Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project Internal Reference:

Project: DECAM

Title: Multi CCD Vacuum Test Vessel – Vessel Analysis

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Key Words: Multi – CCD Test Vessel

Abstract Summary: The Multi – CCD Test Vessel is a vacuum vessel, however does not meet the ASME Code requirements based on the small volume exception. Regardless, the engineering analysis for the vacuum vessel is provided.

Applicable Codes: ASME Boiler and Pressure Vessel Code Section VIII

Vessel Volume

Diameter = 24 inch
Length = 28.375 inch

Volume = 3.14 * (12 inches)^2 * 28.375 inches
Volume = 12830 cubic inches
Volume = 7.4 cubic feet.

The vessel volume is less than 35 cubic foot and does not require a vacuum vessel engineering note.

Vessel Under External Pressure, 15 psi load

Check Stresses:

Longitudinal Stress:

$$SL = \frac{P * Do}{4 * t} = \frac{15 \text{ psi} * 24 \text{ inch}}{4 * .375 \text{ inch}} = 240 \text{ psi}$$

Circumferential Stress:

$$SC = \frac{P * Do}{2 * t} = \frac{15 \text{ psi} * 24 \text{ inch}}{2 * .375 \text{ inch}} = 120 \text{ psi}$$

Max Allowable Stress for SS 304 = 16.7 KSI

Ratio (R) of Allowable Stress / Actual Stress:

Longitudinal Stress:

R = 16,700 psi / 240 psi = 69 OK

Circumferential Stress:

R = 16,700 psi / 120 psi = 34 OK

Max Allowable Internal Working Pressure, UG-27:

Assumed MAWP = 12 PSIG

$$P = \frac{S * E * t}{R + 0.6 * t}$$

S = 16,700 psi, max allowable material stress for SS304
E = 0.45, joint efficiency
t = 0.375, wall thickness
R = 12 inch, outside vessel radius

$$P = \frac{16{,}700 \text{ psi} * 0.45 * 0.375}{12 + 0.6 * 0.375} = \frac{2818}{12.225} = 230 \text{ psi}$$

Ratio (R) of Allowable Stress / Actual Stress:

R = 230 psi / 12 psi = 19 O.K.

Vessel Under External Pressure, 15 psi load Using Section UG-28

UG-28 Thickness of shells under external pressure:

P: The expected external working pressure is 15 psig

Step 1.
Do/t = 24 inch/ .375 inch = 64
L/Do = 28.375 inch / 24 inch = 1.18

Step 2 and 3.
Using Fig G in Subpart 3 of Section II
Factor A = 2.75

Step 4.
Using Factor A and Fig HA-3 Part D for SS304L, and for a room temperature application, Factor B is determined as 17,000

Step 5.
Determine the maximum allowable external working pressure Pa

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

Pa = 4 * 17,000 / (3* (64)) = 354 Psi

Ratio (R) of Allowable Stress / Actual Stress:

R = 354 psi / 15 psi = 23 O.K.

t, the vessel wall thickness is sufficiently thick enough to support the external pressure load.

Unstayed Flat Heads and Covers, UG-34:

Calculating required end cover thickness when the bolts do not cause an edge moment

$t = d (CP / SE)^{0.5}$
(Formula is conservative for bolted end covers because it does not include the additional edge moment loading from the bolts)

Or rearranging to calculate the allowable pressure on the end cover:

$P = (t/d)^2 * SE / C$

T = 1 inch, Plate Thickness
D = 23.25 inches, diameter or short span
S = 10,500 for AL 6061-T6, Maximum allowable stress of the plate
E = 0.45, Joint efficiency
C = 0.25 attachment factor for bolted flanges
P = allowable internal pressure

$P = \underline{(1 \text{ in} / 23.25 \text{ in})^2 * 10{,}500 \text{ psi} * .45 / .25 = 35 \text{ psi internal pressure}}$

Ratio (R) of Allowable Stress / Actual Stress:

R = 35 psid / 2 psid = 17 O.K.

Vessel Positive Pressure Relief

In the event that the internal LN2 vessel ruptures and all of the LN2 is spilled, a positive pressure relief valve is located on the vessel.

A standard 2-5/8 inch Fermi Parallel Plate Relief is mounted to the vessel (dwg # 1620-MB-106391). The documented capacity of the relief is 704 scfm air @2psig. Given that the MAWP of the vessel is 12 psig, the flow rate thru the valve is 1645 SCFM air. This corresponds to a LN2 flow rate of 63 L/min. Reference attached Appendix.

FERMILAB ENGINEERING NOTE	SECTION PPD/E&TT DØ	PROJECT HELIUM PURIFIER	SERIAL-CATEGORY	PAGE 1
SUBJECT 2" LIFT PLATE CAPACITY CALC. AT 2 PSIG		NAME THANG NGUYEN		
		DATE 1-17-00	REVISION DATE	

This is a relief capacity and pressure drop of SV-2628-V.

Find the standard flow rate, Q_s, in SCFM using equation #7 on page 10 in FIKE Booklet.

$$a = \frac{Q_s}{22772\, K C_1 P_o} \sqrt{(t+460)\, M}$$

✓ ok for subsonic

given:

$t = 60°F$ $\quad M = 29$

$K = 0.62$ for rupture discs.

$P_o = 2 + 14.67 = 16.67$ psia ✓ $\quad P_e = 14.67$ psia

$a = \frac{(2.625)^2}{4}\pi = 5.4119\ in^2$ ✓

$C_1 = 0.06784$ ✓ (Assume $P_e/P_o = .88$ ↑) ✓

$$5.4119\, in^2 = \frac{Q_s}{22772\,(0.62)(0.06784)(16.67\text{ psia})} \sqrt{(60+460)\,29}$$

$Q_s = 703.661$ SCFM (716)

29 for N_2

Reynold's number.

$$Re = 22700 \frac{qP}{d\mu} = 22700 \frac{(11.73)(0.0868)(12)}{2.157 \times 5.598\times10^{-4}} > 2000$$

$\simeq 2\times10^3$

$q = \frac{Q_s}{60} = \frac{703.661}{60} = 11.73$ ✓ SCFS

$P = .0868\ lb/ft^3$ @ 2 psi (CRANE PP A-10)

$d = 2.157$ in

$\mu = .018$ centipose $\cong 5.598\times10^{-4}\ \frac{lb}{ft\ sec}$ (CRANE PP A-5)

FERMILAB ENGINEERING NOTE	SECTION PPD/E & TT DØ	PROJECT HELIUM PURIFIER	SERIAL-CATEGORY	PAGE 2
SUBJECT 2" LIFT PLATE CAPACITY CALC. AT 2 PSIG		NAME THANG NGUYEN	DATE 1-17-00	REVISION DATE

PRESSURE DROP CALCULATION: (REFERENCE TO CRANE TECH PAPER 410 pp A-26 to A-29)

K = RESISTANCE COEFFICIENT

$K_{ENTRANCE} = .5$ (assume sharp edge)

90° pipe Bends short R.

r = 2 in r/d ≅ 1

$K_{ELBOW} = 20 f_T = 20(.019) = \boxed{0.38}$

$K_{TEE} = 20 f_T = \boxed{0.38}$ for FLOW Thru Run

K for gradual Enlargement

Assume that $\theta \leq 45°$

$$K_2 = \frac{2.6\left(\sin\frac{\theta}{2}\right)(1-\beta^2)^2}{\beta^4} = \frac{K_1}{\beta^4}$$

$$\beta^2 = \frac{a_1}{a_2}$$

$$a_1 = \frac{2.157^2}{4}\pi \qquad a_2 = \frac{2.625^2}{4}\pi$$

$$\beta^2 = \frac{3.6542}{5.4119} = .67216$$

$$K_2 = \frac{2.6\left(\sin\frac{45°}{2}\right)(1-0.67216)^2}{(0.67216)^2} = \boxed{0.23674}$$

$$K_{straight} = f\frac{L}{D} = (.019)\frac{24\,in}{2.157} = 0.2114$$

$K_{EXIT} = 1.0$

$K_{TOTAL} = \cancel{0.38} + \cancel{0.38} + 0.23674 + 1.0 + 0.2114 = 2.2081$

FERMILAB ENGINEERING NOTE	SECTION PPD/E &TT DØ	PROJECT HELIUM PURIFIER	SERIAL-CATEGORY	PAGE 3
SUBJECT 2" LIFT PLATE CAPACITY CALC. AT 2 PSIG		NAME THANG NGUYEN		
		DATE 1-17-00	REVISION DATE	

- PRESSURE DROP.

$$\Delta P = 43.5 \frac{f K \rho q^2}{d^5} =$$ (page 3-2 in CRANE TECH PAPER)

$L = 2$ ft
$\rho = 0.0868$ lb/ft^3
$d = 2.157$ in
$q = 76$ SCFS = standard cubic feet per second.
$f = .019$

$$\Delta P = 43.5 \frac{(.019)(2.2081)(.0868)(11.73 \frac{ft^3}{s})^2}{(2.157 \text{ in})^5}$$

$\Delta P = \underline{0.4668}$ psig

OK

FERMILAB ENGINEERING NOTE	SECTION PPD/mech	PROJECT 50% test	SERIAL-CATEGORY	PAGE 1
SUBJECT: 2" LIFT PLATE CAP. CALC @ 12psig		NAME: A. Cease		
		DATE: 11-16-04	REVISION DATE	

GIVEN

P_o = 12 psig = 26.67 psia
P_e = 14.67 psia
d = 2.157 inch
t = 60°F
m = 29g
area = 5.4119 in²

Find flow rate Q

$$\text{area} = \frac{Q}{11.4 P_o}\sqrt{\frac{t+460}{520}}\sqrt{\frac{29}{m}}$$ eq 12 Fike booklet

$$5.412 = \frac{Q}{(11.4)(26.67)}\sqrt{\frac{60+460}{520}}\sqrt{\frac{29}{29}}$$

1645 sfm = Q_{air}
27 sf per sec = Q_{air}

Find pressure drop between valve and tank

$$\Delta P = \frac{43.5 \cdot f \cdot k \cdot \rho \cdot Q^2}{d^5}$$

f = .019

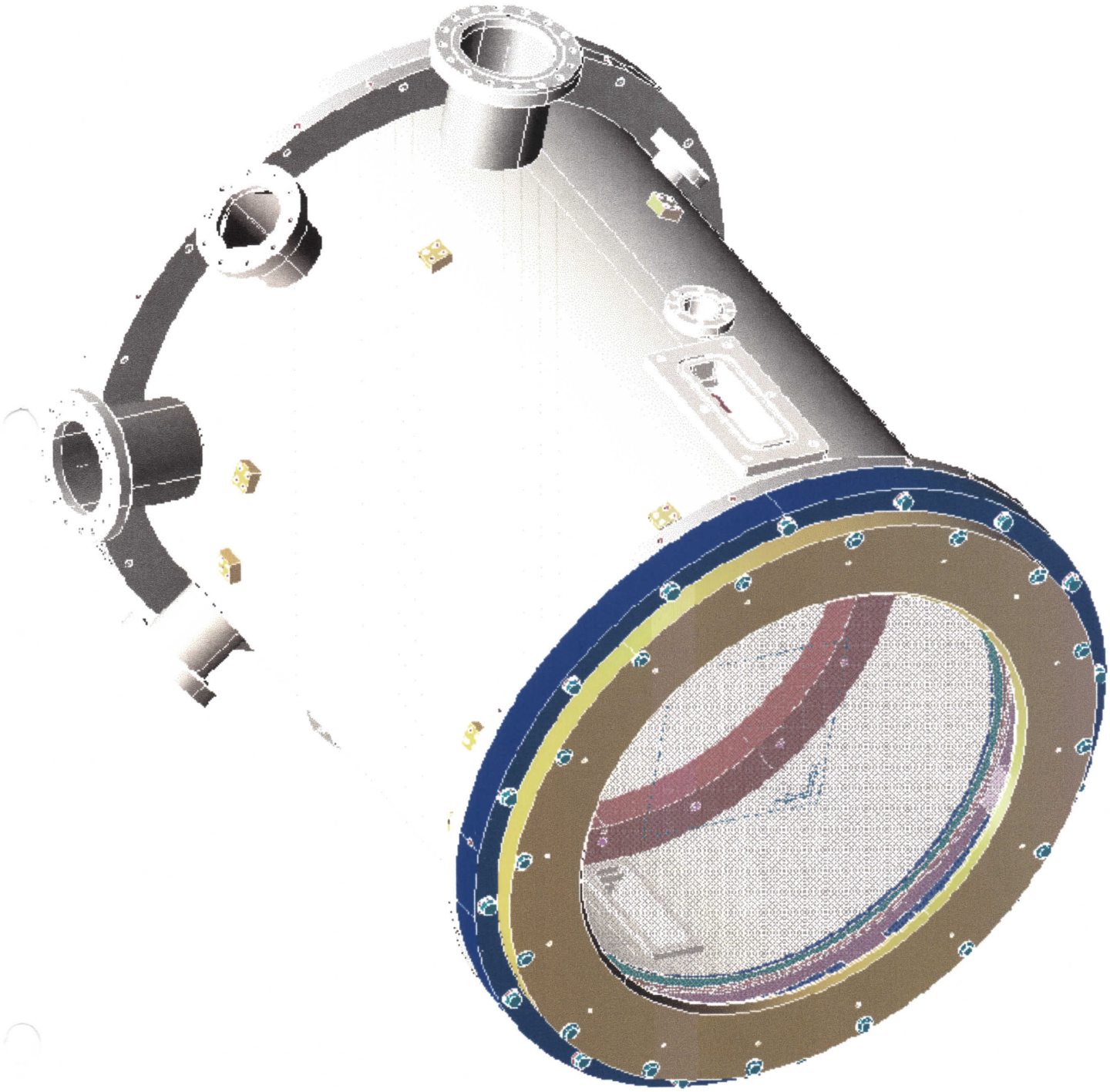
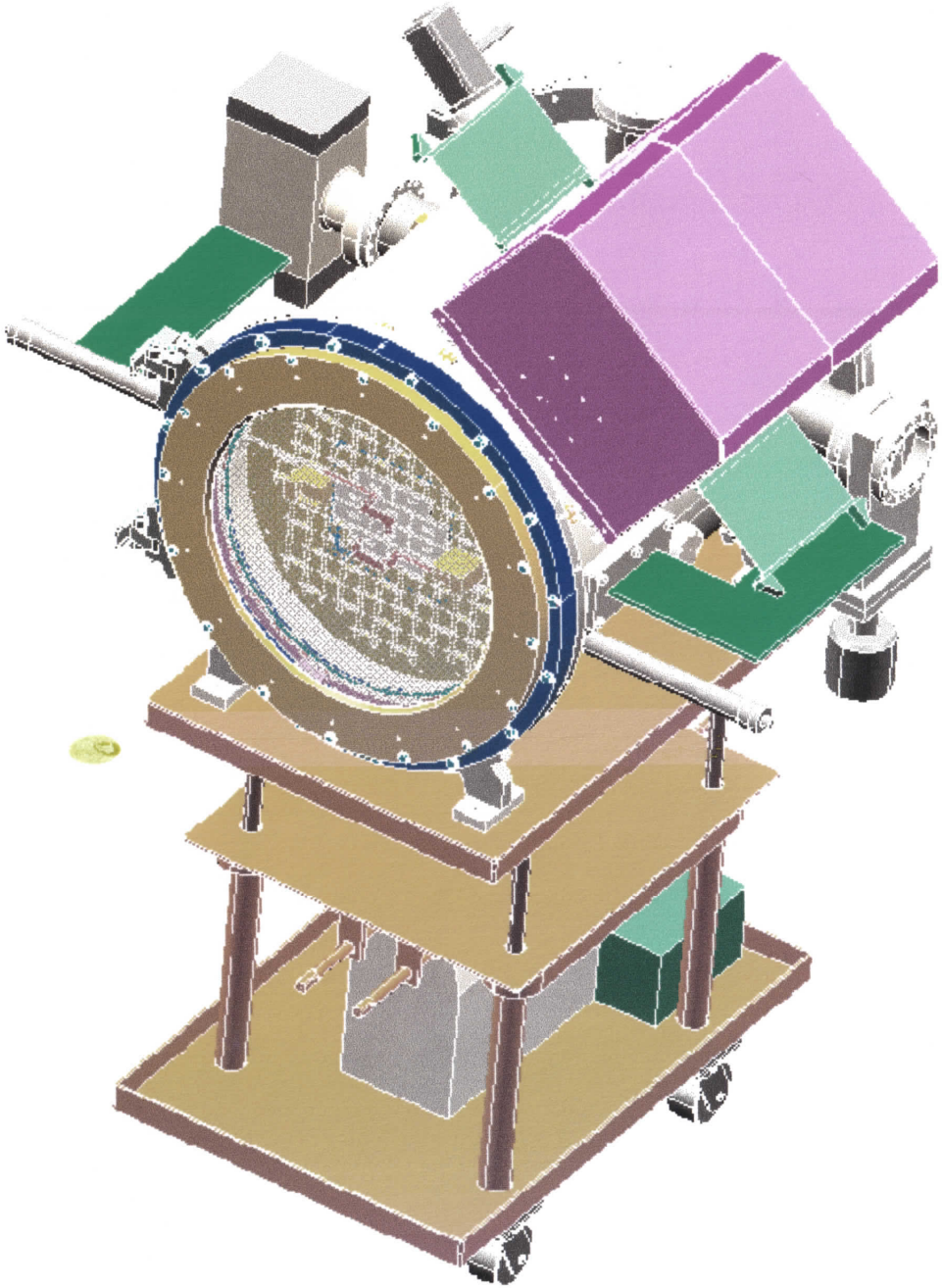
$k = k_{exit} + k_{gradual\ expansion} + k_{start\ pipe}$
k = 1 + .24 + .21 = 1.45
ρ = .14 lbm/ft³ density air at 12psig and 60°F (Crane A-10)
Q = 27 sf per sec
d = 2.157

ΔP = 2.5 psi

Tank pressure = 12psig + 2.5psig = 14.5 psig which is below the rating of the tank (15psig MAWP)

APPENDIX – Max LN2 Flow Rate –

It is possible that a LN2 leak could develop inside the vessel. A 2″ parallel plate relief valve is attached to the vessel. The plate is set to relieve at 2 psid. The maximum flow rate of GN2 thru the orifice is calculated in attached appendix as 1600 SCFM air.

Calculate an equivalent LN2 flow rate assuming an allowable gas flow rate of 1600 scfm:

Density of N2 gas at 300 K = 1.1233 kg /m^3 = 0.032 kg / ft^3
Kg/min flow rate = CFM flow rate * density = 1600 cfm * 0.032 kg / ft^3
= 51.2 kg/min
Density of LN2 = 807 kg/m^3
Liquid Flow rate = massflow rate / L_density = 51.2 kg/min / 807 kg/m^3
= 0.063m^3 / min
= 63 Liters/min LN2 flow rate