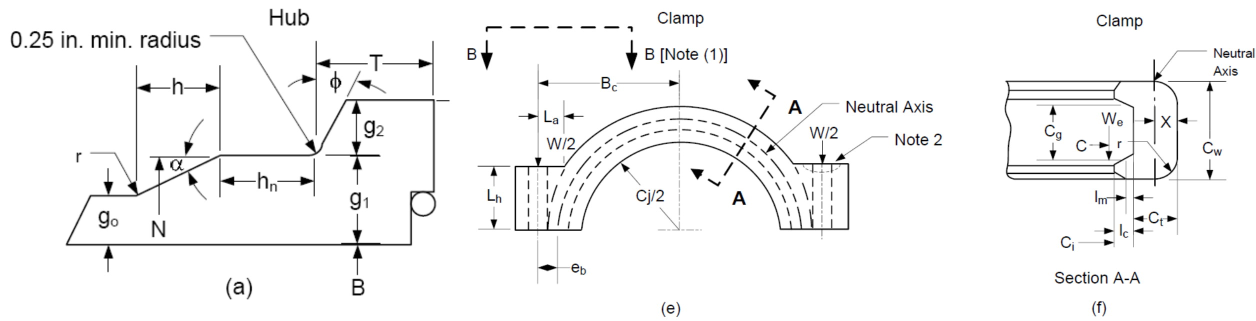
NEXT100 Pressure Vessel Clamp Design **DRAFT** D. Shuman July 18,2011



Sec VIII, div 2 flange design, part 4.17 Clamped Flange Joints

Flange thickness:

inner radius max. allowable pressure

$R_{i\_pv} = 0.57\,\mathrm{m}$ $MAWP_{pv} = 15.4\,\mathrm{bar}$ (gauge pressure)

The flanges and shells will be fabricated from ASME grade 3 CP titanium. Since no titanium bolting is allowed, we use a clamp design, per part 4.17, Clamp may be of Ti grade 3

We will design to use one helicoflex 5mm gasket (smallest size possible) with aluminum facing (softest) loaded for helium leak rate, and one backup O-ring

From sec. VIII div 2, sec 4.7, joints having clamped flanges, with metal-to-metal contact outside of bolt circle and using substantially self-energizing gaskets

4.17.3.4 Hubs and clamps shall not be machined from plate

4.17.4 Design Bolt Loads

a) STEP 1- Design Pressure and Temperature of flange Joint

$P := MAWP_{pv}$ $P = 1.561\,\mathrm{MPa}$ $T_{fl} := 40C$ (100C for bake out but only at vacuum)

b) STEP 2- Select Gasket and determine factors m, y

Helicoflex gasket, 5mm xsec dia. aluminum jacket, from Helicoflex lit.:

Groove width, depth

$G_g := .627\mathrm{cm}$ $F_g := .41\mathrm{cm}$ $Y_1 := 30\dfrac{N}{mm}$ $Y_2 := 220\dfrac{N}{mm}$ (=b*y gasket factors) $P_{u\theta} := 63\mathrm{MPa}$ @20C

c) STEP 3- Determine G, gasket radius

Gasket dia Flange ID Helicoflex gasket mean dia.

$G := 2R_{i\_pv} + G_g + 3\mathrm{mm}$ $G = 1.149\,\mathrm{m}$ $B := 2R_{i\_pv}$ $B = 1.14\,\mathrm{m}$ $D_j := G$

d) STEP 4- Determine Flange Forces for Bolt load Calculation

Force of Pressure on head

$H := .785G^2 \cdot P$ $H = 1.618 \times 10^6\,\mathrm{N}$ (4.17.1)

Minimum Service Load

ASME $H_p := 2\pi \cdot Y_2 \cdot G$

Helicoflex equiv. $H_p := F_m$

$F_m := \pi \cdot D_j \cdot Y_m$

$Y_m := \max\left(Y_1, Y_2 \cdot \frac{P}{P_{u\theta}}\right)$ $Y_m = 30\frac{N}{mm}$ $Y_2 \cdot \frac{P}{P_{u\theta}} = 5.451\frac{N}{mm}$ $e_2 := 0.9mm$

however, per note 1 on sec pg. 5 of helicoflex master catalogue, metric

$\frac{P \cdot D_j}{Y_m} = 59.794$ this is >32 so we use F_j, in stead of F_m

$F_j := \pi D_j \cdot Y_2$

$H_p := F_j$ $H_p = 7.943 \times 10^5 N$ (4.17.4)

Force of Gasket on head (4.17.5)

$H_m := \pi G \cdot Y_2$ $H_m := F_j$

Can we close joint with vacuum? $\frac{H_m}{.785G^2 \cdot 1bar} = 7.559$ no, clamp must compress helicoflex gasket

e) STEP 5- Determine Design Bolt load for Operating Condition

flange angle

$\phi := 15deg$ we need to provide for gasket compression travel, not too shallow

friction angle

$\mu := atan(.1)$ $\mu = 5.711\,deg$ use Tiodize, Canadize coating, or similar dry lube film over anodize typ. mu values .03-.09

from 4.17.4.3, we have some restrictions concerning friction angle:

$\phi minus\mu := \max(\phi - \mu, 5deg)$ $\phi minus\mu = 9.289\,deg$

$W_o := \frac{2}{\pi}(H + H_p)\tan(\phi minus\mu)$ $W_o = 2.512 \times 10^5 N$ (4.17.6)

f) STEP 6- Determine minimum required total bolt load for gasket seating and assembly

$\mu_{min} := \max(\mu, 5deg)$ $\mu_{min} = 5.711\,deg$ (also from 4.17.4.3)

$W_{g1} := \frac{2}{\pi}(H_m)\tan(\phi + \mu_{min})$ $W_{g1} = 1.912 \times 10^5 N$ (4.17.7)

$W_{g2} := \frac{2}{\pi} \cdot (H + H_p) \cdot \tan(\phi + \mu_{min})$ $W_{g2} = 5.807 \times 10^5 N$ (4.17.8)

g) STEP 7- Determine the design bolt load for gasket seating and assembly

$S_{bg} := 37000psi$ (use inconel718bolt $S_{bo} := S_{bg}$

$A_m := \max\left(\frac{W_o}{2S_{bo}}, \frac{W_{g1}}{2S_{bg}}, \frac{W_{g2}}{2S_{bg}}\right)$ $A_m = 11.382\,cm^2$ (4.17.10)

$A_b := 12cm^2$

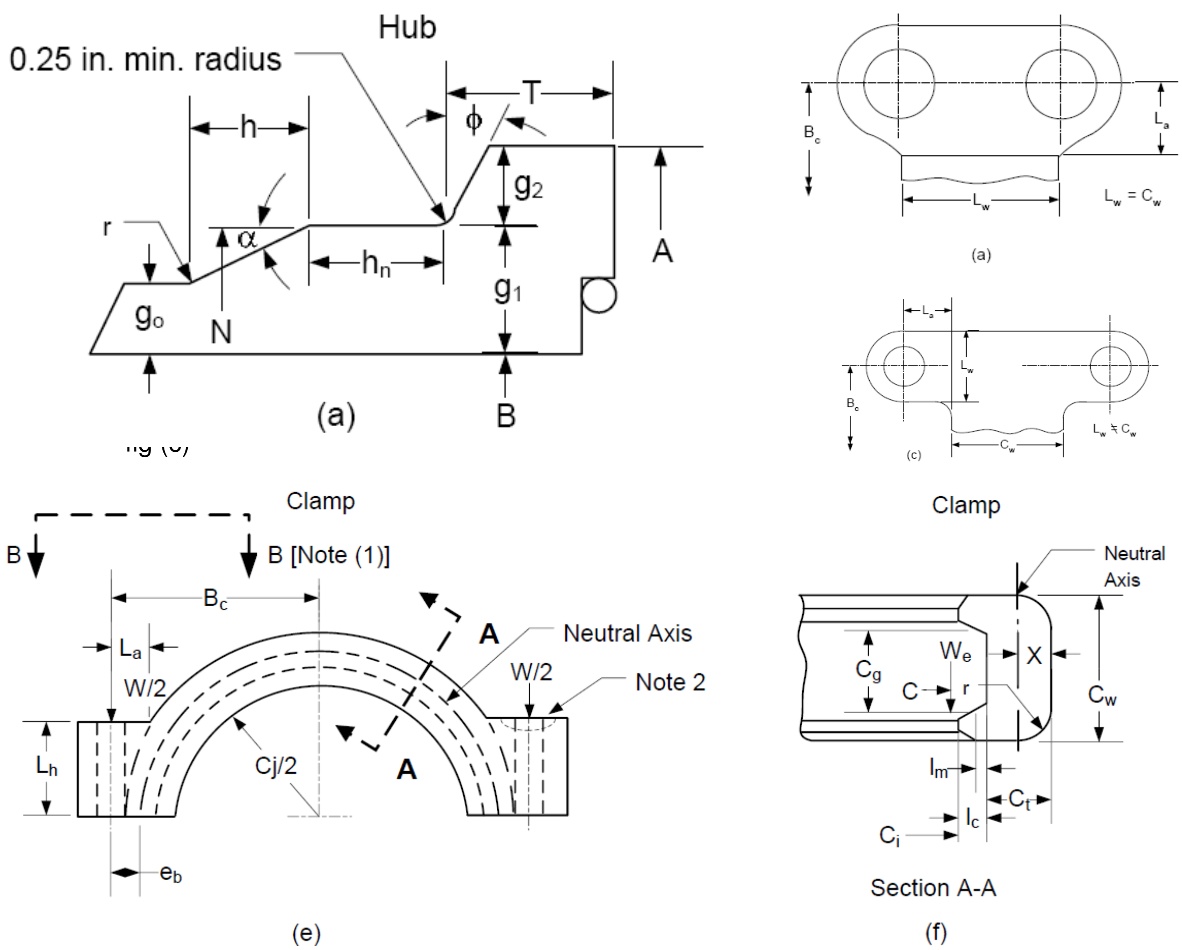
$$W_g := \frac{(A_m + A_b)}{2} \cdot S_{bg} \qquad W_g = 2.982 \times 10^5 \, N \tag{4.17.9}$$

bolt diameter (2 bolts on each end):

$$d_b := \sqrt{\frac{4}{\pi} \frac{A_b}{4}} \qquad d_b = 19.544 \, mm$$

4.17.5 Flange And Clamp Design Procedure

b) STEP 2 - Determine initial Flange and clamp geometry; from Figure 4.17.1



c) STEP 3- Determine Design Bolt load for Operating Condition, W_o and the gasket assembly condition W_g from above paragraph 4.17.4.2

$$W_o = 2.512 \times 10^5 \, N \qquad W_g = 2.982 \times 10^5 \, N$$

d) STEP 4- Determine Flange Forces H, H_p, H_m from above paragraph 4.17.4.2.d

$$B = 1.14 \, m$$

$H_D := .785 \cdot B^2 \cdot MAWP_{pv}$ $\quad H_D = 1.592 \times 10^6 N$

$H_G := \dfrac{1.571 W_o}{\tan(\phi + \mu)} - (H + H_p)$ $\quad H_G = -1.369 \times 10^6 N$

$H_T := H - H_D$ $\quad H_T = 2.6 \times 10^4 N$

e) STEP 5- Determine Flange moment for operating condition

$M_o := M_D + M_G + M_T + M_F + M_P + M_R$

First , we define some fixed dimensions

$g_0 := t$ $\quad g_0 = 0.635 cm$

$g_1 := 2g_0$ $\quad g_1 = 1.27 cm$

$N := B + 2g_0$ $\quad N = 115.3 cm$ $\quad h_G := 1cm$???

Then some trial dimensions to iterate on

$g_2 := 2.5g_0$

check, we need enough travel to compress gasket:

$g_2 \cdot \sin(\phi) > 2 \cdot (0.5e_2) = 1$

$A := N + g_2$ $\quad A = 1.169 m$

$T := 2.0cm$

Then define:

$C_i := \dfrac{A + N}{2}$ $\quad C_i = 1.161 m$

$h_2 := T - \dfrac{g_2 \cdot \tan(\phi)}{2}$ $\quad h_2 = 1.787 cm$

$h' := \dfrac{T^2 g_1 + h_2^{\,2} g_2}{2(T \cdot g_1 + h_2 \cdot g_2)}$ $\quad h' = 0.944 cm$ $\quad$ note: h' is h(bar) in ASME manual)

$h_D := \dfrac{2}{\pi}(H + H_p)\tan(\phi - \mu)$ $\quad h_D = 2.512 \times 10^5 N$

then

$C_i = 1.161 m$

$C := \dfrac{A + C_i}{2}$ $\quad C = 1.165 m$

$M_D := \dfrac{H_D \cdot [C - (B + g_1)]}{2}$ $\quad M_D = 9.479 \times 10^3 J$

$$M_G := H_G \cdot h_G \qquad M_G = -1.369 \times 10^4\,J$$

$$M_T := H_T \cdot \left[\frac{C}{2} - \left(\frac{B+G}{4}\right)\right] \qquad M_T = 259.644\,J$$

$$M_F := H_D \cdot \left(\frac{g_1 - g_0}{2}\right) \qquad M_F = 5.056 \times 10^3\,J$$

$$M_P := P \cdot B \cdot T \cdot \pi \cdot \left(\frac{T}{2} - h'\right) \qquad M_P = 62.733\,J$$

$$M_R := 1.57 W_o \cdot \left[h' - T + \frac{(C-N)\cdot \tan(\phi)}{2}\right] \qquad M_R = -3.536 \times 10^3\,J$$

step 6 - Determine flange moment for gasket seating

$$M_g := \frac{.785 \cdot W_g \cdot (C-G)}{\tan(\phi + \mu)} \qquad M_g = 9.497 \times 10^3\,J$$

$$M_o := M_D + M_G + M_T + M_F + M_P + M_R \qquad M_o = -2.366 \times 10^3\,N \cdot m$$

step 7 - Determine hub factors

$$I_h := \frac{g_1 \cdot T^3}{3} + \frac{g_2 \cdot h_2^{\,3}}{3} - (g_2 \cdot h_2 + g_1 \cdot T) h'^2 \qquad I_h = 1.617 \times 10^{-8}\,m^4$$

$$g' := \frac{T \cdot g_1^{\,2} + h_2 \cdot g_2 \cdot (2 \cdot g_1 + g_2)}{2(T \cdot g_1 + h_2 \cdot g_2)} \qquad g' = 0.014\,m$$

$$F_H := 1 + \frac{1.818}{\sqrt{B \cdot g_1}}\left[T - h' + \frac{3.305 I_h}{g_1^{\,2}(0.5B + g')}\right] \qquad F_H = 1.168$$

step 8 - Determine the reaction shear force at the hub neck for operating condition

$$Q_o := \frac{1.818 M_o}{F_H \cdot \sqrt{B \cdot g_1}} \qquad Q_o = -3.061 \times 10^4\,N$$

step 9 - Determine the reaction shear force at the hub neck for gasket seating condition

$$Q_g := \frac{1.818 M_g}{F_H \cdot \sqrt{B \cdot g_1}} \qquad Q_g = 1.228 \times 10^5\,N$$

step 10 - Determine the clamp factors

first trial define clamp dimensions:

$C_t := 3cm$ $\quad C_w := 3T$ $\quad C_w = 6\,cm$ $\quad B_c := 0.5A + 3cm$ $\quad B_c = 0.614\,m$

then define:

$l_c := g_2 \qquad C_g := T - 2g_2 \cdot \sin(\phi) \qquad C_g = 1.178\,\text{cm}$

clamp factors:

$A_1 := (C_w - 2C_t)C_t \qquad A_1 = 0\,\text{cm}^2$

$A_2 := 1.571C_t^{\,2} \qquad A_2 = 14.139\,\text{cm}^2$

$A_3 := (C_w - C_g)l_c \qquad A_3 = 7.655\,\text{cm}^2$

$A_c := A_1 + A_2 + A_3 \qquad A_c = 21.794\,\text{cm}^2$

$$X := \frac{\left(\frac{C_w}{2} - \frac{C_t}{3}\right)\cdot C_t^{\,2} - 0.5\cdot(C_w - C_g)\cdot l_c^{\,2}}{A_c} \qquad X = 0.547\,\text{cm}$$

$$e_b := B_c - \frac{C_i}{2} - l_c - X \qquad e_b = 1.262\,\text{cm}$$

$$I_c := \left(\frac{A_1}{3} + \frac{A_2}{4}\right)C_t^{\,2} + A_3\cdot l_c^{\,2} - A_c\cdot X^2 \qquad I_c = 44.579\,\text{cm}^4$$

step 11 - Determine hub stress correction factor f using eqs in table 4.16.5 $\quad h := 5\text{cm}$

$X_g := \frac{g_1}{g_0} \qquad X_g = 2 \qquad X_h := \frac{h}{h_{or}} \qquad X_h = 0.58 \qquad h_{or} := \sqrt{A\cdot g_0} \qquad h_{or} = 0.086\,\text{m}$

$$f := \max\left[1, \left(\frac{.0927779 - 0.0336633\cdot X_g + 0.964176\cdot X_g^{\,2} + 0.0566286\cdot X_h + 0.347074\cdot X_h^{\,2} - 4.18699\cdot X_h^{\,3}}{1 - 5.96093\cdot 10^{-3}X_g + 1.62904X_h + 3.49329X_h^{\,2} + 1.39052X_h^{\,3}}\right)\right]$$

$f = 1$

We need some clamp dimensions at this point

$l_m := l_c - 0.5(C - C_i \quad l_m = 1.389\,\text{cm} \quad L_h := 30\text{cm} \quad L_a := d_b + C_t\cdot\left(1 - \cos\left(\text{asin}\left(\frac{L_h}{0.5A + C_t}\right)\right)\right) \quad L_w := C_w$

step 12 - Determine flange and clamp stresses of operating and gasket seating conditions using eqns of table 4.17.1:

set flange (h) and clamp (c) material strengths, at both operating (o) and gasket (g)seating temperatures

$S_{ho} := S_{max\_Ti\_g2\_div2} \qquad S_{co} := S_{ho} \qquad S_{hg} := S_{ho} \qquad S_{cg} := S_{co}$

Operating condition:

Flange stresses

$S_{ho} = 143.4\,MPa$

$$S_{1o} := f\cdot\left[\frac{P\cdot B^2}{4g_1\cdot(B+g_1)} + \frac{1.91M_o}{g_1^{\,2}(B+g_1)\,F_H}\right] \qquad S_{1o} = 13.8\,MPa \qquad \boxed{S_{1o} \le 1.5S_{ho} = 1}$$

$$S_{2o} := P\cdot\left(\frac{N^2+B^2}{N^2-B^2}\right) \qquad S_{2o} = 140.9\,MPa \qquad \boxed{S_{2o} \le S_{ho} = 1}$$

$$S_{3o} := \frac{0.75W_o}{T\cdot(B+2g_1)\tan(\phi-\mu)} \qquad S_{3o} = 49.4\,MPa \qquad \boxed{S_{3o} \le 0.8S_{ho} = 1}$$

$$S_{4o} := \frac{0.477Q_o}{g_1\cdot(B+2g_1)} \qquad S_{4o} = -1\,MPa \qquad \boxed{S_{4o} \le 0.8S_{ho} = 1}$$

Clamp stresses

$S_{co} = 143.4\,MPa$

$$S_{5o} := \frac{W_o}{2C\cdot\tan(\phi-\mu)}\cdot\left[\frac{1}{C_t} + \frac{3(C_t+2l_m)}{C_t^{\,2}}\right] \qquad S_{5o} = 149\,MPa \qquad \boxed{S_{5o} \le 1.5S_{co} = 1}$$

$$S_{6o} := \frac{W_o}{2}\cdot\left[\frac{1}{A_c} + \frac{|e_b|\cdot(C_t-X)}{I_c}\right] \qquad S_{6o} = 144.9\,MPa \qquad \boxed{S_{6o} \le 1.5S_{co} = 1}$$

$$S_{7o} := \frac{1.5W_o}{(C_w-C_g)\cdot C\cdot\tan(\phi-\mu)} \qquad S_{7o} = 41\,MPa \qquad \boxed{S_{7o} \le 0.8S_{co} = 1}$$

$$S_{8o} := \frac{3W_o\cdot L_a}{L_w\cdot L_h^{\,2}} \qquad S_{8o} = 3.26\,MPa \qquad \boxed{S_{8o} \le S_{co} = 1}$$

$$S_{9o} := \frac{W_o}{(A-C_i)\cdot C\cdot\tan(\phi-\mu)} \qquad S_{9o} = 166.2\,MPa \qquad \boxed{S_{9o} \le 1.6\min(S_{ho}, S_{co}) = 1}$$

Gasket seating condition:

Flange stresses

$S_{hg} = 143.4\,MPa$

$$S_{1g} := f\cdot\left[\frac{1.91M_g}{g_1^{\,2}(B+g_1)\,F_H}\right] \qquad S_{1g} = 83.5\,MPa \qquad \boxed{S_{1g} \le 1.5S_{hg} = 1}$$

$$S_{2g} := 0MPa \qquad S_{2g} = 0\,MPa \qquad \boxed{S_{2g} \le S_{hg} = 1}$$

$$S_{3g} := \frac{0.75W_g}{T\cdot(B+2g_1)\tan(\phi-\mu)} \qquad S_{3g} = 58.7\,MPa \qquad \boxed{S_{3g} \le 0.8S_{hg} = 1}$$

$$S_{4g} := \frac{0.477 Q_g}{g_1 \cdot (B + 2 g_1)}$$ $S_{4g} = 4\,\mathrm{MPa}$ $\boxed{S_{4g} \le 0.8 S_{hg} = 1}$

Clamp stresses

$S_{cg} = 143.4\,\mathrm{MPa}$

$$S_{5g} := \frac{W_g}{2C \cdot \tan(\phi - \mu)} \cdot \left[\frac{1}{C_t} + \frac{3(C_t + 2l_m)}{C_t^{\,2}}\right]$$ $S_{5g} = 176.9\,\mathrm{MPa}$ $\boxed{S_{5g} \le 1.5 S_{cg} = 1}$

$$S_{6g} := \frac{W_g}{2} \cdot \left[\frac{1}{A_c} + \frac{|e_b| \cdot (C_t - X)}{I_c}\right]$$ $S_{6g} = 172\,\mathrm{MPa}$ $\boxed{S_{6g} \le 1.5 S_{cg} = 1}$

$$S_{7g} := \frac{1.5 W_g}{(C_w - C_g) \cdot C \cdot \tan(\phi - \mu)}$$ $S_{7g} = 48.7\,\mathrm{MPa}$ $\boxed{S_{7g} \le 0.8 S_{cg} = 1}$

$$S_{8g} := \frac{3 W_g \cdot L_a}{L_w \cdot L_h^{\,2}}$$ $S_{8g} = 3.87\,\mathrm{MPa}$ $\boxed{S_{8g} \le S_{cg} = 1}$

$$S_{9g} := \frac{W_g}{(A - C_i) \cdot C \cdot \tan(\phi - \mu)}$$ $S_{9g} = 197.2\,\mathrm{MPa}$ $\boxed{S_{9g} \le 1.6 \min(S_{hg}, S_{cg}) = 1}$

final OD

$A + 2.C_t = 1.229\,\mathrm{m}$