5. Spool

A connecting spool will be attached to the central 2.75" CF integral flange of the 350 psi MOP head. This spool will carry signal and power cabling to a Kimball Physics octagon vacuum chamber (AKA octagon) having (8) 2.75" CF ports. The spool has a 2.75" CF flange on one end and a 6" CF flange on the other end. To prevent additional loading of the tube from impact or handling forces applied to the octagon or attached cabling, the octagon will be secured by an angle bracket to the table top, which is a 3/4" thick aluminum plate. See figs 3, 4. We include moment from static weight of octagon and cabling per subsection UG-22 Loadings:

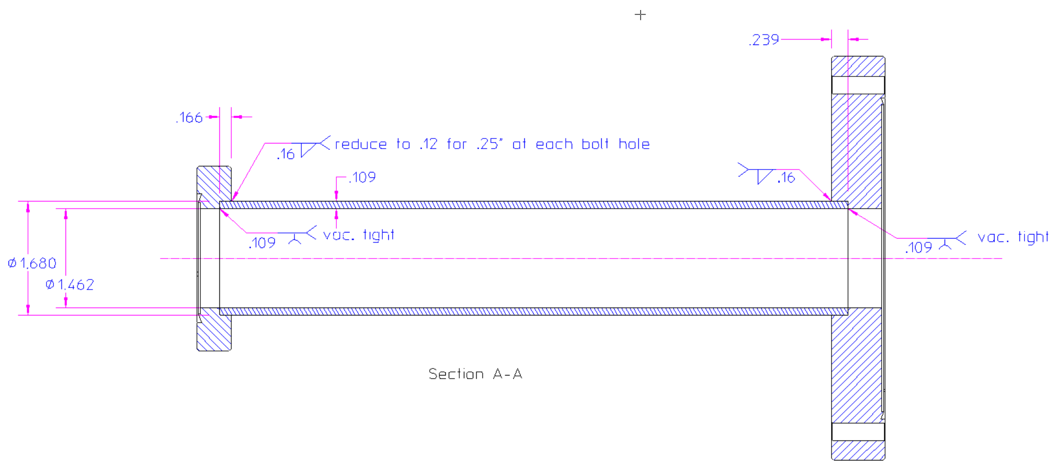


Fig. 10, Spool cross section

Spool Tube

Spool tube is a 1.25" schedule 10S pipe TP304 stainless steel, per ASME SA-312 specification (ASTM A 312)

spool tube diameter, length,thickness, inner radius:

$d_{o\_sp\_tube} := 1.66in \qquad l_{tube} := 9.5in \qquad t_{sp\_tube} := .109in$

$d_{i\_sp\_tube} := d_{o\_sp\_tube} - 2t_{sp\_tube} \qquad R_{i\_sp\_tube} := 0.5d_{i\_sp\_tube} \qquad R_{i\_sp\_tube} = 0.721\,in$

First we calculate minimum thickness required for tube to support weight of octagon and cables. This weight load occurs before the angle bracket restraint can be tightened and is "frozen in by the bracket" before pressure is applied. The load produces a bending moment on the tube which is highest where it is welded to the 2.75 in CF flange. This results in a longitudinal stress. We will then add this minimum thickness to that calculated for longitudinal stress due to pressure.

Weights:

octagon — cabling and feedthrus — CF flanges — source insertion tube and flange

$W_{oct} := 13lbf \qquad W_{cables} := 5lbf \qquad W_{6in\_CF} := 5.5lbf \qquad W_{so\_tube} := 2lbf \qquad l_{oct} = 0.076\,m$

$$W_{cp\_tot} := W_{oct} + W_{cables} + 2\cdot W_{6in\_CF} + W_{so\_tube}$$

$$M_{sp\_tube} := \left(l_{tube} + 0.5l_{oct}\right)\cdot W_{cp\_tot} \qquad M_{sp\_tube} = 341\,lbf\cdot in$$

$$I_{sp\_tube} := \frac{\pi}{64}\left(d_{o\_sp\_tube}^{\;4} - d_{i\_sp\_tube}^{\;4}\right) \qquad I_{sp\_tube} = 0.16\,in^4$$

$$\sigma_{sp\_tube\_mom} := \frac{M_{sp\_tube}\cdot 0.5d_{o\_sp\_tube}}{I_{sp\_tube}} \qquad \sigma_{sp\_tube\_mom} = 1763\,psi$$

Since ASME Pressure Vessel code calculates required thickness, we can perform a similar calculation for the minimum thickness required to withstand the applied bending moment and add this thickness to that require for pressure containment. Using an alternative approximate formula for moment of Inertia, I (using average diameter and thickness):

$$d_{avg\_sp\_tube} := 0.5\left(d_{i\_sp\_tube} + d_{o\_sp\_tube}\right)$$

$$I_{sp\_tube2} := \frac{\pi}{16} d_{avg\_sp\_tube}{}^{3} \cdot t$$

Note: Equations (assignments) which have a small black square in their upper right corner are disabled (not active).

$$\sigma := \frac{Mc}{I} \qquad \sigma := \frac{M \cdot c}{\frac{\pi}{16} \cdot d^{3} t} \qquad \sigma := S \cdot E$$

Solving for t (we need weld efficiency E): $E_{w\_fw} := 0.55$ double fillet weld from Table UW-12 (see weld calc below)

$$t_{sp\_tube\_M} := \frac{M_{sp\_tube} \cdot 0.5 d_{avg\_sp\_tube}}{\frac{\pi}{16} d_{avg\_sp\_tube}{}^{3} \cdot S_{TP304} \cdot E_{w\_fw}} \qquad t_{sp\_tube\_M} = 0.033\,\text{in}$$

Minimum tube thickness required for pressure load, as above, from UG-27:

$$t_{sp\_tube\_min\_circ} := \frac{P_{MAWP} \cdot R_{i\_sp\_tube}}{S_{TP304} \cdot E_{w\_fw} - 0.6 \cdot P_{MAWP}} \qquad t_{sp\_tube\_min\_circ} = 0.023\,\text{in}$$ OK

$$t_{sp\_tube\_min\_long} := \frac{P_{MAWP} \cdot R_{i\_sp\_tube}}{2S_{TP304} \cdot E_{w\_fw} + 0.4 P_{MAWP}} \qquad t_{sp\_tube\_min\_long} = 0.011\,\text{in}$$ OK

Adding the two minimum thicknesses required for longitudinal stress:

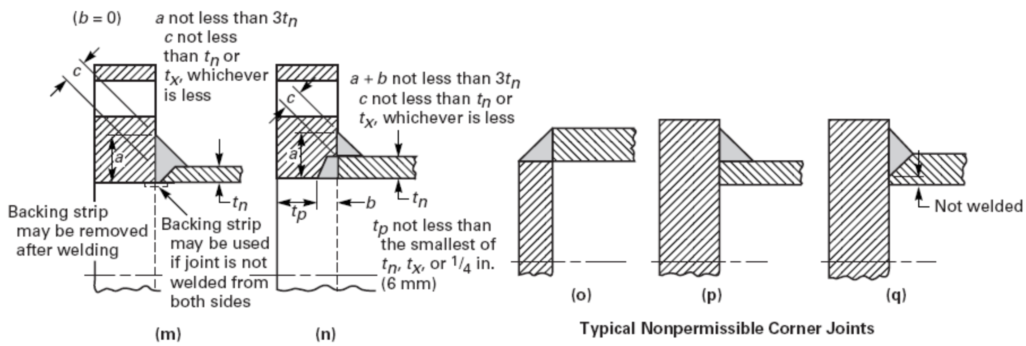
$t_{sp\_tube\_long\_total} := t_{sp\_tube\_min\_long} + t_{sp\_tube\_M}$ $\qquad t_{sp\_tube\_long\_total} = 0.044\,in$ OK

This total required thickness is greater than that required for circumferential pressure, but still less than actual thickness.

Weld design:

From fig. UW-12 welds on both ends of tube are type 4 double full fillet welds, Category C weld (subsection UW-9 Design of Welded Joints , fig. UW-3) of type (n) below and must conform to rules in the figure

FIG. UW-13.2 ATTACHMENT OF PRESSURE PARTS TO FLAT PLATES TO FORM A CORNER JOINT (CONT'D)



Typical Bolted Flange Connections
c, t_n, and t_x are as defined in 2-3

weld dimensions:

outer $\qquad$ inner

$h_{o\_sp} := .16in$ $\qquad h_{i\_sp} := .082in$

dimensions for fig (n) above:

$$c_{sp} := \frac{\sqrt{2}}{2} h_{o\_sp} \qquad c_{sp} = 0.113\,in \qquad t_{n\_sp} := t_{sp\_tube}$$

$$a_{sp} := t_{sp\_tube} + h_{o\_sp} \qquad a_{sp} = 0.269\,in \qquad b_{sp} := h_{i\_sp}$$

weld criteria for fig (n) above:

$c_{sp} = 0.113\,in \quad > \quad t_{n\_sp} = 0.109\,in$ OK

$a_{sp} + b_{sp} = 0.351\,in \quad > \quad 3t_{n\_sp} = 0.327\,in$ OK

CF flange calcs

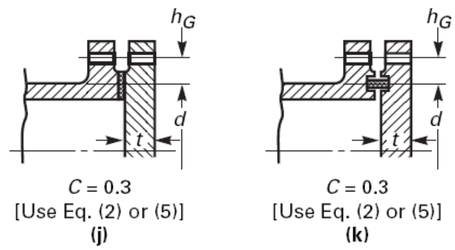
First we consider blank flanges, then consider those with central openings no larger that 0.5D; these are both considered flat unstayed heads. This is the case for the 6 in CF flange of the spool connecting to the octagon, and also for the 6 inch CF flange on the back of the octagon, which will have a central 2.75CF (1.5in dia) opening. From subsection UG-34, Unstayed Flat Heads and Covers :

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE} \qquad (1)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3} \qquad (2)$$



We can use mathCAD's ability to anlalyze a large number of CF flanges simulataneously. The following calculations are parallel calculations (not matrix or vector calcs). Read straight across from desired flange size, OD_{CF} , in order to find associated quantities:

Flange size | Number of bolts | Knife edge diameter

$$OD_{CF} := \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \quad N_{CF} := \begin{pmatrix} 6 \\ 4 \\ 6 \\ 8 \\ 8 \\ 10 \\ 16 \\ 20 \\ 24 \\ 30 \end{pmatrix} \quad d_{ke} := \begin{pmatrix} .72 \\ 1.15 \\ 1.65 \\ 2.25 \\ 2.75 \\ 3.25 \\ 4.54 \\ 6.25 \\ 8.54 \\ 11.5 \end{pmatrix} in \quad \begin{matrix} \text{<- checked} \\ \\ \text{<- checked} \\ \\ \\ \\ \text{<- checked} \\ \\ \text{<- checked} \\ \\ \end{matrix}$$

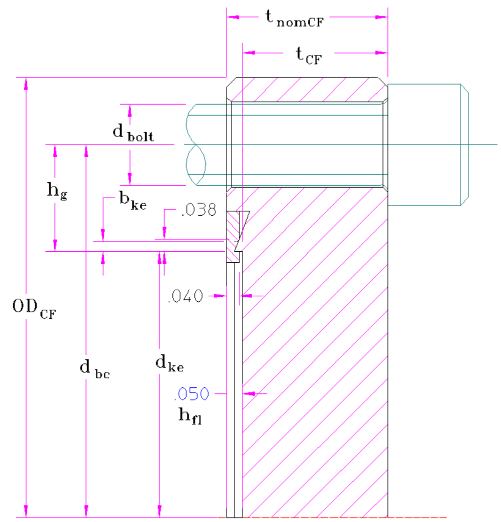


Fig. 11 CF (conflat) flange dimensions

Flange size | Bolt circle dia. | Flange thickness | Bolt dia. | Height of bolt flange

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \quad d_{bc} := \begin{pmatrix} 1.062 \\ 1.625 \\ 2.312 \\ 2.85 \\ 3.628 \\ 4.03 \\ 5.128 \\ 7.128 \\ 9.128 \\ 12.06 \end{pmatrix} in \quad t_{nomCF} := \begin{pmatrix} .285 \\ .47 \\ .5 \\ .62 \\ .68 \\ .75 \\ .78 \\ .88 \\ .97 \\ 1.12 \end{pmatrix} in \quad d_{bolt} := \begin{pmatrix} .16 \\ .25 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .375 \end{pmatrix} in \quad h_{fl} := \begin{pmatrix} .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \end{pmatrix} in$$

Bolt Load W:

We have several choices here, use the flange mfr.'s recommended bolt torque, a typical fastener torque(T_{CF_SAE5}), a torque found to pull flanges together (see ANL note in Appendix) or use a value bolt torque (T_{MAWP}) back calculated to withstand the required pressure (times a suitable safety factor) without exceeding

ASME allowable flange stress for loose flanges, which the 2.75 OD flange is. This is the controlling configuration, and is treated in the section below for Flanges with Large Central Openings. It turns out that higher torques are not necessarily better, the additional edge moment creates flange stresses higher than allowed. If the joint fully closes (flange faces fully touching under bolts), then the joint design is changed and edge moment is reduced or eliminated, however this is not a reliably achievable condition. The Appendix contains a note testing this method (no pressure tests however). We use this back calculated torque T_{rec} (recommended torque) below by assigning T_{rec} to T_{CF}:

Torques, bolt

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad T_{CF\_ANL} := \begin{pmatrix} 40 \\ 163 \\ 163 \\ 197 \\ 217 \\ 190 \\ 217 \\ 246 \\ 260 \\ 330 \end{pmatrix} lbf \cdot in$$

from ref. 3, ANL CF pressure capacity document, torque to pull CF flanges fully together

$$T_{CF\_SAE5} := \begin{pmatrix} 4 \\ 10 \\ 19 \\ 19 \\ 19 \\ 19 \\ 19 \\ 19 \\ 19 \\ 30 \end{pmatrix} lbf \cdot ft \qquad T_{rec} := \begin{pmatrix} .65 \\ 5.5 \\ 4 \\ 7 \\ 8.4 \\ 8.4 \\ 9.5 \\ 7 \\ 11 \\ 19 \end{pmatrix} lbf \cdot ft$$

$$T_{CF} := T_{rec}$$

Total Bolt Load:

$$W_{CF} := \overrightarrow{\frac{N_{CF} \cdot 5 T_{CF}}{d_{bolt}}}$$

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad W_{CF} = \begin{pmatrix} 1463 \\ 5280 \\ 4608 \\ 10752 \\ 12902 \\ 16128 \\ 29184 \\ 26880 \\ 50688 \\ 91200 \end{pmatrix} lbf$$

Flange Thickness, effective:

$$t_{CF} := \overrightarrow{\left(t_{nomCF} - h_{fl}\right)} \qquad OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad t_{CF} = \begin{pmatrix} 0.235 \\ 0.42 \\ 0.45 \\ 0.57 \\ 0.63 \\ 0.7 \\ 0.73 \\ 0.83 \\ 0.92 \\ 1.07 \end{pmatrix} in$$

radial distance from gasket load center to bolt circle:

$$h_g := 0.5\overrightarrow{\left(d_{bc} - d_{ke}\right)} \qquad OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad h_g = \begin{pmatrix} 0.171 \\ 0.238 \\ 0.331 \\ 0.3 \\ 0.439 \\ 0.39 \\ 0.294 \\ 0.439 \\ 0.294 \\ 0.28 \end{pmatrix} in$$

$$E := 1 \qquad C_j := 0.3$$

Solving for pressure in eq (2) above:

$$P_j := \frac{S_{304} \cdot E}{C_j} \overrightarrow{\left(\frac{t_{CF}^2}{d_{ke}^2} - \frac{1.9 \cdot W_{CF} \cdot h_g}{S_{304} \cdot E \cdot d_{ke}^3}\right)} \qquad P_j = \begin{pmatrix} 2858 \\ 3670 \\ 2808 \\ 2485 \\ 1774 \\ 1932 \\ 1143 \\ 870 \\ 622 \\ 471 \end{pmatrix} psi$$

All pressures are greater than:

$P_{MAWP} = 350\,psi$

so all CF blank flanges are suitable for use

CF gasket calculations

From Appendix 2 Section VIII-Div. 1 Rules for Bolted Flange Connections with Ring type Gaskets subsection 2-5, <u>Bolt Loads:</u>

The required bolt load for the operating conditions W_{m1} is determined in accordance with eq. (1).

$$W_{m1} = H + H_p = 0.785G^2P + (2b \times 3.14GmP) \quad (1)$$

(2) Before a tight joint can be obtained, it is necessary to seat the gasket or joint-contact surface properly by applying a minimum initial load (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load required for this purpose W_{m2} shall be determined in accordance with eq. (2).

$$W_{m2} = 3.14bGy \quad (2)$$

where G is the gasket diameter

for flat copper gaskets (from Table 2-5.1):

$m_{Cu\_flat} := 4.75$ $\quad y_{Cu\_flat} := 13000\text{psi}$

effective width b is taken to be 80% of the width of the interference (.0384 in) of the knife edge (to allow for less than full joint closure) and the gasket (.08" thk.):

$b_{ke} := 80\% \cdot .0384\text{in}$ .0384 in. measured from 2.75 in flange MDC CAD model; assume same for all flanges

$b_{ke} = 0.031\,\text{in}$

$G := d_{ke} + 2b_{ke}$ outer diameter of effective compressed gasket area

solving eq (1) above for maximum pressure, (in two stages, to allow concurrent calculation)

$$p_{m1} := \overrightarrow{\frac{1}{\left(0.785G^2 + 2\pi b_{ke} \cdot m_{Cu\_flat} \cdot G\right)}}$$

$$P_{m1} := \overrightarrow{\left(p_{m1} \cdot W_{CF}\right)}$$

and eq(2):

$$W_{m2} := 3.14b_{ke} \cdot G \cdot y_{Cu\_flat}$$

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad P_{m1} = \begin{pmatrix} 1223 \\ 2333 \\ 1191 \\ 1703 \\ 1469 \\ 1385 \\ 1400 \\ 725 \\ 768 \\ 789 \end{pmatrix} psi \qquad W_{m2} = \begin{pmatrix} 980 \\ 1519 \\ 2146 \\ 2899 \\ 3526 \\ 4153 \\ 5770 \\ 7914 \\ 10786 \\ 14498 \end{pmatrix} lbf \quad \text{compare-->} \quad W_{CF} = \begin{pmatrix} 1463 \\ 5280 \\ 4608 \\ 10752 \\ 12902 \\ 16128 \\ 29184 \\ 26880 \\ 50688 \\ 91200 \end{pmatrix} lbf$$

We see that the gasket preloading requirement W_{m2} is easily exceeded by the actual preload W_{CF}, and that the gaskets can hold far higher pressure than necessary (350 psi).

CF Blank Flange maximum opening diameter:

UG-39(b) Single and multiple openings in flat heads that have diameters equal to or less than one-half the head diameter may be reinforced as follows:

UG-39(b)(1) Flat heads that have a single opening with a diameter that does not exceed one-half the head diameter or shortest span, as defined in UG-34, shall have a total cross-sectional area of reinforcement for all planes through the center of the opening not less than that given by the formula

$$A = 0.5dt + tt_n\,(1 - f_{r1})$$

where d, t_n, and f_{r1} are defined in UG-37 and t in UG-34.

The 2.75 inch CF flange of the spool does not meet the above requirement,and is considered a loose flange, in a subsequent section. Nevertheless it is useful at this point to check to see if flanges that meet the requirement above are adequately reinforced for MAWP. Assume in formula above, that nozzle thickness is zero. First we determine minimum thickness required: t (here t_{min}). From subsection UG-34 :

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE} \qquad (1)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3} \qquad (2)$$

from sketches (j), (k) $C := 0.3$

weld efficiency: $E := 1$ (assume stock flanges only

$$t_{min\_CF} := \overrightarrow{\left(OD_{CF} \cdot \sqrt{\frac{C \cdot P_{MAWP}}{S_{304} \cdot E} + \frac{1.9 W_{CF} \cdot h_g}{S_{304} \cdot E \cdot OD_{CF}^{\,3}}} \right)}$$

minimum flange thickness thickness available for reinforcement