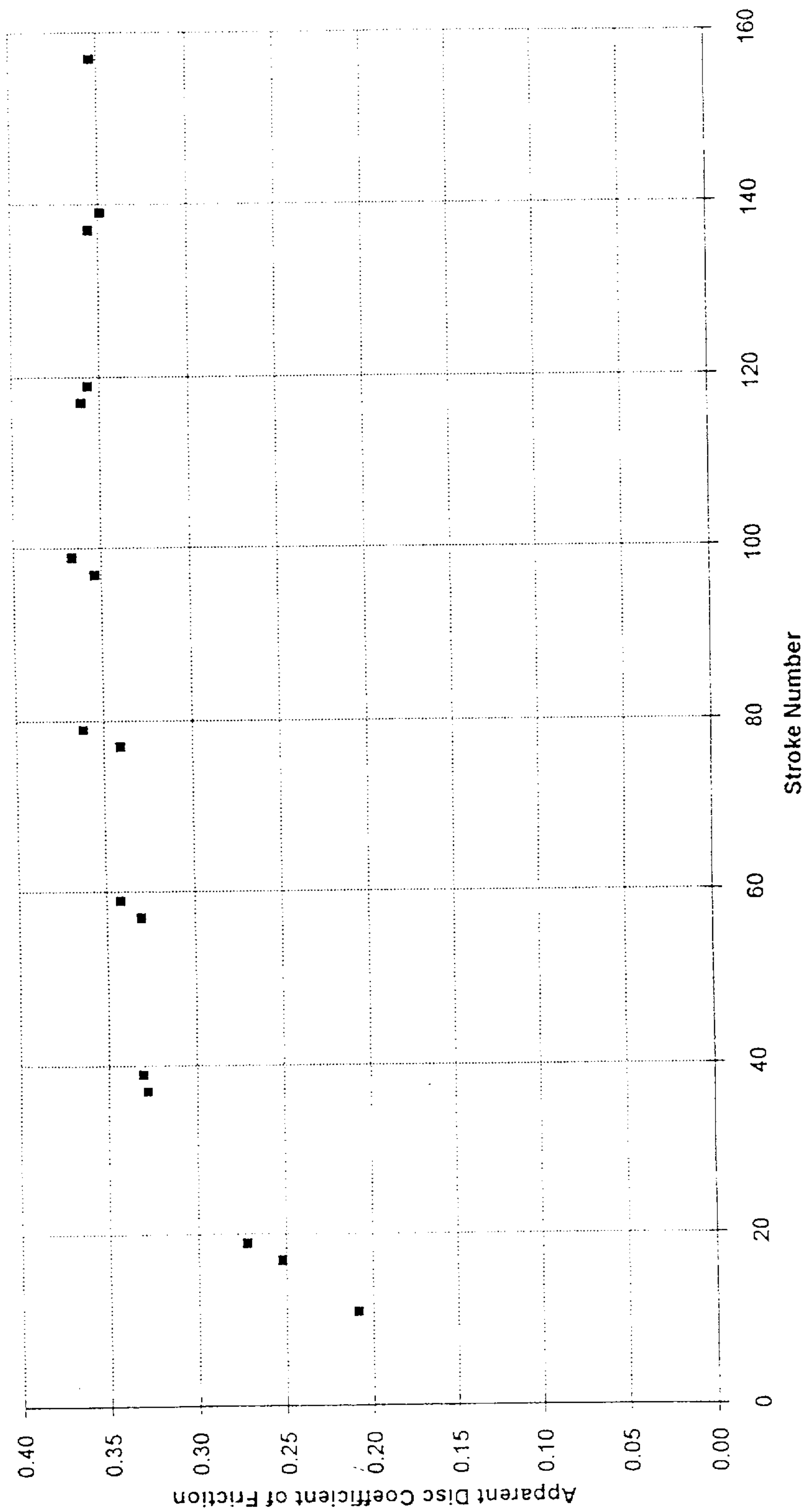
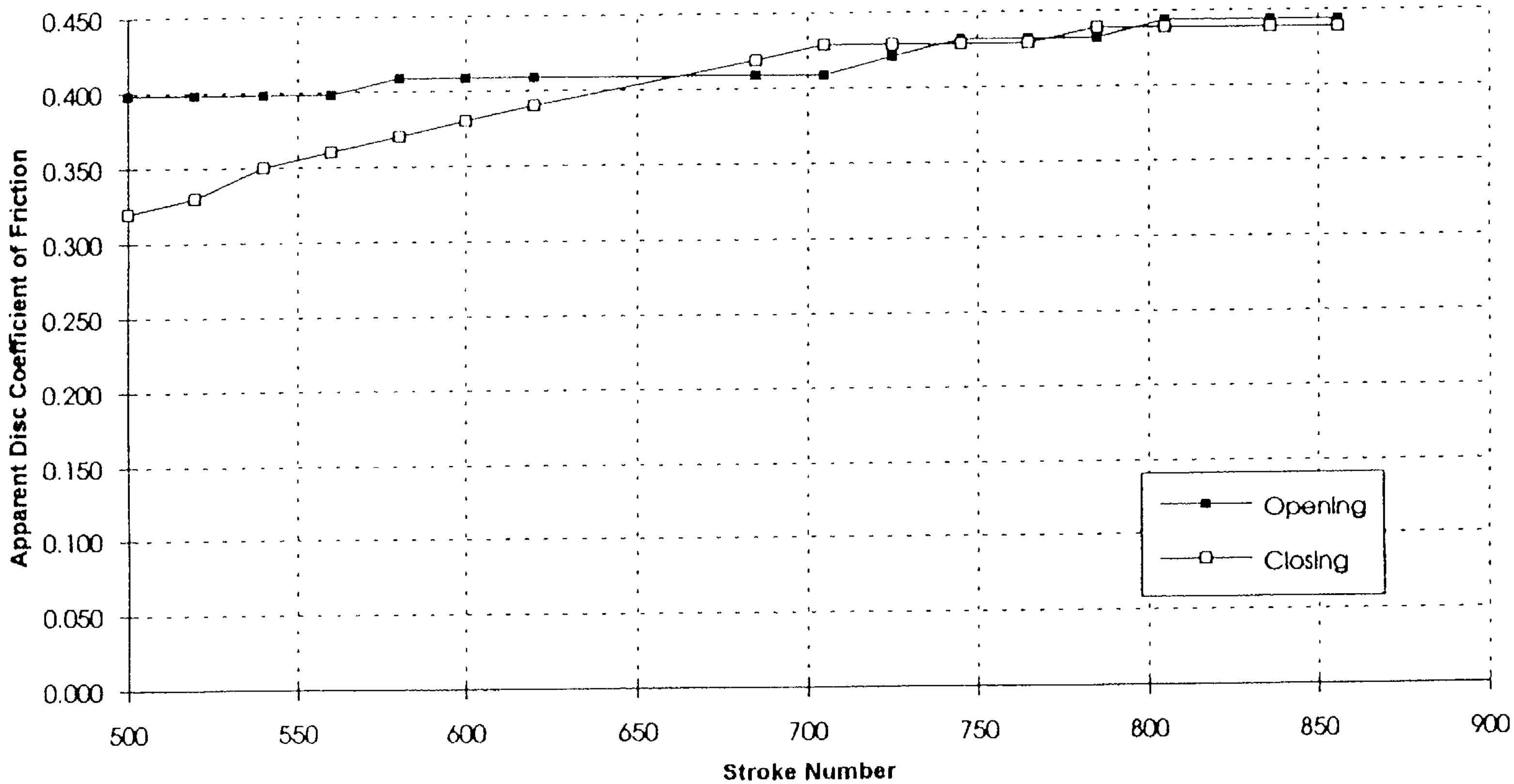


Figure 6-1 Valve Seat Preconditioning Results



Preconditioning Plot for Valve #23

Preconditioning Plot for Valve #24



Note: Apparent disc mu calculations were not performed for preconditioning strokes 101 through 499. See Section 6.

Figure 6-1 Valve Seat Preconditioning Results

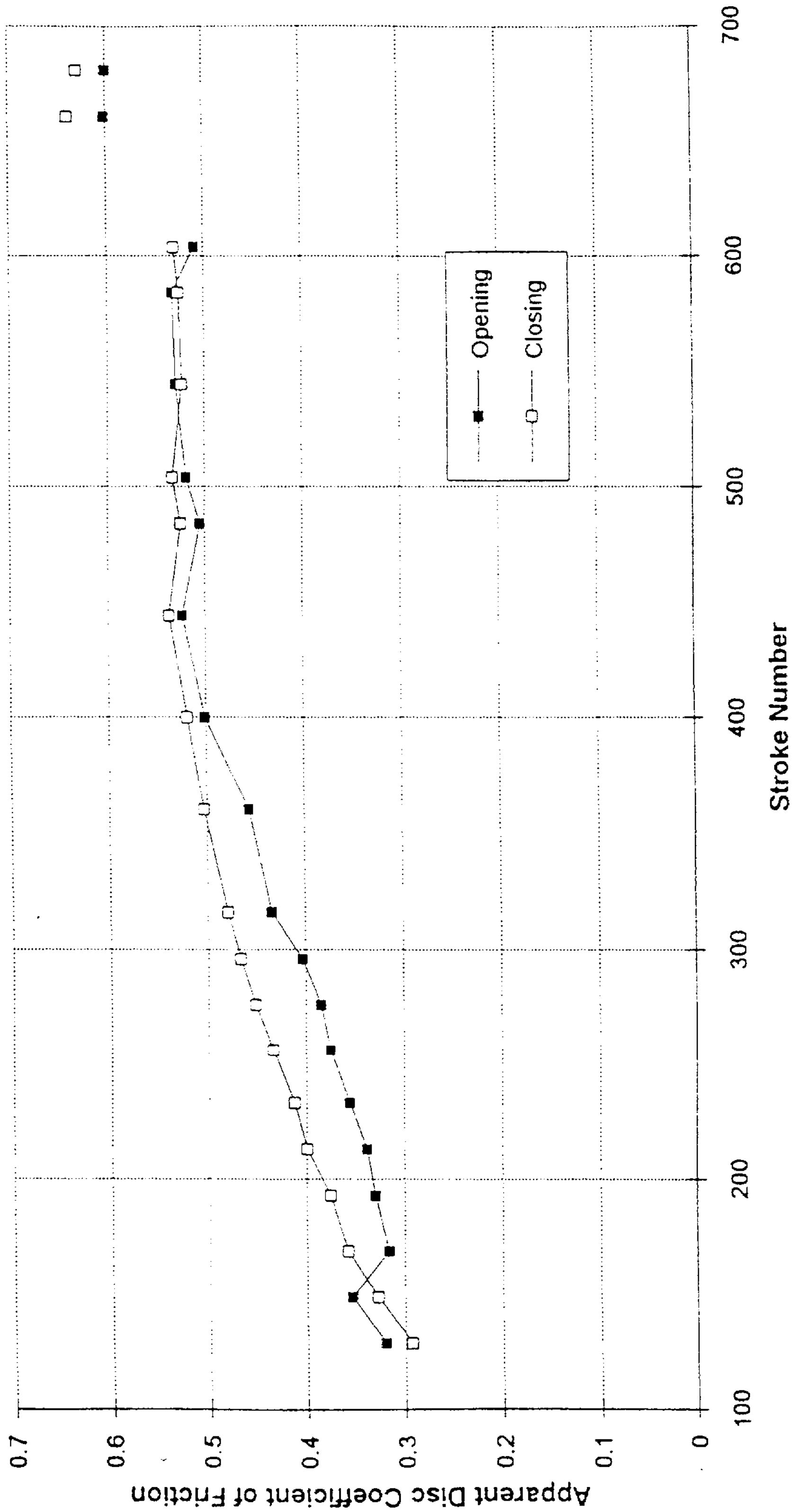
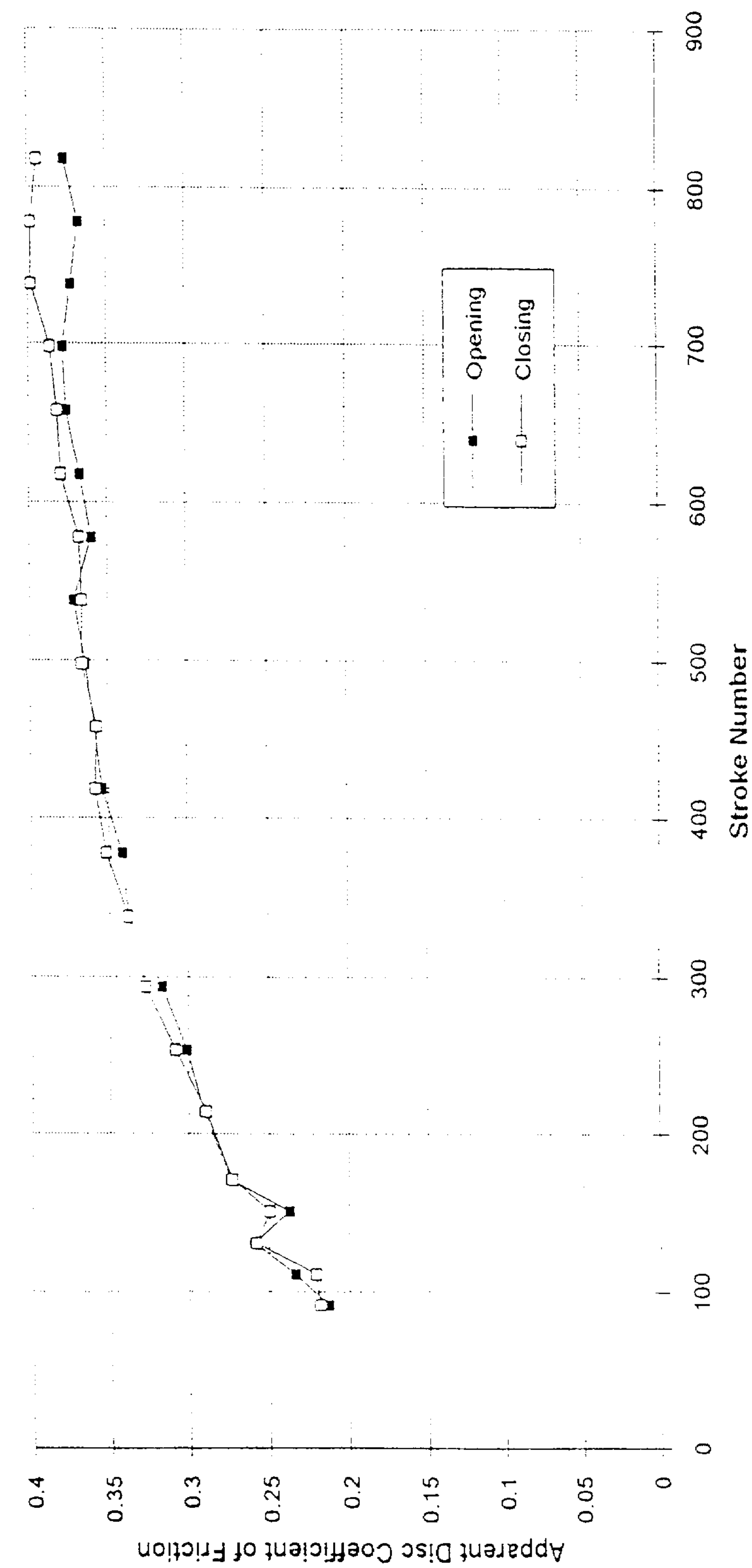
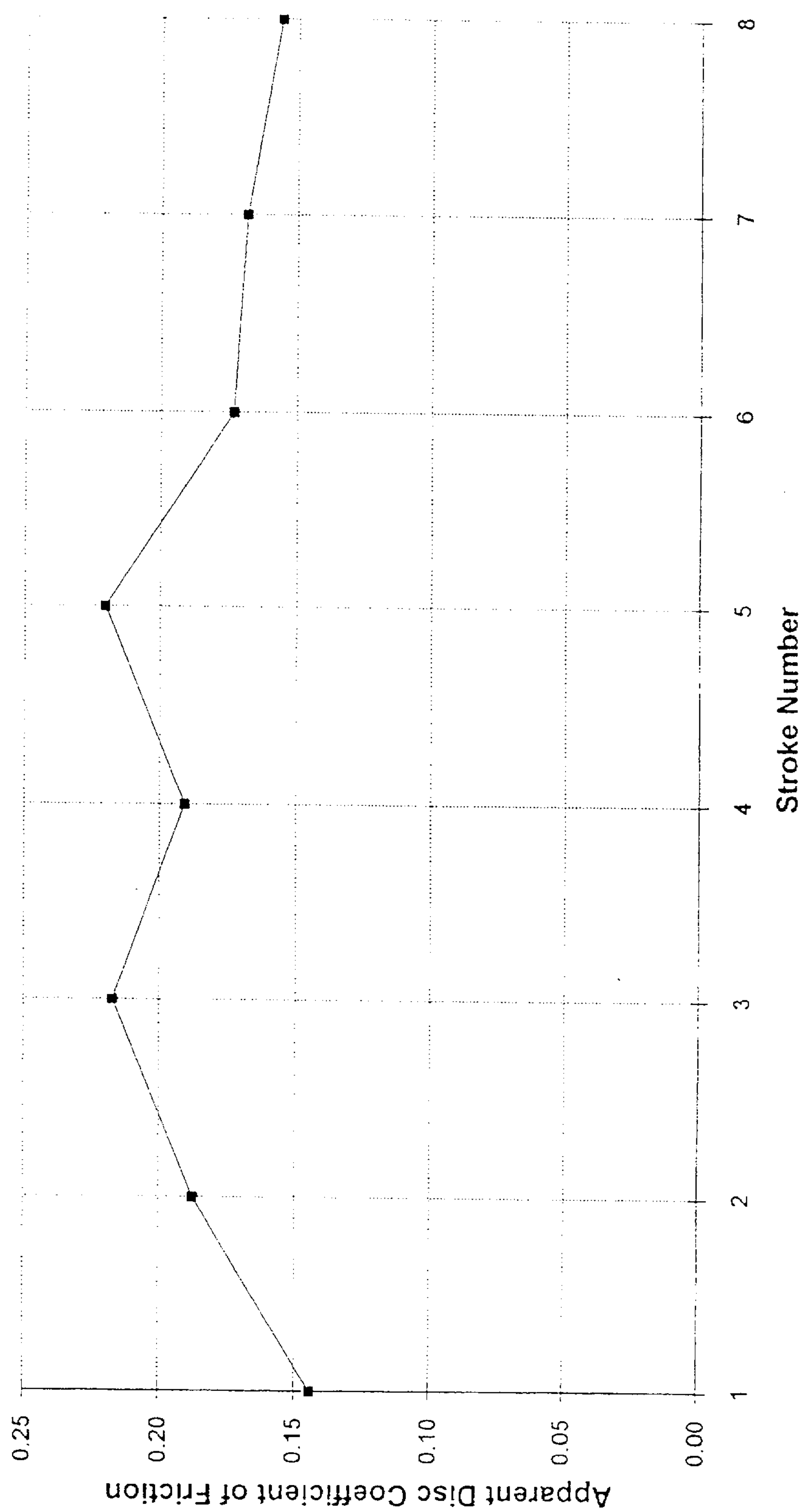


Figure 6-1 Valve Seat Preconditioning Results

Preconditioning Plot for Valve #25



Preconditioning Plot for Valve #31



Preconditioning Plot for Valve #29

November 1, 2000

Mr. John Hosler
Electric Power Research Institute
3270 Veld Way
Cameron Park, CA 95682

Subject: Request to JOG for Gate Valve COF Information

Dear Mr. Hosler:

In your letter dated October 20, 2000 (Subject: Permission to Access JOG PV Data), you requested that the Joint Owners' Group (JOG) allow MPR access to the JOG Periodic Verification (PV) test data to answer the following question.

> For the set of JOG gate valves with self-mated Stellite at the disk-to-seat interface stroked closed at temperatures below 120°F (excluding Borg-Warner gate valves), is the mean apparent disk-to-seat friction coefficient for closing less than 0.42?

Your request was approved by representatives from each of the four Owners' Groups, and this letter documents that the response to your question is "yes." Of the JOG gate valves with at least one approved test package, there were 79 valves that met your criteria and were included in the evaluation. The table below shows the breakdown by manufacturer of valves that met your criteria.

Manufacturer	Number of Valves
Aloyco (split wedge)	5
Anchor/Darling (flex wedge)	21
Anchor/Darling (double disk)	8
Crane	5
Powell	5
Velan	15
Walworth	9
Westinghouse	11
Total:	79

To determine the answer to your question, we followed the instructions in your letter, in the section titled Method for Determining Mean Disk-to-Seat Friction Coefficient. We have retained the documentation of our evaluation at our office. Please note that as additional JOG test packages are received and approved, the valves that meet your criteria, as well as the average coefficient of friction for those valves, may change. If EPRI desires any future information related to the JOG test valves, a separate request will need to be made.

Please call if you have any questions or comments.

Sincerely,

Thomas Walker

Thomas Walker

cc: Wendell Fiock, GE (BWROG)
Ike Ezekoye, Westinghouse (WOG)
Frank Ferraraccio, Westinghouse (CEOG)
Robert Schomaker, Framatome (B&WOG)
Glenn Warren, SNC
Tim Chan, TVA
Chad Smith, Duke Power
Bob Doyle, APS

Appendix B: Additional Validation of Thrust Uncertainty Method

This appendix documents additional validation of the Thrust Uncertainty Method method. The purposes of this additional validation are to:

- Increase the amount of data used to validate the Thrust Uncertainty Method, and
- Show the effect of using ROL bias and random uncertainty values other than the EPRI values (5.6% bias and 26.4% random uncertainty) on the performance of the Thrust Uncertainty Method.

The approach used for this validation is different from the approach used in Addendum 2 of EPRI Topical Report TR-103237. In Addendum 2 of EPRI Topical Report TR-103237, the Thrust Uncertainty Method was implemented for 100% DP strokes of gate valves tested by EPRI to determine the minimum allowable thrust at torque switch trip (TST) for each validation stroke. Plots of measured spring pack displacement versus stem thrust for the validation (dynamic) stroke and the closest static stroke were then used to determine the expected thrust at TST for the dynamic test (if the valve were set up per the Thrust Uncertainty Method in a static test). These plots were required to determine the actual ROL expected at the minimum torque switch setting calculated by the Thrust Uncertainty Method. The expected thrust at TST was then compared to the maximum required thrust for the stroke to determine if the valve would have fully closed prior to TST.

In this appendix, the simplified approach described below is used.

An equation is developed for the ratio of the Thrust Uncertainty Method prediction (minimum allowable thrust at TST, T_{TST}) to the PPM prediction, T_{PPM}. This ratio is a function of the APR (0.697 or 0.775), the ROL bias (B_{ROL}) and random uncertainty (R_{ROL}) values and a parameter x. "x" is the ratio of the sum of the packing and stem rejection loads to the PPM prediction. Using equations from Addendum 2 of EPRI Topical Report TR-103237, the following equation is derived.

$$\frac{T_{TST}}{T_{PPM}} = F * \left[1 + B_{ROL} + \sqrt{R^2_{ROL} + \left(\frac{1}{F} - 1 \right)^2} \right]$$

Where F is the ratio of the nominal thrust predicted by the Thrust Uncertainty Method to the PPM prediction (both the nominal thrust and PPM prediction include stem rejection load and packing load) and

$$F = APR + x - x * APR$$

For example, if x is 0.15, APR is 0.697, B_{ROL} is 0.056 and R_{ROL} is 0.264, then F is:

$$F = 0.697 + 0.15 - 0.15 * 0.697 = 0.742$$

And T_{TST}/T_{PPM} is:

$$\frac{T_{TST}}{T_{PPM}} = 0.742 * \left[1 + 0.056 + \sqrt{0.264^2 + \left(\frac{1}{0.742} - 1 \right)^2} \right] = 1.108$$

So if the PPM predicts 10,000 pounds required thrust, the Thrust Uncertainty Method will predict 11,080 pounds as the minimum allowable thrust at TST. The table below shows T_{CST}/T_{PPM} ratios for various values of APR, ROL and x. As shown, the Thrust Uncertainty Method cannot predict a minimum allowable thrust at TST less than the PPM prediction (i.e., there are no values below 1.000 in the table below).

x	T_{CST}/T_{PPM} for ROL Values of:					
	Cold Water (APR = 0.697)			Hot Water (APR = 0.775)		
	5.6/26.4%	3/18%	0/0%	5.6/26.4%	3/18%	0/0%
0.05	1.096	1.049	1.000	1.128	1.066	1.000
0.10	1.102	1.052	1.000	1.134	1.070	1.000
0.15	1.108	1.055	1.000	1.141	1.073	1.000
0.20	1.114	1.058	1.000	1.147	1.077	1.000
0.25	1.121	1.062	1.000	1.155	1.082	1.000

The Thrust Uncertainty Method prediction will be bounding as long as the actual required thrust due to flow and differential pressure, plus the ROL that actually occurs on that specific stroke, does not exceed the minimum allowable thrust at TST predicted by the Thrust Uncertainty Method. For the example above (x = 0.15, ROL = 5.6/26.4%, APR = 0.697 and T_{PPM} = 10,000), if the actual required thrust is equal to the PPM prediction, there will be 10.8% margin (or 1080 pounds) above the PPM prediction to accommodate ROL (i.e., since T_{CST} is 1.108, the torque switch would have been set at least 10.8% above the PPM prediction).

If the actual required thrust is less than the PPM prediction, then there will be additional margin to accommodate ROL (more than 10.8%). For example, if the actual required thrust is 9,000 pounds (90% of the PPM prediction), the margin to accommodate ROL is as follows.

$$ROL_{margin} = \frac{11{,}080 - 9{,}000}{9{,}000} = 23.1\%$$

In other words, if the actual required thrust were 9,000 pounds and the actual ROL were 23.1%, then the torque switch would need to be set to achieve at least

(9,000)(1.231) = 11,080 pounds at TST, which is the same as the prediction from the Thrust Uncertainty Method.

Based on the discussion above, the amount of ROL that a given Thrust Uncertainty Method prediction can accommodate can be written as a function of the ratio of the actual required thrust to the PPM prediction (prediction ratio, PR), as follows.

$$ROL_{margin} = \frac{T_{CST}/T_{PPM} - PR}{PR} = \frac{T_{CST}/T_{PPM}}{PR} - 1$$

Figures B-1 and B-2 plot PR versus available ROL_{margin} for ROL values of 5.6/26.4%, 3/18% and 0/0% bias/random, for cold water strokes and hot water strokes, respectively. The five different lines for 5.6/26.4% and 3/18% ROL correspond to x values of 0.05, 0.10, 0.15, 0.20 and 0.25. These plots use the T_{CST}/T_{PPM} values shown in the table above. Using the example above, if x = 0.15, ROL = 5.6/26.4%, APR = 0.697 (cold water) and PR is 0.9, the amount of ROL that can be tolerated is 23.1%, as shown on Figure B-1.

The additional validation in this appendix uses the equation above, along with actual PRs and ROL values for EPRI flow loop test valves (covering 77 strokes of 20 valves), to determine whether Thrust Uncertainty Method predictions would have been bounding. For a given valve closing stroke, if the actual ROL is plotted against the actual PR on Figure B-1 or Figure B-2 and the point falls below the line corresponding to the appropriate ROL and x values for the stroke, the Thrust Uncertainty Method would have provided a conservative prediction of T_{CST} for that stroke.

In Figures B-3 and B-4, PR and ROL values are plotted along with the lines shown in Figures B-1 and B-2 for valves not covered by the current Thrust Uncertainty Method validation and for all strokes valves that are covered by the current Thrust Uncertainty Method validation at 100% DP only. The circles in these figures are the new validation data. The x's are for the existing Thrust Uncertainty Method validation strokes. PR values are taken from validation of the gate valve model (EPRI TR-103229) except for "blind" valve strokes (Valves 5 and 30) and double disk gate valve strokes (Valve 41). For Valves 5 and 30, PR values are taken from EPRI TR-103231 (Assessment Report), and for Valve 41, PR values are taken from EPRI TR-103232. ROL values are taken from the Wyle test reports for each valve. ROL is calculated as the thrust at TST for the validation (dynamic) stroke minus the thrust at TST for the static stroke performed at the beginning of the test sequence, divided by the dynamic thrust at TST. Table B-1 lists the PR and ROL values for the cold water strokes evaluated, and Table B-2 lists the PR and ROL values for the hot water strokes evaluated. The following conclusions are drawn from Figures B-3 and B-4.

- When the EPRI ROL values are used in the Thrust Uncertainty Method, all predictions for cold water strokes are bounding, and all but one prediction for hot water strokes are bounding. The prediction for a hot water blowdown stroke of Valve #30 was not bounding. As discussed in Addendum 2 of EPRI Topical Report TR-103237, the PPM was also not bounding for this stroke. (This conclusion is consistent with Addendum 2 of EPRI Topical Report TR-103237.)

- The effectiveness of the Thrust Uncertainty Method in predicting minimum allowable thrust at TST is relatively insensitive to the values of ROL used in the method. The Thrust Uncertainty Method predictions would still be bounding for all cold water strokes and all but one hot water stroke if ROL values of 3% bias and 18% random uncertainty were used.

- For all strokes except four (two cold water and two hot water strokes), the valves would have fully closed prior to torque switch trip even if the torque switch had been set up statically based on the PPM prediction only, with no adjustment for ROL, torque switch repeatability, etc. In other words, for all but four of 77 strokes, the PPM thrust prediction alone is sufficiently conservative to cover all uncertainties related to valve setup, including ROL.

Table B-1. Prediction Ratios (PR) and Rate-of-loading (ROL) Values for Additional Validation -- Cold Water Strokes(3)

Valve	DP level	Thrust (lbs)		PR	Thrust at TST (lbs)		ROL
		Predicted	Measured		Static	Dynamic	
1	25%	1963	1485	0.756	8583	7536	13.9%
1	50%	3335	2400	0.720	8583	7999	7.3%
1	75%	4511	3134	0.695	8583	7983	7.5%
1(1)	100%	5633	3836	0.681	8583	8024	7.0%
2	33%	2988	1086	0.363	9553	9556	0.0%
2	67%	4678	1516	0.324	9553	9131	4.6%
2	100%	6624	1949	0.294	9553	9329	2.4%
3	33%	12776	11300	0.884	39371	40790	-3.5%
3	67%	22806	20429	0.896	39371	41083	-4.2%
3(1)	100%	31280	30853	0.986	39371	40680	-3.2%
4	33%	13336	7968	0.597	35874	36089	-0.6%
4	67%	21651	12245	0.566	35874	35777	0.3%
4(1)	100%	30359	17809	0.587	35874	36885	-2.7%
5	25%	---	---	0.715(2)	49345	47681	3.5%
5(1)	50%	---	---	0.711(2)	49345	47116	4.7%
6	33%	25635	14874	0.580	92777	96345	-3.7%
6	67%	52089	27338	0.525	92777	97565	-4.9%
13	33%	7705	6253	0.812	22432	21445	4.6%
13	67%	11609	9196	0.792	22432	20998	6.8%
13(1)	100%	14731	11657	0.791	22432	20558	9.1%
13	50%	8018	6528	0.814	22452	20654	8.7%
13(1)	100%	14758	11487	0.778	22452	20156	11.4%
14	33%	13521	9196	0.680	48140	48913	-1.6%
14	67%	22930	17629	0.769	48140	49236	-2.2%
14(1)	100%	29878	24118	0.807	48140	48501	-0.7%
14	33%	13152	9197	0.699	49064	48611	0.9%
14	67%	22832	17485	0.766	49064	47835	2.6%
14	100%	29689	24394	0.822	49064	47720	2.8%
16	25%	4319	3736	0.865	18209	18291	-0.4%
16	50%	6597	5724	0.868	18209	18494	-1.5%
16	75%	8930	7821	0.876	18209	18373	-0.9%
16	100%	10755	9334	0.868	18209	18700	-2.6%

Valve	DP level	Thrust (lbs)		PR	Thrust at TST (lbs)		ROL
		Predicted	Measured		Static	Dynamic	
17	33%	6119	4927	0.805	15204	17887	-15.0%
17	67%	10867	8875	0.817	15204	16705	-9.0%
17	100%	15344	11919	0.777	15204	15890	-4.3%
18	33%	1826	949	0.520	5603	5658	-1.0%
18	67%	2649	1502	0.567	5603	5685	-1.4%
18	100%	3382	1961	0.580	5603	5589	0.3%
23	33%	3927	2896	0.737	10636	10669	-0.3%
23	67%	5757	4120	0.716	10636	10376	2.5%
23	100%	7648	4980	0.651	10636	10185	4.4%
23	33%	4477	2645	0.591	10269	10178	0.9%
23	67%	6262	3675	0.587	10269	9899	3.7%
23	100%	8093	6091	0.753	10269	10245	0.2%
24	25%	12480	11488	0.921	48601	43581	11.5%
24	50%	22769	19678	0.864	48601	44345	9.6%
24	75%	31822	24296	0.763	48601	43911	10.7%
24(1)	100%	41690	34024	0.816	48601	46623	4.2%
24	33%	14930	13430	0.900	54015	52629	2.6%
24	67%	27141	23327	0.859	54015	50974	6.0%
24(1)	100%	37212	30363	0.816	54015	50895	6.1%
25	33%	14767	13023	0.882	36131	30391	18.9%
25	67%	27283	23310	0.854	36131	41326	-12.6%
25(1)	100%	38855	32996	0.849	36131	41275	-12.5%
29	33%	2332	815	0.349	8076	7542	7.1%
29	67%	4355	2025	0.465	8076	7298	10.7%
29	100%	6430	3748	0.583	8076	7233	11.7%
30	33%	---	---	0.499(2)	52602	48699	8.0%
30	67%	---	---	0.590(2)	52602	50047	5.1%
30(1)	100%	---	---	0.674(2)	52602	51375	2.4%
31	33%	10747	7304	0.680	27332	26798	2.0%
31	67%	17753	12033	0.678	27332	26680	2.4%
31(1)	100%	24305	17229	0.709	27332	27731	-1.4%
41	25%	9134	7484	0.819	37793	36487	3.6%
41	50%	17542	14124	0.805	37793	35429	6.7%
41	75%	25077	20000	0.798	37793	35755	5.7%

Valve	DP level	Thrust (lbs)		PR	Thrust at TST (lbs)		ROL
		Predicted	Measured		Static	Dynamic	
I7	100%	36146	19738	0.546	39990	34994	14.3%
I8	100%	31173	5543	0.178	35649	36216	-1.6%

Note (1): These strokes were also covered in validation of the Thrust Uncertainty Method.
Note (2): These strokes were "blind" strokes, and prediction ratios are taken directly from the EPRI TR-103231 (Assessment Report).
Note (3): This table covers 68 strokes of 20 valves and includes the cold water strokes used for validation in Addendum 2 of EPRI Topical Report TR-103237.

Table B-2. Prediction Ratios (PR) and Rate-of-loading (ROL) Values for Additional Validation -- Hot Water Strokes[1]

Valve	DP level	Thrust (lbs)		PR	Thrust at TST (lbs)		ROL
		Predicted	Measured		Static	Dynamic	
3	50%	11277	9420	0.835	44465	40043	11.0%
3	100%	19067	16802	0.881	44465	37514	18.5%
24	50%	15148	10896	0.719	48768	45493	7.2%
24	100%	22623	15989	0.707	48768	40118	21.6%
41	100%	17261	12709	0.736	54645	40085	36.3%

Note (1): This table covers 5 strokes of 3 valves and does not include the hot water strokes (four) used for validation in Addendum 2 of EPRI Topical Report TR-103237.

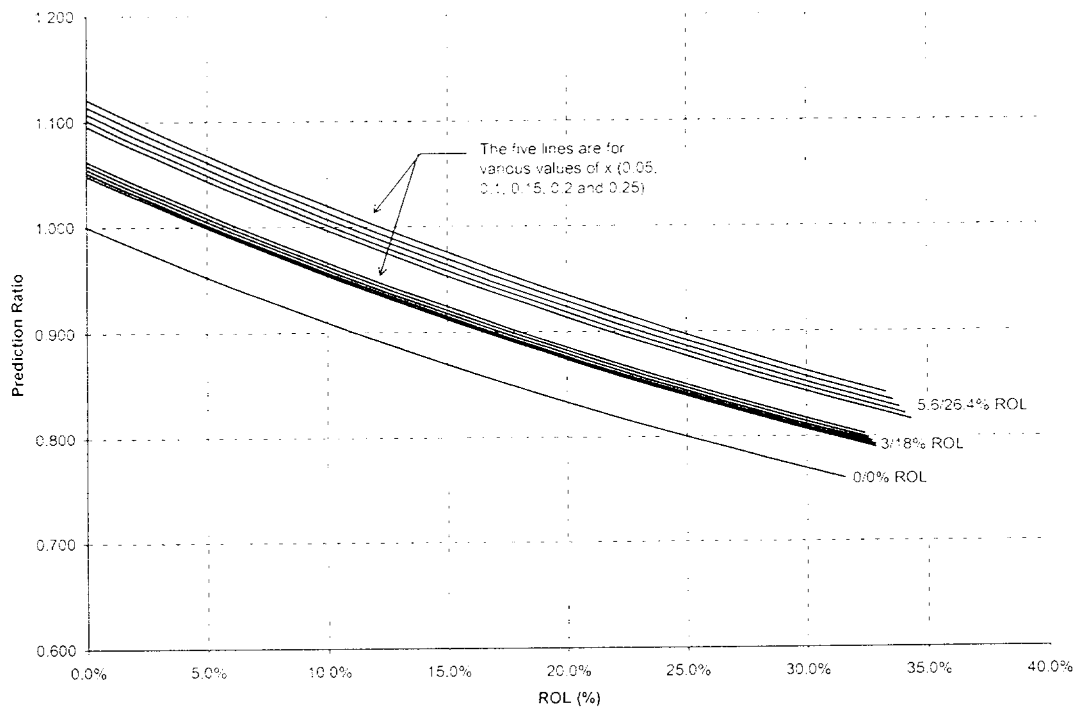


Figure B-1. Prediction Ratio (PR) versus Allowable Rate-of-Loading (ROL) for Cold Water Strokes

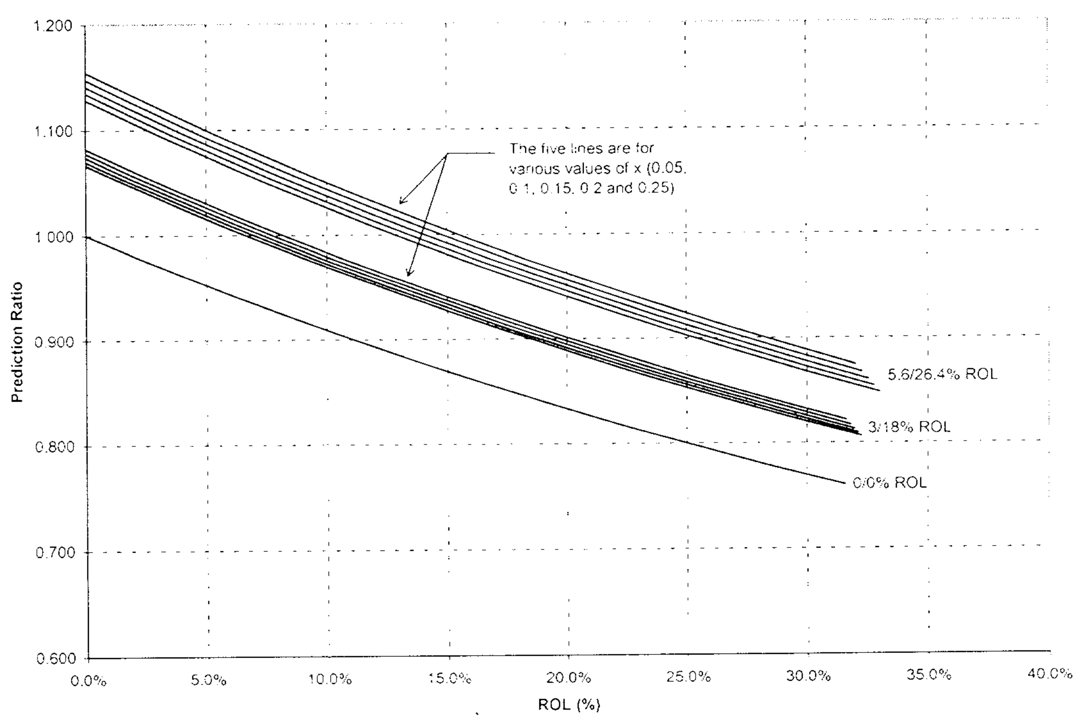


Figure B-2. Prediction Ratio (PR) versus Allowable Rate-of-Loading (ROL) for Hot Water Strokes

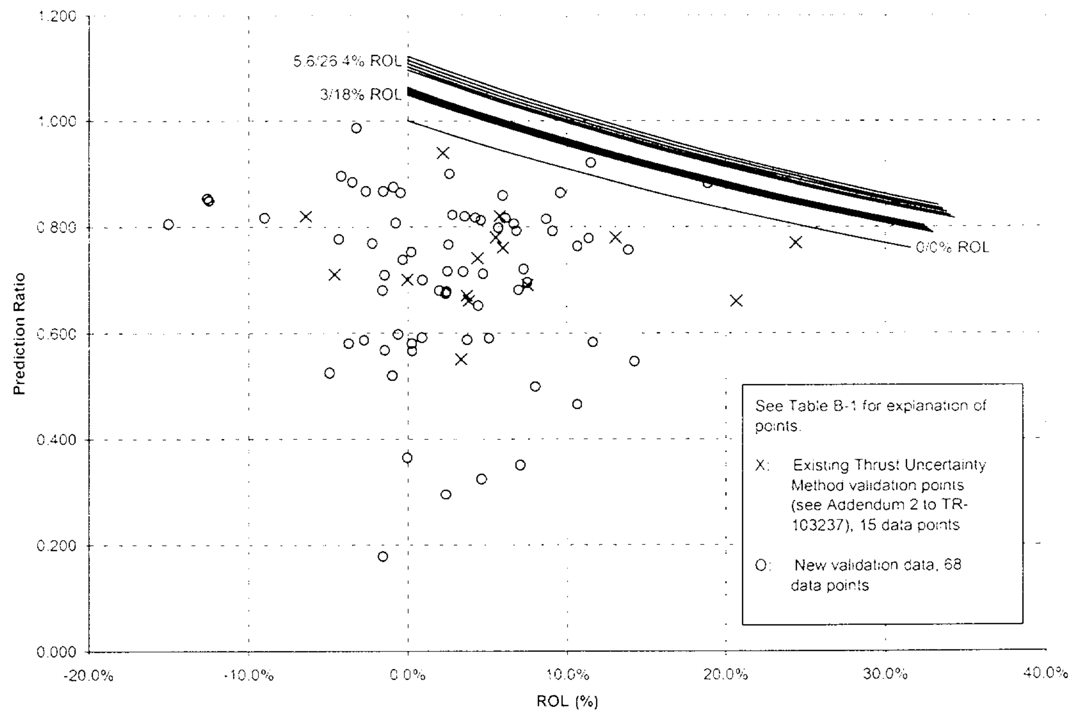


Figure B-3. Prediction Ratio (PR) versus Rate-of-Loading (ROL) for Cold Water Strokes

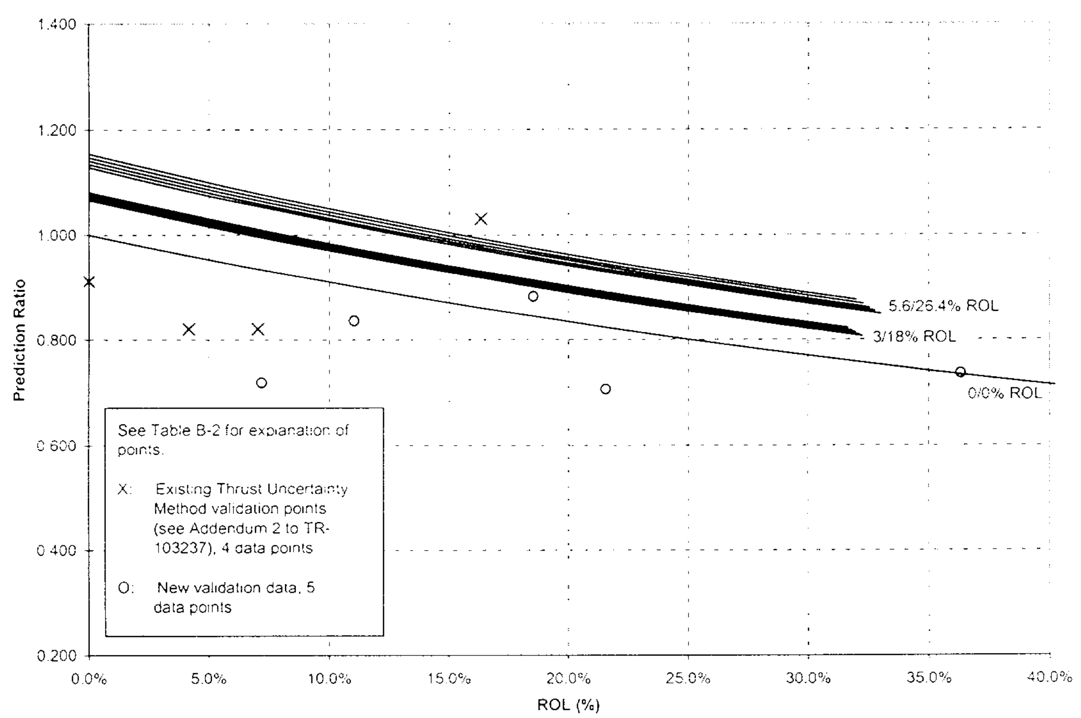


Figure B-4. Prediction Ratio (PR) versus Rate-of-Loading (ROL) for Hot Water Stroke