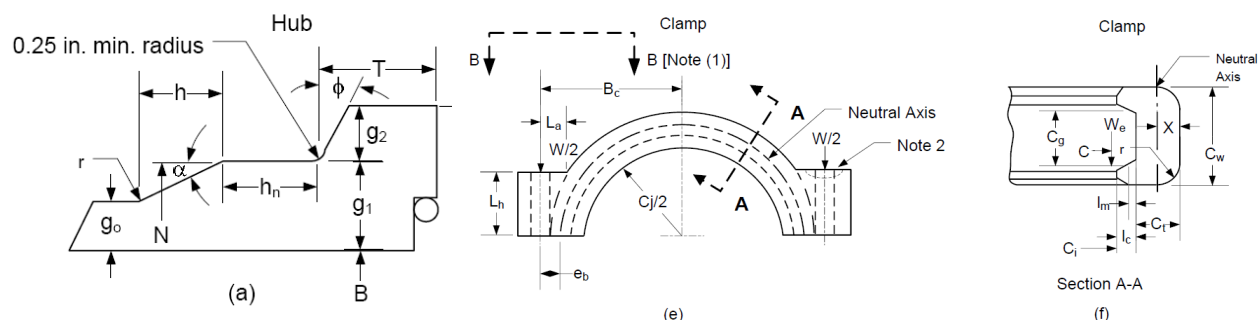


NEXT100 Pressure Vessel Clamp Design **DRAFT**

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

Flange thickness:

inner radius max. allowable pressure
 $R_{i_{pv}} = 0.57 \text{ m}$ $MAWP_{pv} = 15.4 \text{ bar}$ (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

$P := MAWP_{pv}$ $P = 1.561 \text{ MPa}$ $T_{fl} := 40\text{C}$ (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

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

c) STEP 3- Determine G, gasket radius

Gasket dia

Flange ID

Helicoflex gasket mean dia.

$G := 2R_{i_{pv}} + G_g + 3 \text{ mm}$ $G = 1.149 \text{ m}$ $B := 2R_{i_{pv}}$ $B = 1.14 \text{ m}$ $D_j := G$

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

Force of Pressure on head

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

Minimum Service Load

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

Helicoflex equiv. $H_P := F_m$

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

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

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

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

$$F_j := \pi D_j \cdot Y_2$$

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

Force of Gasket on head

$$H_m := \pi G \cdot Y_2 \quad H_m := F_j \quad (4.17.5)$$

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

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

$$\mu := \text{atan}(.1)$$

$\mu = 5.711 deg$ 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:

$$\phi_{\text{minus}\mu} := \max(\phi - \mu, 5deg) \quad \phi_{\text{minus}\mu} = 9.289deg$$

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

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

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

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

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

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

$$S_{bg} := 37000psi \quad (\text{use inconel718bolt} \quad S_{bo} := S_{bg})$$

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

$$A_b := 12cm^2$$

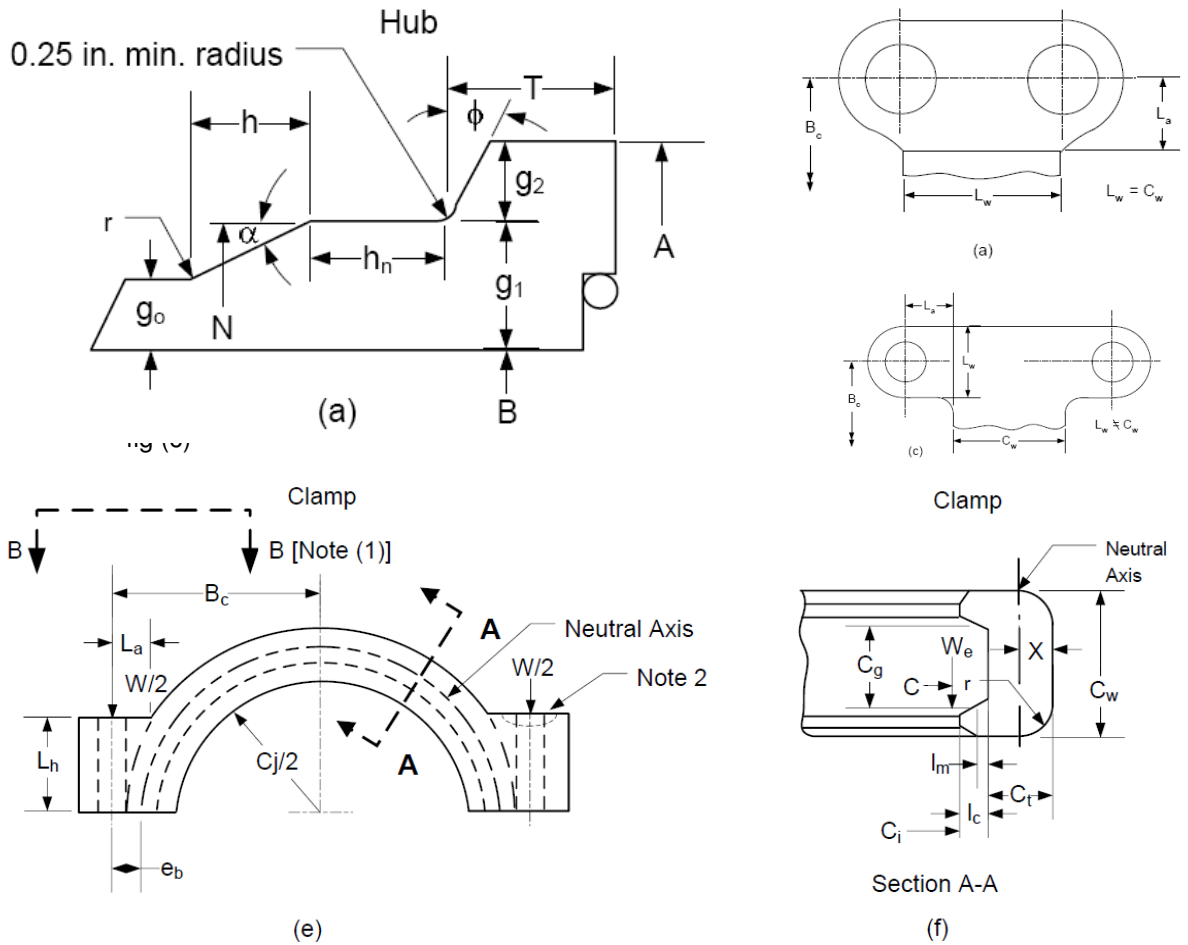
$$W_g := \frac{(A_m + A_b)}{2} \cdot S_{bg} \quad W_g = 2.982 \times 10^5 \text{ N} \quad (4.17.9)$$

bolt diameter (2 bolts on each end):

$$d_b := \sqrt{\frac{4}{\pi} \frac{A_b}{4}} \quad d_b = 19.544 \text{ mm}$$

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

$$W_o = 2.512 \times 10^5 \text{ N} \quad W_g = 2.982 \times 10^5 \text{ N}$$

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

$$B = 1.14 \text{ m}$$

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

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

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

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

$$\begin{aligned} g_0 &:= t & g_0 &= 0.635 \text{ cm} \\ g_{1_min} &:= 1.5g_0 & g_{1_min} &= 0.952 \text{ cm} \quad \text{set } g_1 := 1 \text{ cm} \\ N &:= B + 2g_1 & N &= 116 \text{ cm} & h_G &:= .7 \text{ cm} \quad ??? \end{aligned}$$

Then some trial dimensions to iterate on

$$g_2 := 1g_0 \quad g_2 = 6.35 \text{ mm} \quad \text{min} = .53g_0 \quad \text{rev A}$$

check, we need 2x min travel to compress gasket:

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

$$A_{min.} := N + g_1 + g_2 \quad A_{min.} = 1.1764 \text{ m} \quad \text{set: } A := 1.177 \text{ m}$$

$$T := 3.0 \text{ cm}$$

Then define:

$$C_i := \frac{A + N}{2} \quad C_i = 1.168 \text{ m}$$

$$h_2 := T - \frac{g_2 \cdot \tan(\phi)}{2} \quad h_2 = 2.915 \text{ cm}$$

$$h' := \frac{T^2 g_1 + h_2^2 g_2}{2(T \cdot g_1 + h_2 \cdot g_2)} \quad h' = 1.484 \text{ cm} \quad \text{note: } h' \text{ is } h(\text{bar}) \text{ in ASME manual}$$

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

then

$$C_i = 1.168 \text{ m}$$

$$C := \frac{A + C_i}{2} \quad C = 1.173 \text{ m}$$

$$M_D := \frac{H_D \cdot [C - (B + g_1)]}{2} \quad M_D = 1.811 \times 10^4 \text{ J}$$

$$M_G := H_G \cdot h_G \quad M_G = -9.581 \times 10^3 \text{ J}$$

$$M_T := H_T \cdot \left[\frac{C}{2} - \left(\frac{B + G}{4} \right) \right] \quad M_T = 365.52 \text{ J}$$

$$M_F := H_D \cdot \left(\frac{g_1 - g_0}{2} \right) \quad M_F = 2.906 \times 10^3 \text{ J}$$

$$M_P := P \cdot B \cdot T \cdot \pi \cdot \left(\frac{T}{2} - h' \right) \quad M_P = 27.219 \text{ J}$$

$$M_R := 1.57 W_o \cdot \left[h' - T + \frac{(C - N) \cdot \tan(\phi)}{2} \right] \quad M_R = -5.307 \times 10^3 \text{ J}$$

step 6 - Determine flange moment for gasket seating

$$M_g := \frac{.785 \cdot W_g \cdot (C - G)}{\tan(\phi + \mu)} \quad M_g = 1.454 \times 10^4 \text{ J}$$

$$M_o := M_D + M_G + M_T + M_F + M_P + M_R \quad M_o = 6.524 \times 10^3 \text{ N} \cdot \text{m}$$

step 7 - Determine hub factors

$$I_h := \frac{g_1 \cdot T^3}{3} + \frac{g_2 \cdot h_2^3}{3} - (g_2 \cdot h_2 + g_1 \cdot T) h'^2 \quad I_h = 3.563 \times 10^{-8} \text{ m}^4$$

$$g' := \frac{T \cdot g_1^2 + h_2 \cdot g_2 \cdot (2 \cdot g_1 + g_2)}{2(T \cdot g_1 + h_2 \cdot g_2)} \quad g' = 8.119 \times 10^{-3} \text{ m}$$

$$F_H := 1 + \frac{1.818}{\sqrt{B \cdot g_1}} \left[T - h' + \frac{3.305 I_h}{g_1^2 (0.5B + g')} \right] \quad F_H = 1.293$$

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

$$Q_o := \frac{1.818 M_o}{F_H \sqrt{B \cdot g_1}} \quad Q_o = 8.592 \times 10^4 \text{ N}$$

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

$$Q_g := \frac{1.818 M_g}{F_H \sqrt{B \cdot g_1}} \quad Q_g = 1.915 \times 10^5 \text{ N}$$

step 10 - Determine the clamp factors

first trial define clamp dimensions:

$$C_t := 3\text{cm} \quad C_w := 4T \quad C_w = 12\text{cm} \quad B_c := 0.5A + 3\text{cm} \quad B_c = 0.619\text{m}$$

then define:

$$l_c := g_2 \quad C_g := T - 2g_2 \cdot \sin(\phi) \quad C_g = 2.671\text{cm}$$

clamp factors:

$$\begin{aligned} A_1 &:= (C_w - 2C_t)C_t & A_1 &= 18\text{cm}^2 \\ A_2 &:= 1.571C_t^2 & A_2 &= 14.139\text{cm}^2 \\ A_3 &:= (C_w - C_g)l_c & A_3 &= 5.924\text{cm}^2 \\ A_c &:= A_1 + A_2 + A_3 & A_c &= 38.063\text{cm}^2 \end{aligned}$$

$$X := \frac{\left(\frac{C_w}{2} - \frac{C_t}{3}\right) \cdot C_t^2 - 0.5 \cdot (C_w - C_g) \cdot l_c^2}{A_c} \quad X = 1.133\text{cm}$$

$$e_b := B_c - \frac{C_i}{2} - l_c - X \quad e_b = 1.657\text{cm}$$

$$I_c := \left(\frac{A_1}{3} + \frac{A_2}{4}\right)C_t^2 + A_3 \cdot l_c^2 - A_c \cdot X^2 \quad I_c = 39.354\text{cm}^4$$

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

$$X_g := \frac{g_1}{g_0} \quad X_g = 1.575 \quad X_h := \frac{h}{h_{or}} \quad X_h = 0.578 \quad h_{or} := \sqrt{A \cdot g_0} \quad h_{or} = 0.086\text{m}$$

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

$f = 1$

We need some clamp dimensions at this point

$$\begin{aligned} l_m &:= l_c - 0.5(C - C_i) & L_h &:= 30\text{cm} & L_a &:= d_b + C_t \cdot \left(1 - \cos \left(\arcsin \left(\frac{L_h}{0.5A + C_t} \right) \right) \right) & L_w &:= C_w \\ l_m &= 0.422\text{cm} & L_a &= 2.331\text{cm} \end{aligned}$$

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

$$S_{ho} := S_{\max_Ti_g2_div2} \quad S_{co} := S_{ho} \quad S_{hg} := S_{ho} \quad S_{cg} := S_{co}$$

Operating condition:

Flange stresses

$$S_{1o} := f \cdot \left[\frac{P \cdot B^2}{4g_1 \cdot (B + g_1)} + \frac{1.91M_o}{g_1^2 (B + g_1) F_H} \right] \quad S_{1o} = 127.9 \text{ MPa}$$

$$S_{ho} = 143.4 \text{ MPa}$$

$$S_{1o} \leq 1.5S_{ho} = 1$$

$$S_{2o} := P \cdot \left(\frac{N^2 + B^2}{N^2 - B^2} \right) \quad S_{2o} = 89.8 \text{ MPa}$$

$$S_{2o} \leq S_{ho} = 1$$

$$S_{3o} := \frac{0.75W_o}{T \cdot (B + 2g_1) \tan(\phi - \mu)} \quad S_{3o} = 33.1 \text{ MPa}$$

$$S_{3o} \leq 0.8S_{ho} = 1$$

$$S_{4o} := \frac{0.477Q_o}{g_1 \cdot (B + 2g_1)} \quad S_{4o} = 3.5 \text{ MPa}$$

$$S_{4o} \leq 0.8S_{ho} = 1$$

Clamp stresses

$$S_{5o} := \frac{W_o}{2C \cdot \tan(\phi - \mu)} \cdot \left[\frac{1}{C_t} + \frac{3(C_t + 2l_m)}{C_t^2} \right] \quad S_{5o} = 105.8 \text{ MPa}$$

$$S_{co} = 143.4 \text{ MPa}$$

$$S_{5o} \leq 1.5S_{co} = 1$$

$$S_{6o} := \frac{W_o}{2} \cdot \left[\frac{1}{A_c} + \frac{|e_b| \cdot (C_t - X)}{I_c} \right] \quad S_{6o} = 131.8 \text{ MPa}$$

$$S_{6o} \leq 1.5S_{co} = 1$$

$$S_{7o} := \frac{1.5W_o}{(C_w - C_g) \cdot C \cdot \tan(\phi - \mu)} \quad S_{7o} = 21.1 \text{ MPa}$$

$$S_{7o} \leq 0.8S_{co} = 1$$

$$S_{8o} := \frac{3W_o \cdot L_a}{L_w \cdot L_h^2} \quad S_{8o} = 1.63 \text{ MPa}$$

$$S_{8o} \leq S_{co} = 1$$

$$S_{9o} := \frac{W_o}{(A - C_i) \cdot C \cdot \tan(\phi - \mu)} \quad S_{9o} = 154.1 \text{ MPa}$$

$$S_{9o} \leq 1.6 \min(S_{ho}, S_{co}) = 1$$

Gasket seating condition:

Flange stresses

$$S_{1g} := f \cdot \left[\frac{1.91M_g}{g_1^2 (B + g_1) F_H} \right] \quad S_{1g} = 186.8 \text{ MPa}$$

$$S_{hg} = 143.4 \text{ MPa}$$

$$S_{1g} \leq 1.5S_{hg} = 1$$

$$S_{2g} := 0 \text{ MPa} \quad S_{2g} = 0 \text{ MPa}$$

$$S_{2g} \leq S_{hg} = 1$$

$$S_{3g} := \frac{0.75W_g}{T \cdot (B + 2g_1) \tan(\phi - \mu)} \quad S_{3g} = 39.3 \text{ MPa}$$

$$S_{3g} \leq 0.8S_{hg} = 1$$

$$S_{4g} := \frac{0.477Q_g}{g_l \cdot (B + 2g_l)}$$

$$S_{4g} = 7.9 \text{ MPa}$$

$$S_{4g} \leq 0.8S_{hg} = 1$$

Clamp stresses

$$S_{5g} := \frac{W_g}{2C \cdot \tan(\phi - \mu)} \cdot \left[\frac{1}{C_t} + \frac{3(C_t + 2l_m)}{C_t^2} \right]$$

$$S_{5g} = 125.5 \text{ MPa}$$

$$S_{cg} = 143.4 \text{ MPa}$$

$$S_{5g} \leq 1.5S_{cg} = 1$$

$$S_{6g} := \frac{W_g}{2} \cdot \left[\frac{1}{A_c} + \frac{|e_b| \cdot (C_t - X)}{I_c} \right]$$

$$S_{6g} = 156.4 \text{ MPa}$$

$$S_{6g} \leq 1.5S_{cg} = 1$$

$$S_{7g} := \frac{1.5W_g}{(C_w - C_g) \cdot C \cdot \tan(\phi - \mu)}$$

$$S_{7g} = 25 \text{ MPa}$$

$$S_{7g} \leq 0.8S_{cg} = 1$$

$$S_{8g} := \frac{3W_g \cdot L_a}{L_w \cdot L_h^2}$$

$$S_{8g} = 1.93 \text{ MPa}$$

$$S_{8g} \leq S_{cg} = 1$$

$$S_{9g} := \frac{W_g}{(A - C_i) \cdot C \cdot \tan(\phi - \mu)}$$

$$S_{9g} = 182.9 \text{ MPa}$$

$$S_{9g} \leq 1.6 \min(S_{hg}, S_{cg}) = 1$$

final OD

$$A + 2 \cdot C_t = 1.237 \text{ m}$$

"flange width (total)"

$$C_w = 12 \text{ cm}$$

clamp weight

$$\rho_{ti} \cdot \frac{\pi}{2} \cdot (A + C_t) \cdot C_w \cdot C_i$$

$$\rho_{ti} := 4.5 \frac{\text{gm}}{\text{cm}^3}$$

$$W_{cl} := 1.3 \cdot \rho_{ti} \cdot \frac{\pi}{2} \cdot (A + C_t) \cdot C_w \cdot C_t \quad W_{cl} = 39.929 \text{ kg}$$