POWER CHIMNEY AND DEWAR

The power chimney, storage dewar and associated plumbings contribute to an important portion of the gravity-fed style liquid helium cooling system of the Collider Detector Facility (CDF) superconducting solenoid. (drawing #). Cryogenic valves A and B facilitate cooling down and filling of the magnet from the 2000 ℓℓ helium storage dewar. Because the chimney is in the detector area, it has to be thin (having a small radiation thickness); hence both the cryogenic and vacuum shells are made of aluminum, while those for the dewar are made of stainless steel AISI type 304. Four AISI 304/Al 5083-0 transition joints are therefore required. They are at easily accessible locations such that they can be repaired or replaced conveniently if there were leaks. On top of the chimney there is an 8 in. diameter rupture disk (at 12.5 psig) while on top of the storage dewar a 4 inch one. A combination of the two should be able to handle a continuous 600 kW heat influx emergency situation (cf., Appendix F).

The smaller the power chimney is, the bigger the area covered by the detectors would be and more physics done, hence it is important to keep the chimney as small as possible, provided that structural integrity and emergency safety considerations are not sacrified. There will be provided two different designs (drawing Nos.). The circular one is larger yet easier for construction while the rectangular one occupies less space but inevitably more difficult to build. Also, another limitation is that all the plumbings, bus bars and accessories from the power chimney have to come out of the detector via an opening of 3 ft x 5 ft through the magnet iron yoke on the downstream relative to the p beam) side of magnet. A pair of 8000A rated AMI* leads will be used inside the chimney while water-coooled leads (Flex-Cable Style 300 IFS-2) would be used outside the top hat.

Calculations for the shell thickness requirements for both the chimney and the dewar can be found in Appendix G. Two different designs are provided for the support structure of the dewar (drawings Nos.). One of them (stainless steel neck support) depicts a simple design that can be farmed out to industry for construction readily while the Kevlar support slings design, with a much lower heat leak, calls for in-house fabrication.

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APPENDIX: CALCULATIONS ASSOCIATED WITH THE CDF POWER CHIMNEY AND STORAGE DEWAR

1. Objective

Sizing the wall thicknesses for the power chimney and the LHe storage dewar of the CDF LHe system per ASME pressure vessel code and wherever necessary, the reinforcement requirements for openings are also calculated.

2. Assumptions

(a) Calculations will be done on the basis of the requirement of an internal pressure rating of 75 psig for the LHe compartment and $\geq$ 20 psig for collapse of the vacuum shell.

(b) It is assumed that both shells for the power chimney are constructed out of aluminum 5083-0 and those for the storage dewar SS 304.

3. Actual Calculations

(a) Power chimney vacuum shell:

(i) circular design:

where length of vessel $L = 85''$

diameter of vessel $D_o \approx 13''$

t = required thickness of the vessel wall

Pa = allowable working pressure

assume $t = 5/32''$

$L/D_o = 6.5$

$D_o/t = 83.2$

Figure UGO-28.0 of Section VIII, Div. I of the ASME Pressure Vessel Code then generates a value for the factor A = 0.00023. Using Fig. UNF-28.23 for material Al 5083-0,

factor B = 1200

From Section UG-28

$$Pa = \frac{4B}{3(D_o/t)}$$

$$= \frac{4(1200)}{3(83.2)}$$

$$= 19.2 \text{ psig}$$

$$\leq P_{design} = 20 \text{ psig}$$

Hence, we can choose $t = \frac{3}{16}$" instead of $\frac{5}{32}$".

(ii) Rectangular design

ANSYS calculation shows that a wall thickness of 1/2" is sufficient for an external pressure of 15 psig.

(b) Dewar Vacuum Shell:

$L = 66"$

$D_o = 66"$

Let $t = 1/4"$

$L/D_o = 1, \quad D_o/t = 264$

From Fig. UGO-28.0

$A = 0.0003$

From Fig. UCS-28.1

$$Pa = \frac{4B}{3(D_o/t)}$$

$$= \frac{4(4500)}{3(264)}$$

$$= 22.7 \text{ psig}$$

$$\geq P_{design}$$

We'll choose t = 1/4".

(c) LHe storage dewar vacuum vessel head

Using Section UG-33(e) and a Brighton 80-10 head 66" in diameter

Crown radius = 80% of the diameter of the vessel = 52.8"

inside knuckle radius = 10% of the vessel diameter

Choose t = 1/4"

$$A = \frac{0.125}{(52.8)/(11/4)"}$$

$$= 0.00059$$

From Fig. UCS-28.1

$$B = 8800$$

$$Pa = \frac{B}{(R/t)} = \frac{8800 \times \frac{1}{4}}{52.8}$$

$$= 41.7 \text{ psi}$$

(d) The power chimney cryostat

ℓ = length of cryostat = 88"

D = diameter of cryostat = 8"

P = required burst pressure = 75 psig

γ = D/2

E = welding efficiency

S = maximum allowable stress value per stress limitations specified in UG-24 & UW-12 of Code

t = required thickness

σ = yield strength at room temperature

$\sigma_{4.2K}$ = yield strength at helium temperature

S = 10 Ksi at $100^{o}F$

σ = 18 Ksi at $100^{o}F$

$\sigma_{4.2K}$ = 25.4 Ksi

$$S'_{(4.2K)} = \frac{S}{\sigma} \times \sigma_{4.2K}$$

$$= \frac{10}{18} \times 25.4$$

$$= 14.1 \text{ Ksi}$$

E = 0.95[1]

Part of cryostat might be warm, so use S for calculation.

Following section UG-27 of Code

$$t = \frac{PR}{SE - 0.6P}$$

For P = 75 psig = 90 psia

$$t = \frac{90(4)}{(10{,}000)(0.95) - 0.6\ (90)}$$

$$= 0.038$$

The case of welding and construction, select t = 1/8"

(e) The LHe storage dewar cryostat

$\ell = 58''$ (conservative)

$D = 54''$

$R = D/2 = 27''$

$P = 90$ psia

E = welding efficiency = 0.85 (spot weld)

$S = 18.8$ Ksi

$\sigma = 30$ Ksi

$\sigma_{4.2K} = 60$ Ksi

$$S_{4.2K} = \frac{60}{30} \times 18.8 = 37.6 \text{ Ksi}$$

$$t = \frac{PR}{S_{4.2K} E - o.6 P}$$

$$= \frac{(90)(27)}{37600 \times 0.85 - 0.6\ (90)}$$

$$= 0.076''$$

Choose t = 1/8" for ease of fabrication.

(f) LHe storage dewar cryostat head thickness requirement per Code section UA-4 Appendix I -- Mandatory

Let

L = diameter of torispherical head

D_o = diameter of vessel = 54"

P = max. design pressure

E = welding efficiency = 0.8K

S = Max. allowable working stress at 4.2K for SS304

= 37.6 Ksi (as in (d))

$$M = \frac{1}{4} (3 + \sqrt{\frac{L}{r}})$$

r = knuckle radius

Using a Brighton 80-10 head,

γ = 10% of D_o

L = 80% of D_o

$$M = \frac{1}{4} (d + \sqrt{\frac{0.8}{0.1}})$$

$$= 1.46$$

$$t = \frac{PLM}{2 SE - 0.2 P} = \frac{(90)(43.2)(1.46)}{2(37600)(0.85) - (0.2)(90)}$$

$$= 0.088''$$

The Brighton 80-10 is a more efficient design even than conventional 100% crown radius, 6% knuckle radius design.

Select a 3/16" head for it's the thinnest made by Brighton.

Reinforcement Calculations

1. Vacuum shell opening at chimney

A = area of reinforcement required = d x tr x F x $\frac{1}{2}$ *

*according to UG-37(c) external pressure loading condition.

where

t_r = required thickness for shell = t = 9/16"

t = nominal for shell

F = correction factor as mentioned in Sec. UG-37

= 0.98 (for a 9.5^o incline to tangent)

t_n, t_{rn} = actual and required wall thickness of nozzle

$$A = \frac{1}{2} \times \frac{9}{16} \times 12\frac{1}{4} \times 0.98$$

$$= 3.38 \text{ in}^2$$

A_1 = area of reinforcement available from excess thickness in vessel wall

A_2 = area of reinforcement available from excess thickness in nozzle wall

A_3 = Area of reinforcement available when nozzle wall extends inside vessel wall

A_4 = area of reinforcement available from welds

A_5 = additional required area of reinforcement (usually supplied by collars)

It is required that

$$\sum_{i=1}^{5} A_i \geq A$$

E_1 = welding efficiency, < 1 when opening has to go through a weld seam on cylinder.

$$A_1 = (E_1 t - F\ t_r)d$$

$$= (\frac{9}{16})\ (1 - 0.98)(\ 12\frac{1}{4}\ )$$

$$= 0.14 \text{ in}^2$$

A_2 = smaller of $(t_n - t_{rn})\ 5t_n$ or

$(t_n - t_{rn})(5t)$

here $= (t_n - t_{rn})\ 5t_n$

$= (3/16 - 5/32)5(3/16)$

$= 0.03\ in^2$

$A_3 = (t_n - c)h \times 2$

$h \leq 2.5\ t_n$

here we can't afford it, $A_3 = 0$

Weld requirements follow Fig. UW-16.1(m),

Weld A required $= 0.7\ t_{min}$

$= (0.7)(\frac{3}{16})$

We'll use (3/16)" for ease in welding

Weld B required $= \frac{1}{2}\ t_{min}$

$\approx \frac{1}{2} \times t$

$\approx \frac{9}{32}$

$A_4 = 2\ (0.5)\ \ (\frac{3}{16})^2 + (\frac{9}{32})^2 = 0.04\ in^2$

$= 0.114\ in^2$

$A_5 = A - (A_1 + A_2 + A_3 + A_4)$

$= 3.38 - (0.14 + 0.03 + 0 + 0.114)$

$(2w)t_e = 3.10$

Let $w = 2$, $t_e = 0.775$ or 25/32"

If we set $w = 2\frac{1}{2}$, $t_e = \frac{3.10}{5} = 0.62$ or 5/8"

Choose $w = 2\frac{1}{2}$", $t_e = 5/8$ "

2. For helium cryostat opening

A simplified (conservative) way to size reinforcement is to set

$$A_5 = A$$

in this case, for internal pressure

$$2\ wt_e = 7\frac{3}{4} \times 0.98 \times \frac{5}{16}$$

$$= 2.373$$

set $w = 1$ $\quad t_e = 1.19''$

$w = 2$ $\quad t_e = 0.59$ or $19/32''$

This is a special situation, where there is the thick ring, there requires no ring, and where there isn't, use a $w = 2''$, $t_e = 19/32''$ collar type reinforcement

Reinforcement: $w = 2''$, $t_e = 19/32''$

SUMMARY

Power chimney:	Vacuum shell	(Al 5083-0)	sidewalls	use	$t = 3/16''$
	Cryostat	(Al 5083-0)	sidewalls	use	$t = 1/8''$
LHe Storage Dewar:	Vac. shell	(SS 304)	sidewalls	use	$t = 1/4''$
	Vac. shell	(SS 304)	head	use	$t = 1/4''$
	Cryostat	(SS 304)	sidewalls	use	$t = 1/8''$
	Cryostat	(SS 304)	head	use	$t = 3/16''$

Reinforcement collars of chimney into magnet vacuum vessel: $w = 2\frac{1}{2}$, $t_e = 5/8''$

Reinforcement collars of chimney into magnet cryostat, $w = 2''$, $t_e = \frac{19}{32}''$

All thickness of vessels and reinforcements are sized for an internal pressure rating of 75 psig and an external collapse pressure of $\geq$ 20 psi and should meet ASME Pressure Vessel Code.