Report 9664I
November 27, 1996

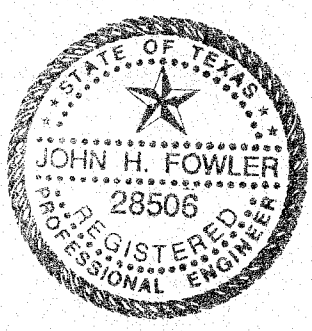
ON-LINE RESOURCES

Mechanical Engineering Consulting Services and Software

Analysis of 4-1/16"- 5000 psi API 6B Flange with External Bending and Tension Loads

for Pikotek Inc.

Lakewood, CO



ABSTRACT:

An API 6B 4-1/16" 5000 psi flange was analyzed based on the use of a Pikotek VCS gasket, with external bending moments and tension applied in addition to the internal pressure. Stresses were found to be within API 6A allowable limits. A maximum bending moment of 50,746 ft-lbf or 68,800 N-m can be applied to the flange when preloaded to API recomended torques.

BY John H. Fowler, PE DATE 11/27/96

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BACKGROUND

The flanges in question are API Type 6B 4-1/16" 5000 psi flanges, with the folowing combination of pressure, tension, and bending moments applied:

Pressure:	143.9 bar	2087 psi
Bending:	13754 N-m	10145 ft-lbf
Tension:	4980 N	1120 lbf

The materials of the flanges and studs are:

Flange A	ASTM A182-F51	90,000 psi min. tensile	65,000 psi min. yield
Flange B	API 60K	85,000 psi min. tensile	60,000 psi min. yield
Studs	ASTM A193-B7	125,000 psi min. tensile	105,000 psi min. yield

Design pressure is 5000 psi. Operating temperature is 77° C (170° F).

METHODS AND ASSUMPTIONS

The flanges were analyzed based on the methods of the M. W. Kellogg publication, Design of Piping Systems (see Attachment B). The method in this reference involves calculating an equivalent pressure which takes into account the effect of the tension and bending moment on the flange, then analyzing the flange using the standard ASME method (ASME Code, Section VIII, Division 1, Appendix 2).

The ASME flange calculations were performed using the BASIC FLANGE computer program. This program permits the use of API 6A allowable stresses as an alternative to the more conservative ASME allowables. API allowables were used for the analysis. Flange allowable stresses were based on the API 60K material, which is slightly weaker than the mating Duplex Stainless Steel flange.

In addition, the load on the bolting was calculated based on the equivalent tension method, using the bolt circle diameter as the effective diameter of the bolt forces. This method assumes the bolt loading is distributed uniformly around the bolt circle rather than concentrated at the bolt centers, but is fairly accurate for eight or more bolts. This calculation assumed that the bolts were initially tensioned to the values recommended in API Specification 6A Appendix D.

RESULTS

Attachment A shows the calculation of the limiting moment based on bolt stresses. This moment was higher than the moment calculated based on flange strength; therefore, the bolting is not the limiting element with respect to bending. Amaximum moment of 50,746 ft-lbf (68,800 N-m) can be applied to the flange bolting.

The equivalent pressure for the pressure plus tension plus bending analysis is calculated in Attachment B. The combined effect of the loading on the flange body is equivalent to an internal pressure of 5869 psi.

The flange was analyzed for both the design pressure case of 5000 psi (run 9664IA.DAT) and 5869 psi (run 9664IB.DAT). The highest stress at working pressure, relative to the allowable stress, was the flange tangential stress. These stresses for the two cases are shown on Attachment C.

Attachment C then calculates the highest equivalent pressure that this flange could withstand before exceeding the allowable stress. The pressure and tension loading is then decucted from this total, leaving

that portion of the equivalent pressure which represents the bending load. Converting this to a bending moment yielded a maximum bending moment of 36153 ft-lbf or 49015 N-m.

CONCLUSIONS

The flange/gasket system will withstand the loading required by this application while keeping stresses well within API 6A limits. The maximum bending moment that can be applied to this flange is 36153 ft-lbf or 49015 N-m.

Flange Bending Moment Effect on Bolt Loading - A193-B7 Studs

Input Data

4-1/16" - 5000 API 6B Flange

Bolt Root Area	$A_b := 0.929 \cdot in^2$	1-1/4" - 8UN-2
Number of Bolts	$N_b := 8$	
Bolt Circle Diameter	$D := 9.50 \cdot in$	
Bolt Yield Strength	$Y := 105000 \cdot psi$	
Axial Tension	$T := 1120 \cdot lbf$	

Calculated Data

Total Bolt Load Limit	$F_{max} := 0.83 \cdot A_b \cdot N_b \cdot Y$	$F_{max} = 647699 \cdot lbf$
Preload Force	$F_p := 0.5 \cdot A_b \cdot N_b \cdot Y$	$F_p = 390180 \cdot lbf$
Available Force for Bending at 0 psi	$F_b := F_{max} - F_p - T$	$F_b = 256399 \cdot lbf$
Maximum Bending Moment	$M := \frac{F_b \cdot D}{4}$	$M = 608947 \cdot in \cdot lbf$ $M = 50746 \cdot ft \cdot lbf$ $M = 68800 \cdot newton \cdot m$

Flange Bending and Tension Capacity by the Equivalent Pressure Method

Reference: Design of Piping Systems, M. W. Kellogg Co., John Wiley and Sons, New York, 1956, p. 78

Units

$bar := 10^5 \cdot \frac{newton}{m^2}$

Input Data

Operating Pressure	$P_w := 143.9 \cdot bar$	$P_w = 2087 \cdot psi$
G Diameter	$G := 5.496 \cdot in$	
Bending Moment	$M := 13754 \cdot newton \cdot m$	$M = 10145 \cdot ft \cdot lbf$
Axial Tension	$T := 4980 \cdot newton$	$T = 1120 \cdot lbf$

Calculated Data

Equivalent Pressure	$P_e := \frac{16 \cdot M}{\pi \cdot G^3} + \frac{4 \cdot T}{\pi \cdot G^2}$	$P_e = 3782 \cdot psi$
Total Pressure	$P := P_w + P_e$	$P = 5869 \cdot psi$
		$P = 404.6 \cdot bar$

Determination of Maximum Allowable Bending Moment

Input Data

Rated Pressure	$P_0 := 5000 \cdot psi$
Operating Conditions Equivalent Pressure	$P_1 := 5869 \cdot psi$
Stress at P_0	$S_0 := 12948 \cdot psi$
Stress at P_1	$S_1 := 15199 \cdot psi$
Allowable Stress	$S_m := 40000 \cdot psi$
Operating Moment	$M := 10145 \cdot ft \cdot lbf$
Operating Force	$T := 1120 \cdot lbf$
Operating Pressure	$P_w := 2087 \cdot psi$
G Diameter	$G := 5.496 \cdot in$

Calculated Data

Max. Equivalent Pressure	$P_{max} := P_0 + \frac{S_m - S_0}{S_1 - S_0} \cdot (P_1 - P_0)$	$P_{max} = 15443 \cdot psi$
Portion Due to Pressure and Applied Tension	$P_{tare} := \frac{4 \cdot T}{\pi \cdot G^2} + P_w$	$P_{tare} = 2134 \cdot psi$
Portion available for bending moment	$P_b := P_{max} - P_{tare}$	$P_b = 13309 \cdot psi$
Bending Moment	$M := \frac{\pi \cdot G^3 \cdot P_b}{16}$	$M = 36153 \cdot ft \cdot lbf$ $M = 49015 \cdot newton \cdot m$

BASIC FLANGE FLANGE ANALYSIS PROGRAM RESULTS

The methods used in calculating the flange stresses, as well as much of the nomenclature, are found in the ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, Appendix 2. All units in this report are in the inch/pound system.

RUN DATE : 11-27-1996

Title : API Type 6B 4-1/16 - 5000 psi Flange

For : Pikotek

Program Option 1 : 1 -- W is set to 0.5 (Am+Ab) Sa (ASME Default)
Program Option 2 : 2 -- API 6A/16A Allowable Stresses
Program Option 3 : 1 -- API 6A Test Pressure Allowables

Analyzed by John H. Thorton, PE Date 11/27/96

Checked by _____ Date _____

INPUT DATA

Data were last saved on 11-27-1996 11:03:59

1.	Flange Bore	'B' [in]	=	4.0600
2.	Flange OD	'A' [in]	=	12.2500
3.	Bolt circle	'C' [in]	=	9.5000
4.	Bolt Nominal Diameter	'D' [in]	=	1.2500
5.	Number of Bolts	'n'	=	8
6.	Flange Thickness	't' [in]	=	2.1200
7.	Hub Length	'h' [in]	=	2.7500
8.	Hub major diameter	'x1' [in]	=	6.3800
9.	Hub minor diameter	'x2' [in]	=	4.5000
10.	Hub Major Thickness	'g1 '[in]	=	1.1600
11.	Hub Minor Thickness	'go' [in]	=	0.2200
12.	Gasket Diameter	'G' [in]	=	5.4960
13.	Gasket effective width	'bo' [in]	=	0.4810
14.	Gskt Matl # = 4 -- Pikotek VCS			
15.	Flange Material File	= API-60K		
17.	Bolt Material File	= A193-B7		
18.	Operating Temperature	'TOp' [°F]	=	200
19.	Design Working Pressure	'P' [psi]	=	5,000
20.	Hydrostatic TEST Pressure	'TP' [psi]	=	7,500
21.	Flange Young's Modulus	'E' [psi]	=	30,000,000
22.	Flange type: <L>ap, <I>ntegral, 6B<X> = I -- Integral			
25.	Company Name = Pikotek			
26.	Report Title = API Type 6B 4-1/16 - 5000 psi Flange			

BASIC FLANGE Version 1.03 - Dec. 1996

C A L C U L A T I O N R E S U L T S

********** FLANGE FACTORS **********

Factor ho	=	0.945093
Factor A	=	4.272727
Factor C	=	3,131.2373
Factor h/ho	=	2.909768
Factor f	=	1.000000; was -0.143535
B sub 1	=	5.220000
Factor F	=	0.454119
Factor V	=	0.013224
Factor K	=	3.01724138
Factor T	=	1.20139407
Factor U	=	2.04210524
Factor Y	=	1.85832012
Factor Z	=	1.24679946

Gasket factor	m	=	0.0000
Min Design Seating Stress	y	=	12,500
Basic Gasket Seating Width	bo	=	0.4810
Effec. Gasket Seating Width	b	=	0.3468

Factor d	=	7.0640
Factor e	=	0.480502
Factor L	=	3.029099

****

********** MOMENT ARMS **********

Moment arm HD	=	2.1400 in
Moment arm HG	=	2.0020 in
Moment arm HT	=	2.3610 in

****
********** FLANGE AND BOLTING MATERIALS **********
FLANGE MATERIAL: API-60K
DESCRIPTION: API 60K Alloy Steel
BOLTING MATERIAL: A193-B7
DESCRIPTION: A193 Grade B7 High Strength Alloy Steel Bolting Ma

CACULATIONS BASED ON [W O R K I N G P R E S S U R E]

WORKING PRESSURE	P	=	5,000	TEMPERATURE 200 deg F
ALLOW. BOLT STRESS	Sa	=	52,500	
ALLOW. FLANGE STRESS	Sn	=	40,000	

********** F L A N G E F O R C E S **********

TOTAL HYDRO FORCE	H	=	118,619	lb
HYDRO END FORCE	HD	=	64,731	lb
DIFFERENCE H-HD	HT	=	53,888	lb
GASKET RETAIN'G LOAD	HP	=	0	lb

********** B O L T L O A D S **********

MIN. OPERATING BOLT LOAD	Wm1	=	118,619
MIN. GASKET SEATING BOLT LOAD	Wm2	=	74,843
REQ'D BOLT AREA FOR OPERATING	Am1	=	2.259404
REQ'D GASKET SEATING BOLT AREA.	Am2	=	1.425574
MINIMUM REQUIRED BOLT AREA	Am	=	2.259404
ACTUAL BOLT AREA	Ab	=	7.997637

------- NUMBER OF BOLTS AND SIZE ARE OK -------

***** FLANGE MOMENTS BASED ON OPERATING CONDITIONS *****

FLANGE BOLT LOAD	W	=	118,619
GASKET LOAD	HG	=	0
MOMENT OF HD	MD	=	138,524
MOMENT OF HG	MG	=	0
MOMENT OF HT	MT	=	127,229
TOTAL MOMENT	Mo	=	265,753

***** FLANGE STRESSES BASED ON OPERATING CONDITIONS ******

HUB LONGITUDINAL STRESS	SH	=	12,490	VS	60,000	----- OK -----
FLANGE RADIAL STRESS	SR	=	11,322	VS	40,000	----- OK -----
FLANGE TANGENTIAL STRESS	ST	=	12,948	VS	40,000	----- OK -----
[SH+SR]/2		=	11,906	VS	40,000	----- OK -----
[SH+ST]/2		=	12,719	VS	40,000	----- OK -----

```
***** ALLOWABLE STRESSES FOR GASKET SEATING CONDITION *****
ALLOW. BOLT STRESS     Sa =      52,500
ALLOW. FLANGE STRESS   Sn =      40,000

****** FLANGE MOMENTS BASED ON GASKET SEATING LOAD ******
FLANGE BOLT LOAD       W  =     269,247
TOTAL FLANGE MOMENT    Mo =     539,033

****** FLANGE STRESSES BASED ON GASKET SEATING LOAD ******
HUB LONGITUDINAL STRESS    SH =  25,335 VS  60,000 ----- OK -----
FLANGE RADIAL STRESS       SR =  22,965 VS  40,000 ----- OK -----
FLANGE TANGENTIAL STRESS   ST =  26,263 VS  40,000 ----- OK -----
[SH+SR]/2                     =  24,150 VS  40,000 ----- OK -----
[SH+ST]/2                     =  25,799 VS  40,000 ----- OK -----
```

CACULATIONS BASED ON [T E S T P R E S S U R E]

TEST PRESSURE		TP =	7,500
ALLOW. BOLT STRESS AT TEST PRESS.		Sa =	87,150
ALLOW. FLANGE STRESS AT TEST PRESS.		Sn =	49,800

********** F L A N G E F O R C E S **********

TOTAL HYDRO FORCE	H =	177,928	lb
HYDRO END FORCE	HD =	97,096	lb
DIFFERENCE H-HD	HT =	80,832	lb
GASKET RETAIN'G LOAD	HP =	0	lb

********** B O L T L O A D S **********

MIN. TEST PRESSURE BOLT LOAD	Wm1 =	177,928	
MINIMUM REQUIRED BOLT AREA	Am =	2.041630	
ACTUAL BOLT AREA	Ab =	7.997637	

------- NUMBER OF BOLTS AND SIZE ARE OK -------

***** FLANGE MOMENTS BASED ON TEST CONDITIONS *****

FLANGE BOLT LOAD	W =	177,928	
GASKET LOAD	HG =	0	
MOMENT OF HD	MD =	207,786	
MOMENT OF HG	MG =	0	
MOMENT OF HT	MT =	190,844	
TOTAL MOMENT	Mo =	398,630	

***** FLANGE STRESSES BASED ON TEST CONDITIONS ******

HUB LONGITUDINAL STRESS	SH =	18,736	VS	74,700	----- OK -----
FLANGE RADIAL STRESS	SR =	16,983	VS	49,800	----- OK -----
FLANGE TANGENTIAL STRESS	ST =	19,422	VS	49,800	----- OK -----
[SH+SR]/2	=	17,859	VS	49,800	----- OK -----
[SH+ST]/2	=	19,079	VS	49,800	----- OK -----

BASIC FLANGE FLANGE ANALYSIS PROGRAM RESULTS

The methods used in calculating the flange stresses, as well as much of the nomenclature, are found in the ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, Appendix 2. All units in this report are in the inch/pound system.

RUN DATE : 11-27-1996

Title : API Type 6B 4-1/16 - 5000 psi Flange

For : Pikotek

Program Option 1 : 1 -- W is set to 0.5 (Am+Ab) Sa (ASME Default)
Program Option 2 : 2 -- API 6A/16A Allowable Stresses
Program Option 3 : 1 -- API 6A Test Pressure Allowables

Analyzed by John H. Thomas, PE Date 11/27/96

Checked by _____ Date _____

INPUT DATA

Data were last saved on 11-27-1996 11:07:56

1.	Flange Bore	'B'	[in]	=	4.0600
2.	Flange OD	'A'	[in]	=	12.2500
3.	Bolt circle	'C'	[in]	=	9.5000
4.	Bolt Nominal Diameter	'D'	[in]	=	1.2500
5.	Number of Bolts	'n'		=	8
6.	Flange Thickness	't'	[in]	=	2.1200
7.	Hub Length	'h'	[in]	=	2.7500
8.	Hub major diameter	'x1'	[in]	=	6.3800
9.	Hub minor diameter	'x2'	[in]	=	4.5000
10.	Hub Major Thickness	'g1 '	[in]	=	1.1600
11.	Hub Minor Thickness	'go'	[in]	=	0.2200
12.	Gasket Diameter	'G'	[in]	=	5.4960
13.	Gasket effective width	'bo'	[in]	=	0.4810
14.	Gskt Matl # = 4 -- Pikotek VCS				
15.	Flange Material File	= API-60K			
17.	Bolt Material File	= A193-B7			
18.	Operating Temperature	'TOp'	[°F]	=	200
19.	Design Working Pressure	'P'	[psi]	=	5,869
20.	Hydrostatic TEST Pressure	'TP'	[psi]	=	7,500
21.	Flange Young's Modulus	'E'	[psi]	=	30,000,000
22.	Flange type: <L>ap, <I>ntegral, 6B<X> = I -- Integral				
25.	Company Name = Pikotek				
26.	Report Title = API Type 6B 4-1/16 - 5000 psi Flange				

BASIC FLANGE Version 1.03 - Dec. 1996

C A L C U L A T I O N R E S U L T S

********** FLANGE FACTORS **********

```
Factor ho    =   0.945093
Factor A     =   4.272727
Factor C     =   3,131.2373
Factor h/ho  =   2.909768
Factor f     =   1.000000; was  -0.143535
B sub 1      =   5.220000
Factor F     =   0.454119
Factor V     =   0.013224
Factor K     =   3.01724138
Factor T     =   1.20139407
Factor U     =   2.04210524
Factor Y     =   1.85832012
Factor Z     =   1.24679946

Gasket factor                m  =   0.0000
Min Design Seating Stress    y  =   12,500
Basic  Gasket Seating Width  bo =   0.4810
Effec. Gasket Seating Width  b  =   0.3468

Factor d     =     7.0640
Factor e     =   0.480502
Factor L     =   3.029099
```

****

********** MOMENT ARMS **********

```
Moment arm HD =   2.1400 in
Moment arm HG =   2.0020 in
Moment arm HT =   2.3610 in
```

****

********** FLANGE AND BOLTING MATERIALS **********

```
FLANGE MATERIAL:  API-60K
DESCRIPTION: API 60K Alloy Steel
BOLTING MATERIAL: A193-B7
DESCRIPTION: A193 Grade B7 High Strength Alloy Steel Bolting Ma
```

CACULATIONS BASED ON [W O R K I N G P R E S S U R E]

WORKING PRESSURE	P =	5,869	TEMPERATURE 200 deg F
ALLOW. BOLT STRESS	Sa =	52,500	
ALLOW. FLANGE STRESS	Sn =	40,000	

********** F L A N G E F O R C E S **********

TOTAL HYDRO FORCE	H =	139,235	lb
HYDRO END FORCE	HD =	75,981	lb
DIFFERENCE H-HD	HT =	63,253	lb
GASKET RETAIN'G LOAD	HP =	0	lb

********** B O L T L O A D S **********

MIN. OPERATING BOLT LOAD	Wm1 =	139,235
MIN. GASKET SEATING BOLT LOAD	Wm2 =	74,843
REQ'D BOLT AREA FOR OPERATING	Am1 =	2.652089
REQ'D GASKET SEATING BOLT AREA.	Am2 =	1.425574
MINIMUM REQUIRED BOLT AREA	Am =	2.652089
ACTUAL BOLT AREA	Ab =	7.997637

------- NUMBER OF BOLTS AND SIZE ARE OK -------

***** FLANGE MOMENTS BASED ON OPERATING CONDITIONS *****

FLANGE BOLT LOAD	W =	139,235	
GASKET LOAD	HG =	0	
MOMENT OF HD	MD =	162,600	
MOMENT OF HG	MG =	0	
MOMENT OF HT	MT =	149,341	
TOTAL MOMENT	Mo =	311,941	

***** FLANGE STRESSES BASED ON OPERATING CONDITIONS ******

HUB LONGITUDINAL STRESS	SH =	14,661	VS	60,000	----- OK -----
FLANGE RADIAL STRESS	SR =	13,290	VS	40,000	----- OK -----
FLANGE TANGENTIAL STRESS	ST =	15,199	VS	40,000	----- OK -----
[SH+SR]/2	=	13,976	VS	40,000	----- OK -----
[SH+ST]/2	=	14,930	VS	40,000	----- OK -----

***** ALLOWABLE STRESSES FOR GASKET SEATING CONDITION *****

ALLOW. BOLT STRESS	Sa =	52,500	
ALLOW. FLANGE STRESS	Sn =	40,000	

****** FLANGE MOMENTS BASED ON GASKET SEATING LOAD ******

FLANGE BOLT LOAD	W =	279,555	
TOTAL FLANGE MOMENT	Mo =	559,670	

****** FLANGE STRESSES BASED ON GASKET SEATING LOAD ******

HUB LONGITUDINAL STRESS	SH =	26,305	VS	60,000	----- OK -----
FLANGE RADIAL STRESS	SR =	23,844	VS	40,000	----- OK -----
FLANGE TANGENTIAL STRESS	ST =	27,269	VS	40,000	----- OK -----
[SH+SR]/2	=	25,074	VS	40,000	----- OK -----
[SH+ST]/2	=	26,787	VS	40,000	----- OK -----

CACULATIONS BASED ON [T E S T P R E S S U R E]

TEST PRESSURE		TP =	7,500
ALLOW. BOLT STRESS AT TEST PRESS.		Sa =	87,150
ALLOW. FLANGE STRESS AT TEST PRESS.		Sn =	49,800
********** F L A N G E	F O R C E S	**********	
TOTAL HYDRO FORCE	H =	177,928	lb
HYDRO END FORCE	HD =	97,096	lb
DIFFERENCE H-HD	HT =	80,832	lb
GASKET RETAIN'G LOAD	HP =	0	lb

********** B O L T	L O A D S	**********
MIN. TEST PRESSURE BOLT LOAD	Wm1 =	177,928
MINIMUM REQUIRED BOLT AREA	Am =	2.041630
ACTUAL BOLT AREA	Ab =	7.997637

------- NUMBER OF BOLTS AND SIZE ARE OK -------

***** FLANGE MOMENTS BASED ON TEST CONDITIONS *****

FLANGE BOLT LOAD	W =	177,928	
GASKET LOAD	HG =	0	
MOMENT OF HD	MD =	207,786	
MOMENT OF HG	MG =	0	
MOMENT OF HT	MT =	190,844	
TOTAL MOMENT	Mo =	398,630	

***** FLANGE STRESSES BASED ON TEST CONDITIONS ******

HUB LONGITUDINAL STRESS	SH =	18,736	VS	74,700	----- OK -----
FLANGE RADIAL STRESS	SR =	16,983	VS	49,800	----- OK -----
FLANGE TANGENTIAL STRESS	ST =	19,422	VS	49,800	----- OK -----
[SH+SR]/2	=	17,859	VS	49,800	----- OK -----
[SH+ST]/2	=	19,079	VS	49,800	----- OK -----