USER'S GUIDE FOR PRESLOK, A GATE VALVE PRESSURE LOCKING ANALYSIS PROGRAM USING THE COMMONWEALTH EDISON MODEL

REVISION 0

January 2, 1996

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RECORD OF REVISION PAGE

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INTRODUCTION

Pressure locking is a phenomenon which can cause the unseating thrust for a gate valve to increase dramatically from its typical static unseating thrust. This can possibly result in the valve failing to open due to the actuator having insufficient thrust capability. Pressure locking can also result in valve damage in cases where the actuator thrust capability exceeds the valve structural capacity. For these reasons, a proper understanding of the conditions which may cause pressure locking, as well as a methodology for predicting the increase in unseating thrust for a pressure locked valve, are necessary.

A method of analyzing gate valves to predict the increase in unseating thrust for a pressure locked valve has been developed by Commonwealth Edison, and has been presented by Mr. Brian Bunte (Ref. 1). The Westinghouse Owner's Group, in the Pressure Locking/Thermal Binding Task Team meeting on November 13 and 14, 1995, authorized the preparation of a MATHCAD program and accompanying user's manual to allow the uniform use of the Commonwealth Edison pressure locking analysis methodology. This manual is the result of that authorization.

This manual and the program file for performing the analysis are available from the Westinghouse Owner's Group and may be obtained by contacting L. I. Ezekoye at (412) 374-6643 or W. E. Moore at (412) 374-6351. Please indicate whether the program is to be supplied on 3.5 inch diskettes or 5.25 inch diskettes.

HARDWARE/SOFTWARE REQUIREMENTS

The program has been written using the MATHCAD 5.0 for Windows program. This program is available from

MathSoft, Inc.
101 Main Street
Cambridge, MA 02142
1-800-628-4223 or
617-577-1017
Fax: 617-577-8829

The program is also widely available from software vendors.

The following hardware and software requirements for running the MATHCAD 5.0 for Windows program are extracted from the User's Guide which is supplied with the MATHCAD program:

- An 80386 or higher IBM® or compatible computer. A math coprocessor is not required, but its presence will significantly improve performance.
- Microsoft® Windows™ Version 3.1 or later or Windows NT.
- At least 4MB of RAM. All memory above 640K should be configured as extended memory.
- At least 14MB of free hard disk space for MATHCAD files.
- An additional 1MB on the hard disk where MATHCAD is installed.
- At least 8MB of virtual memory. See the Windows user manual for how to specify virtual memory.
- A monitor and graphics card compatible with Windows.
- A mouse supported by Windows.
- Any printer supported by Windows.

The User's Guide supplied with the MATHCAD program should be followed for installation of the MATHCAD program onto your computer. The scope of this manual is to explain the usage of the PRESLOK analysis using the MATHCAD program.

GETTING STARTED

The PRESLOK files are supplied to you on either a 3.5 inch or a 5.25 inch diskette, per your request. It is recommended that the first step to use the files is to copy a "working version" of the files to your hard disk so that the diskette can be retained as a record copy. The files which are included are as follows:

preslok1.mcd	MATHCAD program using the closing valve factor as an input.
preslok2.mcd	MATHCAD program using the coefficient of friction between disk and seat as an input.
plinput1.dat	ASCII file of input data required by version 1 of the PRESLOK program.
plinput2.dat	ASCII file of input data required by version 2 of the PRESLOK program.

The next step to use the program is to create a data file to transfer the input values for the variables to the PRESLOK analysis program. The PRESLOK program is expecting these variables to appear in text file in plain ASCII format with the name "plinput1.dat" for use with version 1 or "plinput2.dat" for use with version 2. The various numbers in the "plinput1.dat" or "plinput2.dat" file can be separated by spaces, commas, or carriage returns, and may appear as integers, floating point numbers, or as E-format numbers such as 2.35E-2 . An ASCII text file can be created using the Windows utility Notepad, or by numerous other methods. This file should be located in the same directory as the PRESLOK file, since when the PRESLOK file is loaded, that directory will become the MATHCAD default directory. The user is also referred to the chapter on "Data Files" in the MATHCAD User's Guide if further explanation of the use of the ".dat" file is needed.

Sample data files are included in the program diskette which can be used simply by changing the input values to the proper values for your analysis. Alternately, other file names can be used for the input data by changing the input file name on the page 1 of the PRESLOK program to the file name desired.

RUNNING THE PRESLOK ANALYSIS

At this point it is assumed that the user has the MATHCAD 5.0 program loaded onto his computer, and that the PRESLOK Version 1 or PRESLOK Version 2 file and the "plinput1.dat" or "plinput2.dat" file are available to the computer in the same directory. To run the PRESLOK analysis, the user should perform the following steps:

1. Double click on the MATHCAD 5.0 icon to start the MATHCAD program.

2. Go to the File pulldown menu and click on Open (or click on the Open File icon on the Tool Bar.)

3. In the Open dialogue box, select the directory containing the preslok1.mcd or preslok2.mcd file and select the desired version of the program. Then click on OK.

4. The PRESLOK program will pick up the input values from the plinput1.dat or plinput2.dat file and perform the analysis if the program is in the automatic mode (Automatic Mode has a check mark next to it in the Math pulldown menu.) If the MATHCAD program is not in the automatic mode, it can be forced to perform the calculation by clicking on the Calculate Document function in the Math pulldown menu. Results may be inspected by using the scroll bar on the right hand side of the display to scroll through the display as desired.

5. To change the inputs, open the Windows utility Notepad and open the plinput1.dat or plinput2.dat file. Make the desired changes to the file and then save it. To have MATHCAD re-perform the analysis with the new input values, open the Math pulldown menu and click on Calculate Document. This alternate use of Notepad and the MATHCAD function Calculate Document should be repeated until the analysis is correct.

6 The output may be printed using the Print command in the pulldown menu under File or using the print icon in the Tool Bar. The user is referred to the MATHCAD User's Guide if any changes are desired to the Page Setup or the Printer Setup.

   Note that valve identifiers or other identifying titles may be added to the output by using the MATHCAD text entry methods given in the MATHCAD User's Guide. If the user desires to add the identifier/title to each page, the use of a header is recommended. The header can be defined through the Headers/Footers command in the Edit pulldown menu or through the Header command in the Page Setup dialogue box. See the Documents and Windows

RUNNING THE PRESLOK ANALYSIS (continued)

section of the MATHCAD User's Guide for further information about Headers.

7. The program may be exited using the Exit command in the File pulldown menu.

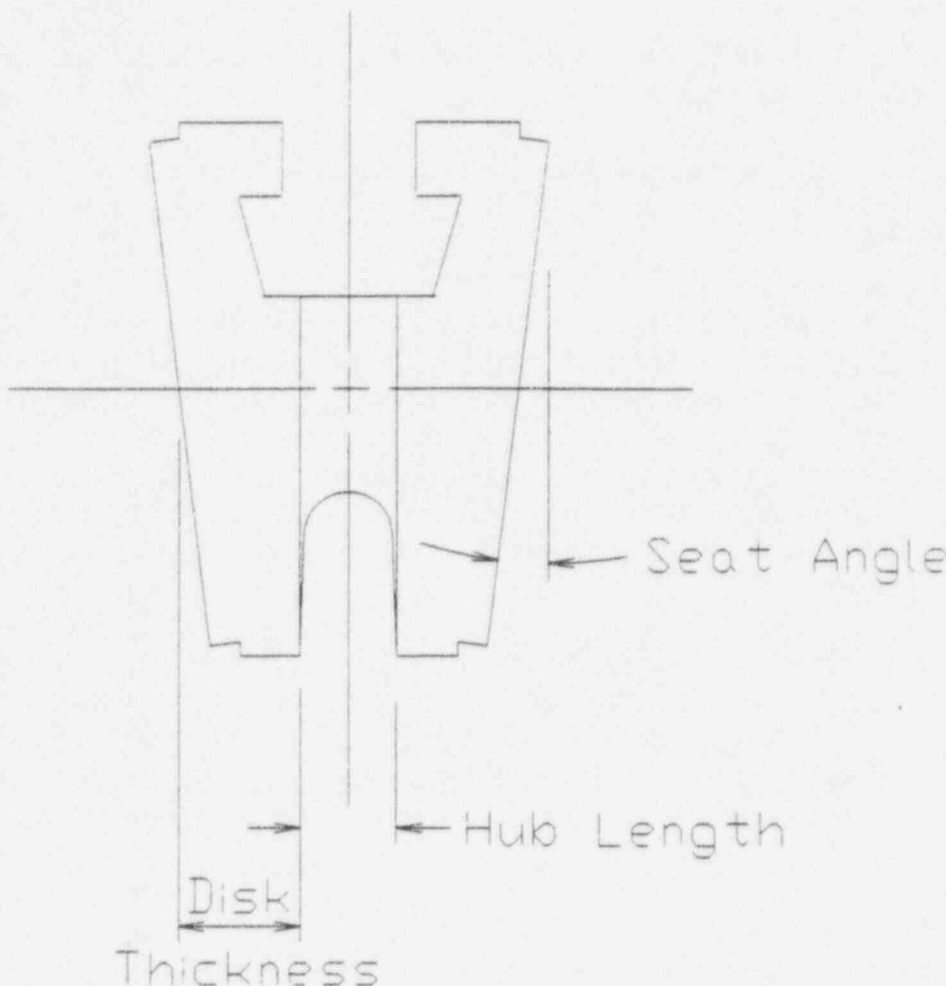


FIGURE 1 Disk Geometry

INPUT PREPARATION

The following inputs are required for the use of the PRESLOK analysis using version 1 of the program:

- Pressure Conditions at the time of the pressure locking event. This includes the upstream, downstream, and bonnet pressure.

Bonnet Pressure:	P_{bonnet}	psi
Upstream Pressure:	P_{up}	psi
Downstream Pressure:	P_{down}	psi

- Valve Disk Geometry. This includes the hub radius, hub length, mean seat radius, average disk thickness, and seat angle.

Disk Thickness:	**t**	inches
Seat Radius:	**a**	inches
Hub Radius:	**b**	inches
Hub Length:	Hub_{length}	inches
Seat Angle:	θ	degrees

The disk thickness recommended for use in these calculations is the thickness at the centerline of the disk vertically. See Figure 1. This will normally be a value which is intermediate between the minimum and maximum thickness of the disk, and this is the thickness which has been used in the comparisons of test measurements which Commonwealth Edison is making with the analytical results. It is noted that the magnitude of the pressure locking force increases with the thickness of the disk, so that use of the maximum disk thickness would yield conservative results. The pressure locking forces predicted by using the maximum value of disk thickness are likely to be unreasonably high though.

The seat radius used in these calculations is the mean seat radius which corresponds to the radius at which one half of the seat area would be outside the mean seat radius and one half of the seat area would be inside the mean radius. Thus, given the inner and outer seat diameters, the mean seat radius is

$$a = \sqrt{\frac{OD_{seat}^2 + ID_{seat}^2}{8}}$$

When the hub cross-section is not reasonably circular (e.g. many Westinghouse gate valve designs), then an effective hub radius is used which corresponds to a circle of equal area to the hub cross-sectional area.

$$b = \sqrt{\frac{Hub\ Area}{\pi}}$$

The hub length is the distance from the inside face of the hub to the inside face of the hub at the hub radius, as shown on Figure 1. The seat angle is as shown on Figure 1.

- Valve Disk Material Properties. This includes the modulus of elasticity and the Poisson's ratio for the disk base material, at the temperature being considered.

Poisson's Ratio:	ν	dimensionless
Modulus of Elasticity:	**E**	psi

- Valve Stem Diameter

Stem Diameter:	D_{stem}	inches

  This is the stem diameter in the region of the stem which is inside the packing.

- Static Unseating Thrust

Static Pullout Force:	F_{po}	pounds

  This is the static pullout force obtained from testing of the valve for which the calculation is being performed.

- Closing Valve Factor

Valve Factor:	**VF**	dimensionless

  It is suggested that this valve factor be the factor obtained from test measurements of closing the valve being considered in a DP test, if possible.

To use version 2 of the program instead of version 1, the closing valve factor VF is replaced by the co-efficient of friction to be considered between the disk and the seat, and the input data file is named plinput2.dat. All other inputs remain the same as for version 1. The different input value is

- Coefficient of Friction between Disk and Seat

Seat to Disk Coefficient of Friction:	μ	dimensionless

THEORY

ASSUMPTIONS

1. The valve disk is assumed to act as two ideal disks connected by a hub. That is, the disks are assumed to be round, of uniform thickness, and perpendicular to a cylindrical, concentric hub. A line perpendicular to the hub centerline and at the middle of the hub length is an axis of symmetry for the wedge. The equations in reference 2 for this idealized structure are assumed to conservatively model the actual load due to pressure forces. This assumption is considered conservative since inspection of the disk drawings show large fillets between the disk hub and seats which should make the valve disk stiffer than assumed in the reference 2 equations.

2. The coefficient of friction between the valve seat and disk is assumed to be the same under pressure locking conditions as it is under DP conditions. This assumption is considered to be justified based on bench marking of the calculations against ComEd and EPRI pressure locking test data for similar flex-wedge gate valves.

3. The upstream, downstream, and bonnet pressure values are considered to be known.

DESIGN INPUTS

The following design inputs are used in calculating the force required to unseat a pressure locked MOV:

- Pressure Conditions at the time of the pressure locking event. This includes the upstream, downstream, and bonnet pressure.

Bonnet Pressure:	P_{bonnet}	psi
Upstream Pressure:	P_{up}	psi
Downstream Pressure:	P_{down}	psi

- Valve Disk Geometry. This includes the hub radius, hub length, mean seat radius, and average disk thickness.

Disk Thickness:	t	inches
Seat Radius:	a	inches
Hub Radius:	b	inches

Hub Length:	$\mathbf{Hub_{length}}$	inches
Seat Angle:	θ	degrees

The disk thickness recommended for use in these calculations is the thickness at the centerline of the disk vertically. See Figure 1. This will normally be a value which is intermediate between the minimum and maximum thickness of the disk, and this is the thickness which has been used in the comparisons of test measurements which Commonwealth Edison is making with the analytical results. It is noted that the magnitude of the pressure locking force increases with the thickness of the disk, so that use of the maximum disk thickness would yield conservative results. The pressure locking forces predicted by using the maximum value of disk thickness are likely to be unreasonably high though.

The seat radius used in these calculations is the mean seat radius which corresponds to the radius at which one half of the seat area would be outside the mean seat radius and one half of the seat area would be inside the mean radius. Thus, given the inner and outer seat diameters, the mean seat radius is

$$a = \sqrt{\frac{OD_{seat}^2 + ID_{seat}^2}{8}}$$

When the hub cross-section is not reasonably circular (e.g. many Westinghouse gate valve designs), then an effective hub radius is used which corresponds to a circle of equal area to the hub cross-sectional area.

$$b = \sqrt{\frac{Hub\ Area}{\pi}}$$

The hub length is the distance from the inside face of the hub to the inside face of the hub at the hub radius, as shown on Figure 1. The seat angle is as shown on Figure 1.

- Valve Disk Material Properties. This includes the modulus of elasticity and the Poisson's ratio for the disk base material.

Poisson's Ratio:	ν	dimensionless
Modulus of Elasticity:	**E**	psi

- Valve Stem Diameter

Stem Diameter:	$\mathbf{D_{stem}}$	inches

This is the stem diameter in the region of the stem which is inside the packing.

- Static Unseating Thrust

  Static Pullout Force: F_{po} pounds

  This is the static pullout force obtained from testing of the valve for which the calculation is being performed.

- Coefficient of Friction between Disk and Seat

  Seat to Disk Coefficient of Friction: μ dimensionless

The analysis program is presented in two versions, one of which requires that the coefficient of friction to be used between the disk and the seat be input directly, and the other which allows the input of the closing valve factor instead. For the version which allows the input of the closing valve factor, the coefficient of friction is calculated as follows:

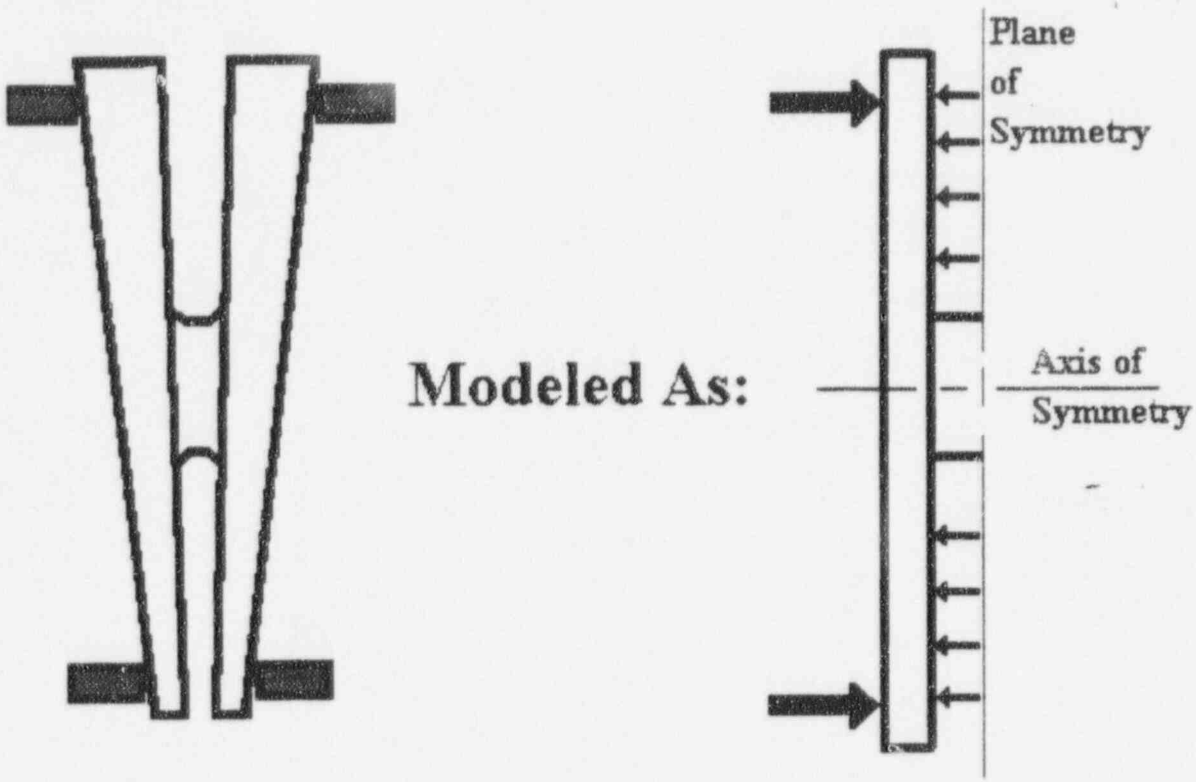
$$\mu = VF \cdot \frac{\cos \theta}{1 + VF \cdot \sin \theta}$$

CALCULATIONS

The methodology for calculating the thrust required to open the MOVs under the pressure locking scenario is based on the Reference 2 (Roark's) engineering handbook. The methodology determines the total force required to open the valve under a pressure locking scenario by solving for the four components to this force. The four components of the force are the pressure locking component, the static unseating component, the piston effect component, and the "reverse piston effect" component. These magnitudes of these components are determined using the following steps:

Pressure Locking Component of Force Required to Open the Valve

The valve disk is modeled as two plates attached at the center by a hub which is concentric with the valve disk. A plane of symmetry is assumed between the valve disks. This plane of symmetry is considered fixed in the analysis.



Based on this geometry, the following constants are calculated using the reference 2 equations:

Average DP Across Disk

$$DP_{avg} = P_{bonnet} - \frac{P_{up} + P_{down}}{2}$$

Disk Stiffness Constants

$$D = \frac{E \cdot t^3}{12 \cdot (1 - \nu^2)}$$

$$G = \frac{E}{2 \cdot (1 + \nu)}$$

Geometry Factors

$$C_2 = \frac{1}{4}\cdot\left[1-\left(\frac{b}{a}\right)^2\left(1+2\cdot\ln\left(\frac{a}{b}\right)\right)\right]$$

$$C_3 = \frac{b}{4a}\left\{\left[\left(\frac{b}{a}\right)^2+1\right]\ln\left(\frac{a}{b}\right)+\left(\frac{b}{a}\right)^2-1\right\}$$

$$C_8 = \frac{1}{2}\left[1+\nu+(1-\nu)\left(\frac{b}{a}\right)^2\right]$$

$$C_9 = \frac{b}{a}\left\{\frac{1+\nu}{2}\ln\left(\frac{a}{b}\right) + \frac{1-\nu}{4}\left[1-\left(\frac{b}{a}\right)^2\right]\right\}$$

Deflection Due To Pressure Force

The pressure force is assumed to act uniformly upon the inner surface of the disk between the hub diameter and the outer disk diameter. The outer edge of the disk is assumed to be unimpeded and allowed to deflect away from the pressure force. In addition, the disk hub is allowed to stretch. The total displacement at the outer edge of the valve disk due to shear and bending and due to hub stretch are calculated using the reference 2 equations.

Corresponding Equations

Additional Geometry Factors (r_0 = b for Case 2L)

$$L_{11} = \frac{1}{64}\left\{1+4\cdot\left(\frac{r_0}{a}\right)^2-5\cdot\left(\frac{r_0}{a}\right)^4-4\cdot\left(\frac{r_0}{a}\right)^2\left[2+\left(\frac{r_0}{a}\right)^2\right]\ln\left(\frac{a}{r_0}\right)\right\}$$

$$L_{17} = \frac{1}{4}\left\{1-\frac{1-\nu}{4}\left[1-\left(\frac{r_0}{a}\right)^4\right]-\left(\frac{r_0}{a}\right)^2\left[1+(1+\nu)\ln\left(\frac{a}{r_0}\right)\right]\right\}$$

Moment Factors (r_0 = b for Case 2L)

$$M_{rb} = \frac{-DP_{avg} \cdot a^2}{C_8}\left[\frac{C_9}{2 \cdot a \cdot b}\left(a^2 - r_0^2\right) - L_{17}\right]$$

$$Q_b = \frac{-DP_{avg}}{2 \cdot b}\left(a^2 - r_0^2\right)$$

Should be "+".
See "Verification of Pressure Locking Analysis Program - Preslock (MUHP-6050)", Westinghouse Owners Group Calc No. V-EC-1606.
RH 2-26-96

Bending Deflection due to Pressure

$$y_{bq} = M_{rb}\frac{a^2}{D}C_2 + Q_b\frac{a^3}{D}C_3 - \frac{DP_{avg} \cdot a^4}{D}L_{11}$$

Shear Deflection due to Pressure (r_0 = b for Case 2L)

$$K_{sa} = -0.3 \cdot \left[2 \cdot \ln\left(\frac{a}{b}\right) - 1 + \left(\frac{r_0}{a}\right)^2\left(1 - 2 \cdot \ln\left(\frac{r_0}{b}\right)\right)\right]$$

$$y_{sq} = \frac{K_{sa} \cdot DP_{avg} \cdot a^2}{t \cdot G}$$

Deflection from Hub Stretch due to Pressure

$$P_{force} = \pi\left(a^2 - b^2\right) \cdot DP_{avg}$$

$$y_{stretch} = -\frac{P_{force}}{\pi \cdot b^2}\frac{Hub_{length}}{2E}$$

Total Deflection due to Pressure

$$y_q = y_{bq} + y_{sq} + y_{stretch}$$

An evenly distributed force is assumed to act between the valve seat and the outer edge of the valve disk. This force acts to deflect the outer diameter of the valve disk inward and to compress the disk hub. The pressure force is reacted to by an increase in this contact force between the valve disk and seats. The valve body seats are conservatively assumed to be fixed. Therefore, the deflection due to the known pressure load must be balanced by the deflection due to the unknown seat load. The deflection due to the pressure force was previously calculated. Now, the reference 2

equations are used to determine the contact force between the seat and disk which results in a deflection which is equal and opposite to the deflection due to the pressure force. This is done by first calculating the amount deflection created by a unit load of seat contact force (w = 1 lb/in). The equilibrium contact load is then determined by dividing the deflection caused by the unit contact load into the previously calculated deflection due to the pressure force. The equations are provided below:

Additional Geometry Factors (For Case 1L, $r_0 = a$, $\therefore L_3 = L_9 = 0$

$$L_3 = \frac{r_0}{4a}\left\{\left[\left(\frac{r_0}{a}\right)^2 + 1\right]\cdot\ln\left(\frac{a}{r_0}\right) + \left(\frac{r_0}{a}\right)^2 - 1\right\}$$

$$L_9 = \frac{r_0}{a}\left\{\frac{1+\nu}{2}\cdot\ln\left(\frac{a}{r_0}\right) + \frac{1-\nu}{4}\cdot\left[1 - \left(\frac{r_0}{a}\right)^2\right]\right\}$$

Bending Deflection due to Seat Load ($r_0 = a$)

$$y_{bw} = -\frac{a^3}{D}\cdot\left[\frac{C_2}{C_8}\cdot\left(\frac{r_0\cdot C_9}{b} - L_9\right) - \frac{r_0\cdot C_3}{b} + L_3\right]$$

Shear Deflection due to Seat Load ($r_0 = a$)

$$K_{sa} = -1.2\frac{r_0}{a}\ln\left(\frac{r_0}{b}\right)$$

$$y_{bw} = K_{sa}\frac{a}{t\cdot G}$$

Deflection from Hub Compression Due to Seat Load
(w = 1, $\therefore$ Compressive force = $2\pi a$)

$$y_{compr} = -\frac{2\pi a}{\pi b^2}\left(\frac{Hub_{length}}{2E}\right)$$

Total Deflection from Unit Seat Load (w = 1)

$$y_w = y_{bw} + y_{sw} + y_{compr}$$

Therefore, the equilibrium contact load distribution (lb/in) and the corresponding load applied to each seat is calculated using the relationship below:

$$w_{equilibrium} = \frac{y_q}{y_w}, \text{ where } y_w \text{ is calculated for } w = 1$$

$$\text{Load per seat} = 2\pi a\left(\frac{y_q}{y_w}\right)$$

Determining The Disk To Seat Friction Coefficient

Several methods can be used to determine an appropriate seat to disk friction coefficient. The coefficient of friction between the seat and disk is perhaps best determined based on the open valve factor from a DP test. However, due to the difficulty sometimes encountered in obtaining a good, consistent valve of the opening valve factor from testing, the PRESLOK program is written to accept a closing valve factor or a co-efficient of friction directly. The equation used to calculate the coefficient of friction from the closing valve factor is given in the Design Inputs section of this User's Manual.

The stem force required to overcome the contact load between the seat and disk which opposes the pressure force is equal to:

(seat load) × [$\mu \cos \theta - \sin \theta$] × 2 (for two disk faces).

Static Unseating Force

The static unseating force represents the opening packing load and the pullout force due to wedging of the valve disk during closure. These loads are superimposed on the loads due to the pressure forces which occur during pressure locking. The value for this force is based on static test data for the MOVs.

Piston Effect

The piston effect due to valve internal pressure exceeding outside pressure is calculated using the standard industry equation. This force assists movement of the valve stem in the open direction.

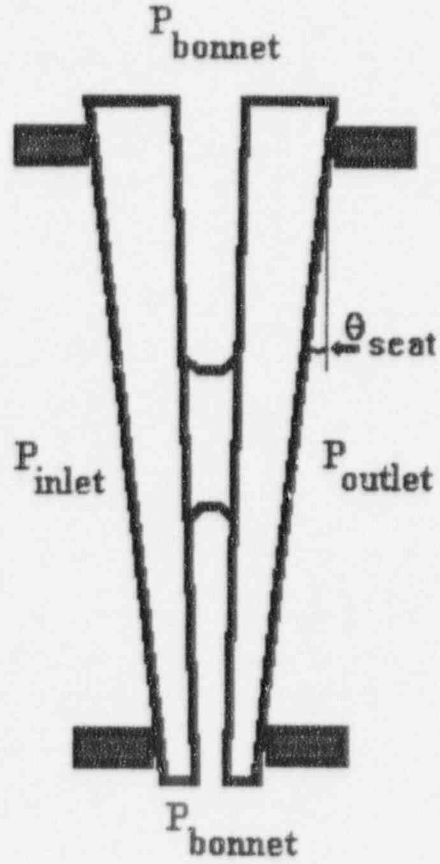
$$F_{piston\ effect} = \frac{\pi}{4} D_{stem}^2 \left(P_{bonnet} - P_{atm}\right)$$

Reverse Piston Effect (F_{vert})

The reverse piston effect is the term used in this calculation to refer to the pressure

force acting downward against the valve disk. This force is equal to the differential pressure across the valve disk times the area of the valve disk times the sine of the seat angle times 2 (for two disk faces).

$$F_{vert} = \pi \cdot a^2 \cdot \sin\theta \cdot (2 \cdot P_{bonnet} - P_{up} - P_{down})$$



Total Force Required to Overcome Pressure Locking

As mentioned previously, the total stem force (tension) required to overcome pressure locking is the sum of the four components discussed above. All of the terms are positive with the exception of the piston effect component.

The acceptance criteria recommended for use in this calculation is that the available motor operator thrust capability be at least 120% of that required to unseat the MOV under pressure locking conditions. The 20% margin is provided to allow for uncertainty in the measurement of stem factor, open valve factor, static unseating thrust as well as other effects such as stem factor variation and motor-to-motor torque capability variations. All of these effects are random in nature.

EXAMPLE OF AN ANALYSIS PERFORMED WITH PRESLOK, VERSION 1

The following is an image of the input file plinput1.dat used to run an example problem on version 1 of the PRESLOK analysis program:

```
1005    380     350     2       4.36    1.25    0.5     5
0.3     27.6E6  1.875   15409   0.52
```

The input file corresponds to input values as shown:

Bonnet Pressure:	P_{bonnet} = 1005 psi	
Upstream Pressure:	P_{up} = 380 psi	
Downstream Pressure:	P_{down} = 350 psi	
Disk Thickness:	**t** = 2.00 inches	
Seat Radius:	**a** = 4.36 inches	
Hub Radius:	**b** = 1.25 inches	
Hub Length:	**L** = 0.50 inches	
Seat Angle:	θ = 5 degrees	
Poisson's Ratio:	ν = 0.3	(dimensionless)
Modulus of Elasticity:	**E** = 27,600,000 psi	
Stem Diameter:	D_{stem} = 1.875 inches	
Static Pullout Force:	F_{po} = 15,409 pounds	
Valve Factor:	**VF** = 0.52	(dimensionless)

The next five pages contain the output of the PRESLOK program, Version 1, using the above input.

This Mathcad Program is designed to calculate the estimated opening force under pressure locking scenarios for flex-wedge gate valves using a calculational methodology that accounts for wedge stiffness resisting pressure locking forces. This program was prepared by the Westinghouse Owner's Group based upon the calculational methods developed by Commonwealth Edison.

This section of the program reads the thirteen items of input data from the plinput1.dat file.

$i := 0..12$

$input_i := READ(plinput1)$

$P_{bonnet} := input_0 \cdot psi$

$P_{up} := input_1 \cdot psi$

$P_{down} := input_2 \cdot psi$

$t := input_3 \cdot in$

$a := input_4 \cdot in$

$b := input_5 \cdot in$

$Hub_{length} := input_6 \cdot in$

$\theta := input_7 \cdot deg$

$\nu := input_8$

$E := input_9 \cdot psi$

$D_{stem} := input_{10} \cdot in$

$F_{po} := input_{11} \cdot lbf$

$VF := input_{12}$

INPUTS:

Bonnet Pressure	$P_{bonnet} = 1005 \cdot psi$
Upstream Pressure	$P_{up} = 380 \cdot psi$
Downstream Pressure	$P_{down} = 350 \cdot psi$
Disk Thickness (taken at centerline of the hub vertically)	$t = 2 \cdot in$
Seat Radius (corresponding to mean seat diameter)	$a = 4.36 \cdot in$
Hub Radius (taken at plane of symmetry, perpendicular to the hub, radius of circle of equivalent area for non-circular hubs)	$b = 1.25 \cdot in$
Seat Angle	$\theta = 5 \cdot deg$
Poisson's Ratio (disk material at temperature)	$\nu = 0.3$
Modulus of Elasticity (disk material at temperature)	$E = 2.76 \cdot 10^{7} \cdot psi$
Static Pullout Force (measured value from diagnostic test)	$F_{po} = 15409 \cdot lbf$
Close Valve Factor	$VF = 0.52$
Stem Diameter	$D_{stem} = 1.875 \cdot in$
Hub Length (from inside face of disk to inside face of disk)	$Hub_{length} = 0.5 \cdot in$

PRESSURE FORCE CALCULATIONS

Coefficient of friction between disk and seat:

$$\mu := VF\cdot\frac{\cos(\theta)}{1 + VF\cdot\sin(\theta)}$$ $\mu = 0.496$

Average DP across disks:

$$DPavg := P_{bonnet} - \frac{P_{up} + P_{down}}{2}$$ $DPavg = 640\cdot psi$

Disk Stiffness Constants

$$D := \frac{E\cdot(t)^3}{12\cdot\left(1 - \nu^2\right)}$$ $D = 2.022\cdot 10^7\ \cdot lbf\cdot in$

$$G := \frac{E}{2\cdot(1 + \nu)}$$ $G = 1.062\cdot 10^7\ \cdot psi$

Geometry Factors:

$$C_2 := \frac{1}{4}\cdot\left[1 - \left(\frac{b}{a}\right)^2\cdot\left(1 + 2\cdot\ln\left(\frac{a}{b}\right)\right)\right]$$ $C_2 = 0.1781$

$$C_3 := \frac{b}{4\cdot a}\cdot\left[\left[\left(\frac{b}{a}\right)^2 + 1\right]\cdot\ln\left(\frac{a}{b}\right) + \left(\frac{b}{a}\right)^2 - 1\right]$$ $C_3 = 0.0311$

$$C_8 := \frac{1}{2}\cdot\left[1 + \nu + (1 - \nu)\cdot\left(\frac{b}{a}\right)^2\right]$$ $C_8 = 0.6788$

$$C_9 := \frac{b}{a}\cdot\left[\frac{1 + \nu}{2}\cdot\ln\left(\frac{a}{b}\right) + \frac{1 - \nu}{4}\cdot\left[1 - \left(\frac{b}{a}\right)^2\right]\right]$$ $C_9 = 0.2789$

$$L_3 := \frac{a}{4\cdot a}\cdot\left[\left[\left(\frac{a}{a}\right)^2 + 1\right]\cdot\ln\left(\frac{a}{a}\right) + \left(\frac{a}{a}\right)^2 - 1\right]$$ $L_3 = 0$

$$L_9 := \frac{a}{a}\cdot\left[\frac{1 + \nu}{2}\cdot\ln\left(\frac{a}{a}\right) + \frac{1 - \nu}{4}\cdot\left[1 - \left(\frac{a}{a}\right)^2\right]\right]$$ $L_9 = 0$

Program PRESLOK, Version 1

Geometry Factors: (continued)

$$L_{11} = \frac{1}{64}\cdot\left[1 + 4\cdot\left(\frac{b}{a}\right)^2 - 5\cdot\left(\frac{b}{a}\right)^4 - 4\cdot\left(\frac{b}{a}\right)^2\cdot\left[2 + \left(\frac{b}{a}\right)^2\right]\cdot\ln\left(\frac{a}{b}\right)\right] \qquad L_{11} = 0.0069$$

$$L_{17} = \frac{1}{4}\cdot\left[1 - \frac{1-\nu}{4}\cdot\left[1 - \left(\frac{b}{a}\right)^4\right] - \left(\frac{b}{a}\right)^2\cdot\left[1 + (1+\nu)\cdot\ln\left(\frac{a}{b}\right)\right]\right] \qquad L_{17} = 0.1526$$

Moment

$$M_{rb} = \frac{-DPavg\cdot a^2}{C_8}\cdot\left[\frac{C_9}{2\cdot a\cdot b}\cdot\left(a^2 - b^2\right) - L_{17}\right] \qquad M_{rb} = -5265\cdot lbf$$

$$Q_b = \frac{DPavg}{2\cdot b}\cdot\left(a^2 - b^2\right) \qquad Q_b = 4466.5\cdot\frac{lbf}{in}$$

Deflection due to pressure and bending:

$$y_{bq} = M_{rb}\cdot\frac{a^2}{D}\cdot C_2 + Q_b\cdot\frac{a^3}{D}\cdot C_3 - \frac{DPavg\cdot a^4}{D}\cdot L_{11} \qquad y_{bq} = -3.9041\cdot 10^{-4}\cdot in$$

Deflection due to pressure and shear stress:

$$K_{sa} = -0.3\cdot\left[2\cdot\ln\left(\frac{a}{b}\right) - 1 + \left(\frac{b}{a}\right)^2\right] \qquad K_{sa} = -0.4743$$

$$y_{sq} = \frac{K_{sa}\cdot DPavg\cdot a^2}{t\cdot G} \qquad y_{sq} = -2.7177\cdot 10^{-4}\cdot in$$

Deflection due to hub stretch:

$$P_{force} = \pi\cdot\left(a^2 - b^2\right)\cdot DPavg$$

$$y_{stretch} = \frac{P_{force}}{\pi\cdot t^2}\cdot\frac{Hub_{length}}{(2\cdot E)} \qquad y_{stretch} = 6.4731\cdot 10^{-5}\cdot in$$

Total Deflection due to pressure forces:

$$y_q = y_{bq} + y_{sq} - y_{stretch} \qquad y_q = -7.2691\cdot 10^{-4}\cdot in$$

Deflection due to seat contact force and shear stress (per lbf/in.):

$$y_{sw} := -\left[\frac{1.2\cdot\left(\frac{a}{a}\right)\cdot\ln\left(\frac{a}{b}\right)\cdot a}{t\cdot G}\right] \qquad y_{sw} = -3.079\cdot 10^{-7}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Deflection due to seat contact force and bending (per lbf/in.):

$$y_{bw} := -\left(\frac{a^3}{D}\right)\cdot\left[\left(\frac{C_2}{C_8}\right)\cdot\left[\left(\frac{a\cdot C_9}{b}\right) - L_9\right] - \left[\left(\frac{a}{b}\right)\cdot C_3\right] + L_3\right] \qquad y_{bw} = -6.012\cdot 10^{-7}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Deflection due to hub compression:

$$y_{cmpr} := -\left(\frac{2\cdot\pi\cdot a}{\pi\cdot b^2}\cdot\frac{Hub_{length}}{2\cdot E}\right) \qquad y_{cmpr} = -5.055\cdot 10^{-8}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Total deflection due to seat contact force (per lbf/in.):

$$y_w := y_{bw} + y_{sw} + y_{cmpr} \qquad y_w = -9.597\cdot 10^{-7}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Seat Contact Force for which deflection is equal to previously calculated deflection from pressure forces:

$$F_s := 2\cdot\pi\cdot a\cdot\frac{y_q}{y_w} \qquad F_s = 20750.5\cdot lbf$$

UNSEATING FORCES

$F_{packing}$ is included in measured static pullout Force

$$F_{piston} := \frac{\pi}{4}\cdot D_{stem}{}^2\cdot P_{bonnet} \qquad F_{piston} = 2775\cdot lbf$$

$$F_{vert} := \pi\cdot a^2\cdot\sin(\theta)\cdot\left(2\cdot P_{bonnet} - P_{up} - P_{down}\right) \qquad F_{vert} = 6662.4\cdot lbf$$

$$F_{preslock} := 2\cdot F_s\cdot(\mu\cdot\cos(\theta) - \sin(\theta)) \qquad F_{preslock} = 16871\cdot lbf$$

$$F_{total} := -F_{piston} + F_{vert} + F_{preslock} + F_{po} \qquad y_{sw} = +3.079\cdot 10^{-7}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

$$F_{total} = 36167.4\cdot lbf$$

EXAMPLE OF AN ANALYSIS PERFORMED WITH PRESLOK, VERSION 2

The following is an image of the input file plinput2.dat used to run an example problem on version 2 of the PRESLOK analysis program:

1005	380	350	2	4.36	1.25	0.5	5
0.3	27.6E6	1.875	15409	0.496			

The input file corresponds to input values as shown:

Bonnet Pressure:	P_{bonnet} = 1005 psi	
Upstream Pressure:	P_{up} = 380 psi	
Downstream Pressure:	P_{down} = 350 psi	
Disk Thickness:	**t** = 2.00 inches	
Seat Radius:	**a** = 4.36 inches	
Hub Radius:	**b** = 1.25 inches	
Hub Length:	**L** = 0.50 inches	
Seat Angle:	θ = 5 degrees	
Poisson's Ratio:	ν = 0.3	(dimensionless)
Modulus of Elasticity:	**E** = 27,600,000 psi	
Stem Diameter:	D_{stem} = 1.875 inches	
Static Pullout Force:	F_{po} = 15,409 pounds	
Seat to Disk Coefficient of Friction:	μ = 0.496	(dimensionless)

The next five pages contain the output of the PRESLOK program, Version 2, using the above input.

Program PRESLOK, Version 2
Revision 0
December 22, 1995

This Mathcad Program is designed to calculate the estimated opening force under pressure locking scenarios for flex-wedge gate valves using a calculational methodology that accounts for wedge stiffness resisting pressure locking forces. This program was prepared by the Westinghouse Owner's Group based upon the calculational methods developed by Commonwealth Edison.

While this information is presented in good faith and believed to be accurate, the Westinghouse Owner's Group does not guarantee satisfactory results from reliance upon such information. Nothing contained herein is to be construed as a warranty, express or implied, regarding the performance, merchantability, fitness or any other matter with respect to the product, nor as a recommendation to use any product or process in conflict with any patent. The Westinghouse Owner's Group reserves the right, without notice, to alter or improve the methods described herein.

This section of the program reads the thirteen items of input data from the plinput2.dat file.

$i := 0..12$

$input_i := READ(plinput2)$

$P_{bonnet} := input_0 \cdot psi$

$P_{up} := input_1 \cdot psi$

$P_{down} := input_2 \cdot psi$

$t := input_3 \cdot in$

$a := input_4 \cdot in$

$b := input_5 \cdot in$

$Hub_{length} := input_6 \cdot in$

$\theta := input_7 \cdot deg$

$\nu := input_8$

$E := input_9 \cdot psi$

$D_{stem} := input_{10} \cdot in$

$F_{po} := input_{11} \cdot lbf$

$\mu := input_{12}$

Program PRESLOK, Version 2

INPUTS:

Bonnet Pressure	$P_{bonnet} = 1005 \cdot psi$
Upstream Pressure	$P_{up} = 380 \cdot psi$
Downstream Pressure	$P_{down} = 350 \cdot psi$
Disk Thickness (taken at centerline of the hub vertically)	$t = 2 \cdot in$
Seat Radius (corresponding to mean seat diameter)	$a = 4.36 \cdot in$
Hub Radius (taken at plane of symmetry, perpendicular to the hub, radius of circle of equivalent area for non-circular hubs)	$b = 1.25 \cdot in$
Seat Angle	$\theta = 5 \cdot deg$
Poisson's Ratio (disk material at temperature)	$\nu = 0.3$
Modulus of Elasticity (disk material at temperature)	$E = 2.76 \cdot 10^{7} \cdot psi$
Static Pullout Force (measured value from diagnostic test)	$F_{po} = 15409 \cdot lbf$
Coefficient of Friction between disk and seat:	$\mu = 0.496$
Stem Diameter	$D_{stem} = 1.875 \cdot in$
Hub Length (from inside face of disk to inside face of disk)	$Hub_{length} = 0.5 \cdot in$

Program PRESLOK, Version 2

PRESSURE FORCE CALCULATIONS

Average DP across disks:

$$DPavg := P_{bonnet} - \frac{P_{up} + P_{down}}{2}$$ $DPavg = 640 \cdot psi$

Disk Stiffness Constants

$$D := \frac{E \cdot (t)^3}{12 \cdot \left(1 - \nu^2\right)}$$ $D = 2.022 \cdot 10^7 \cdot lbf \cdot in$

$$G := \frac{E}{2 \cdot (1 + \nu)}$$ $G = 1.062 \cdot 10^7 \cdot psi$

Geometry Factors:

$$C_2 := \frac{1}{4} \cdot \left[1 - \left(\frac{b}{a}\right)^2 \cdot \left(1 + 2 \cdot \ln\left(\frac{a}{b}\right)\right)\right]$$ $C_2 = 0.1781$

$$C_3 := \frac{b}{4 \cdot a} \cdot \left[\left[\left(\frac{b}{a}\right)^2 + 1\right] \cdot \ln\left(\frac{a}{b}\right) + \left(\frac{b}{a}\right)^2 - 1\right]$$ $C_3 = 0.0311$

$$C_8 := \frac{1}{2} \cdot \left[1 + \nu + (1 - \nu) \cdot \left(\frac{b}{a}\right)^2\right]$$ $C_8 = 0.6788$

$$C_9 := \frac{b}{a} \cdot \left[\frac{1 + \nu}{2} \cdot \ln\left(\frac{a}{b}\right) + \frac{1 - \nu}{4} \cdot \left[1 - \left(\frac{b}{a}\right)^2\right]\right]$$ $C_9 = 0.2789$

$$L_3 := \frac{a}{4 \cdot a} \cdot \left[\left[\left(\frac{a}{a}\right)^2 + 1\right] \cdot \ln\left(\frac{a}{a}\right) + \left(\frac{a}{a}\right)^2 - 1\right]$$ $L_3 = 0$

$$L_9 := \frac{a}{a} \cdot \left[\frac{1 + \nu}{2} \cdot \ln\left(\frac{a}{a}\right) + \frac{1 - \nu}{4} \cdot \left[1 - \left(\frac{a}{a}\right)^2\right]\right]$$ $L_9 = 0$

Program PRESLOK, Version 2

Geometry Factors: (continued)

$$L_{11} := \frac{1}{64}\cdot\left[1+4\cdot\left(\frac{b}{a}\right)^2-5\cdot\left(\frac{b}{a}\right)^4-4\cdot\left(\frac{b}{a}\right)^2\cdot\left[2+\left(\frac{b}{a}\right)^2\right]\cdot\ln\left(\frac{a}{b}\right)\right] \qquad L_{11}=0.0069$$

$$L_{17} := \frac{1}{4}\cdot\left[1-\frac{1-\nu}{4}\cdot\left[1-\left(\frac{b}{a}\right)^4\right]-\left(\frac{b}{a}\right)^2\cdot\left[1+(1+\nu)\cdot\ln\left(\frac{a}{b}\right)\right]\right] \qquad L_{17}=0.1526$$

Moment

$$M_{rb} := \frac{-DPavg\cdot a^2}{C_8}\cdot\left[\frac{C_9}{2\cdot a\cdot b}\cdot\left(a^2-b^2\right)-L_{17}\right] \qquad M_{rb}=-5265\cdot lbf$$

$$Q_b := \frac{DPavg}{2\cdot b}\cdot\left(a^2-b^2\right) \qquad Q_b=4466.5\cdot\frac{lbf}{in}$$

Deflection due to pressure and bending:

$$y_{bq} := M_{rb}\cdot\frac{a^2}{D}\cdot C_2+Q_b\cdot\frac{a^3}{D}\cdot C_3-\frac{DPavg\cdot a^4}{D}\cdot L_{11} \qquad y_{bq}=-3.9041\cdot 10^{-4}\cdot in$$

Deflection due to pressure and shear stress:

$$K_{sa} := -0.3\cdot\left[2\cdot\ln\left(\frac{a}{b}\right)-1+\left(\frac{b}{a}\right)^2\right] \qquad K_{sa}=-0.4743$$

$$y_{sq} := \frac{K_{sa}\cdot DPavg\cdot a^2}{t\cdot G} \qquad y_{sq}=-2.7177\cdot 10^{-4}\cdot in$$

Deflection due to hub stretch:

$$P_{force} := \pi\cdot\left(a^2-b^2\right)\cdot DPavg$$

$$y_{stretch} := \frac{P_{force}}{\pi\cdot b^2}\cdot\frac{Hub_{length}}{(2\cdot E)} \qquad y_{stretch}=6.4731\cdot 10^{-5}\cdot in$$

Total Deflection due to pressure forces:

$$y_q := y_{bq}+y_{sq}-y_{stretch} \qquad y_q=-7.2691\cdot 10^{-4}\cdot in$$

Deflection due to seat contact force and shear stress (per lbf/in.):

$$y_{sw} := -\left[\frac{1.2\cdot\left(\frac{a}{a}\right)\cdot\ln\left(\frac{a}{b}\right)\cdot a}{t\cdot G}\right] \qquad y_{sw} = -3.079\cdot10^{-7}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Deflection due to seat contact force and bending (per lbf/in.):

$$y_{bw} := -\left(\frac{a^3}{D}\right)\cdot\left[\left(\frac{C_2}{C_8}\right)\cdot\left[\left(\frac{a\cdot C_9}{b}\right)-L_9\right]-\left[\left(\frac{a}{b}\right)\cdot C_3\right]+L_3\right] \qquad y_{bw} = -6.012\cdot10^{-7}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Deflection due to hub compression:

$$y_{cmpr} := -\left(\frac{2\cdot\pi\cdot a}{\pi\cdot b^2}\cdot\frac{Hub}{2\cdot E}\frac{length}{}\right) \qquad y_{cmpr} = -5.055\cdot10^{-8}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Total deflection due to seat contact force (per lbf/in.):

$$y_w := y_{bw} + y_{sw} + y_{cmpr} \qquad y_w = -9.597\cdot10^{-7}\cdot\frac{in}{\left(\frac{lbf}{in}\right)}$$

Seat Contact Force for which deflection is equal to previously calculated deflection from pressure forces:

$$F_s := 2\cdot\pi\cdot a\cdot\frac{y_q}{y_w} \qquad F_s = 20750.5\cdot lbf$$

UNSEATING FORCES

$F_{packing}$ is included in measured static pullout Force

$$F_{piston} := \frac{\pi}{4}\cdot D_{stem}{}^2\cdot P_{bonnet} \qquad F_{piston} = 2775\cdot lbf$$

$$F_{vert} := \pi\cdot a^2\cdot\sin(\theta)\cdot\left(2\cdot P_{bonnet} - P_{up} - P_{down}\right) \qquad F_{vert} = 6662.4\cdot lbf$$

$$F_{preslock} := 2\cdot F_s\cdot(\mu\cdot\cos(\theta) - \sin(\theta)) \qquad F_{preslock} = 16889.1\cdot lbf$$

$$F_{total} := -F_{piston} + F_{vert} + F_{preslock} + F_{po} \qquad F_{po} = 15409\cdot lbf$$

$$F_{total} = 36185.5\cdot lbf$$

REFERENCES

1. Bunte, Brian, "ComEd Pressure Locking Methodology and Test Program," presented at the NRC Region 3 Workshop on Pressure Locking and Thermal Binding, November 7, 1995.

2. Roark, Raymond J., and Young, Warren C., *Formulas for Stress and Strain, Fifth Edition*, McGraw-Hill Book Company, 1975.

3. Liberal use has also been made of a draft of a report being prepared by Mr. Brian Bunte of Commonwealth Edison Company, tentatively titled "Pressure Locking /Thermal Binding Report."