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Particle Physics Division

Engineering and Technical Teams

Mechanical Support Engineering Note

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Project: E-907

Project Internal Reference:

Title: RICH Low Pressure Engineering Note

Author(s): Jim Kilmer, Ang Lee

Reviewer(s): Ingrid Fang

Key Words:
E-907, RICH

Abstract/Summary:

This note documents the requirements for using the E-907 RICH vessel as a low pressure vessel. Included are gas supply and venting calculations, and strength calculations where needed.

Applicable Codes:

CGA, ASME

Fermilab
RD/MSD/Engineering Analysis Group
MS219, P.O.Box 500,Batavia, IL60510

ENGINEERING ANALYSIS REPORT (EAR) # 159

Engineering Analysis for the Kevlar Window Used in E-781 (Down Stream)

Ang Lee

April 5 , 1995

Index

1. Introduction
2. Specifications
3. Vessel Strength calculations
4. Vessel venting calculations
5. Vessel gas supply data

Introduction

The E-907 RICH vessel was previously used on experiment E-781 in exactly the same configuration. The vessel holds the radiator gas for the cerenkov counter. The main vessel was designed at Fermilab to standard ASME VIII Division 1 requirements for a heavy duty vessel which would take full vacuum. Those calculations will not be duplicated here. Other parts of the vessel limit its working pressure to less than 15 PSIG. The thin beam windows are very large and will not take full vacuum. A calculation for their strength is attached in part 3. Also in part 3 are the calculations for the phototube plate. This plate is 3" thick aluminum, but has almost 3000 holes in it. Here the ligament stress calculations are shown. These two components drive the MAWP of the vessel. In the present experiment it will be filled with carbon dioxide by displacement of the air in a flow purge. In part 4 are the calculations for the relief valve. Part 5 will contain the principal flow restrictor in the gas supply system, which is the regulator.

Specifications

Vessel volume	1540 cu. Ft.
Vessel diameter and length	93" ID X 402.5" long
Vessel wall	0.5"
MAWP	2 psig
Normal operating pressure	0.5 to 1.0 psig
Relief valve	Anderson Greenwood 930203FA

Drawing List

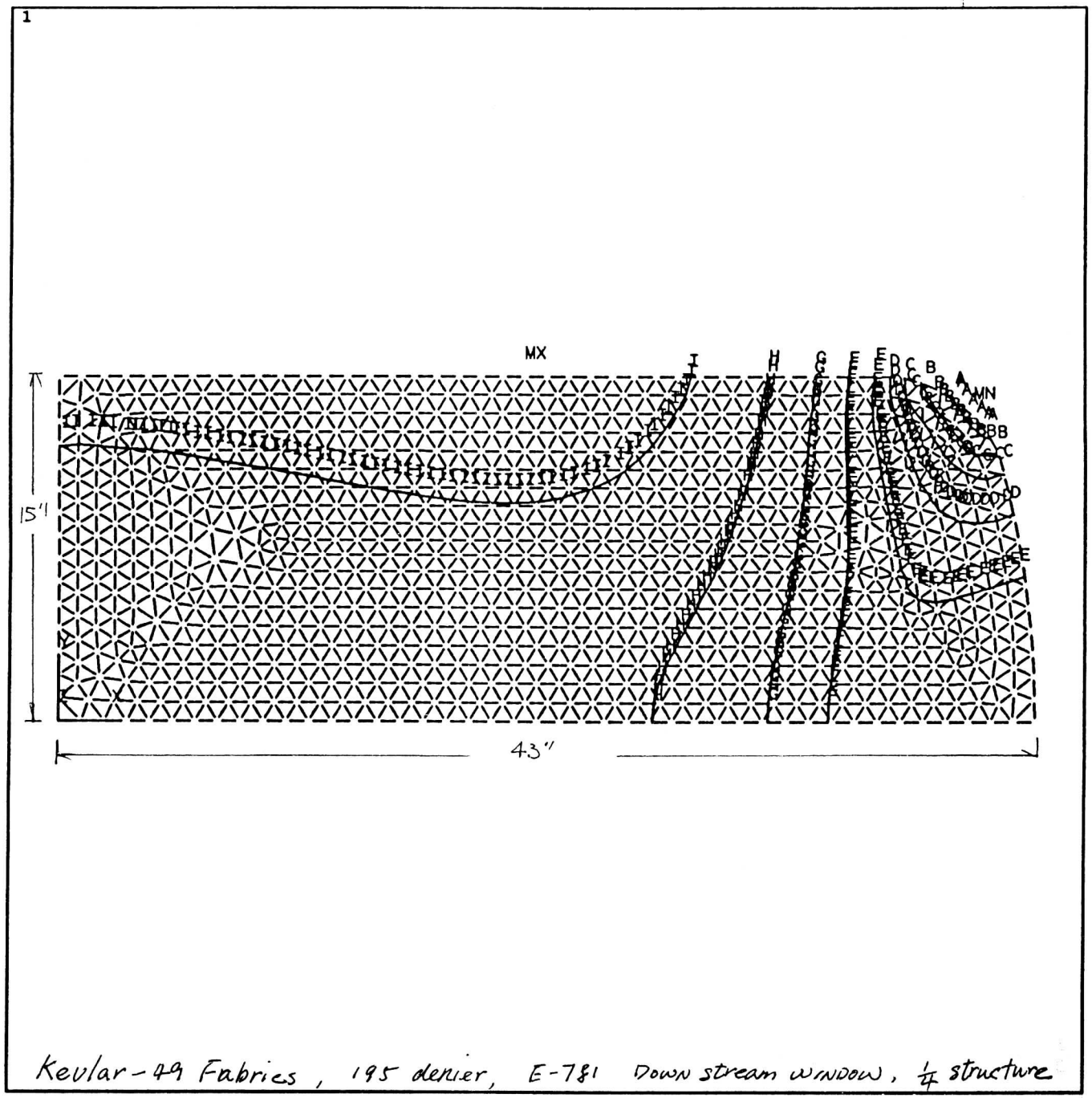
9211.600-ME-285812	Sheet 1 of 2	External vessel Weldment
9211.600-ME-285812	Sheet 2 of 2	External vessel Weldment
9213.150-ME285811		Cerenkov Main Assembly
9213.150-ME-285821		Phototube Plate Assembly

Engineering Analysis for the Kevlar Window Used in E-781 (Down Stream)

Ang Lee

April 5 , 1995

This note contains an engineering analysis for the Kevlar window used in the E-781__down stream. The material is Kevlar-49 fabrics with 240 lbf/in tensile strength in both warp and fill directions. The yarn denier is 195x195 (warp x fill). The cross section area of the yarn is estimated based on the weight / density and the technical data provided from Dupont. The window have been modeled as thin membrane plate with a thickness estimated based on the equivalent membrane stiffness. The 2 psi normal pressure is applied over the window surface. The result shows that the maximum stress is about 166 ksi as shown Figure 1. Compared with the tensile strength of the Kevlar 49 fabric, the SF is 1.76. The maximum deflection is about 1.74" as shown in Figure 2. The data sheet regarding the kevlar 49 is attached on the appendix.



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MAR 1 1995
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SMN =23727
SMX =174151
A =32084
B =48798
C =65511
D =82225
E =98939
F =115653
G =132366
H =149080
I =165794 psi.

$p = 2$ psi.

$\sigma_{max} = 165{,}794$ psi.

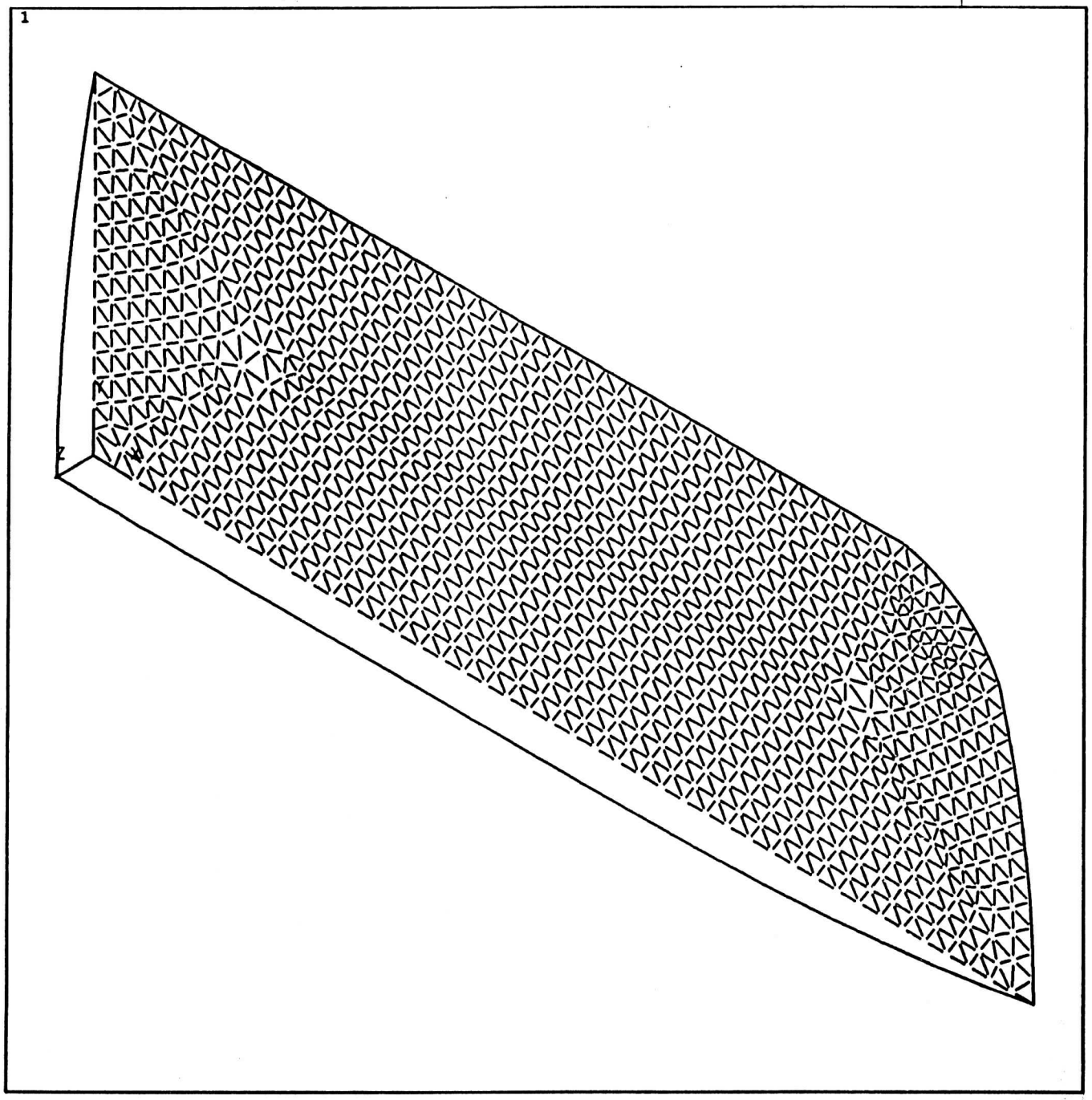
$$\sigma_{Tensile} = \frac{240 \text{ lb/in}}{34 * 2.412 \times 10^{-5}}$$

$= 292{,}654$ psi.

$$SF = \frac{\sigma_{Tensile}}{\sigma_{max}}$$

$= 1.765$.

Figure 1. stress plot ($p = 2$ psi)



ANSYS 5.0 A
MAR 1 1995
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DMX =1.738

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XV =1
YV =1
ZV =1
DIST=17.374
XF =21.5
YF =7.5
ZF =0.836142
EDGE

Dmax = 1.738"

Figure 2. displacement plot ($p=2$ psi).

Appendix

CLARK-SCHWEBEL FIBER GLASS CORPORATION

813 225-7028

5 CORPORATE PARK DRIVE WHITE PLAINS, N.Y. 10604 • Tel. 914 - 694 - 9090

PRODUCT DATA SHEET

CATEGORY

KEVLAR-49 FABRICS

No. 12D-10

DATE JAN. 1, 1990

PAGE 1 OF 1

C-S STYLE	FORMER DUPONT STYLE	WEIGHT OZ/SQ/YD	THICK-NESS* INCHES	COUNT	TENSILE LBS./INCH WARP	TENSILE LBS./INCH FILL	YARN DENIER WARP	YARN DENIER FILL	WEAVE
328	328	6.4	.012	17x17	700	750	1420	1420	PLAIN
343	143	5.5	.011	100x20	1200	140	380	195	CROWFOOT
345		1.7	.003	34x34	210	210	195	195	CROWFOOT
348	181	4.9	.008	50x50	625	625	380	380	8H SATIN
349	81	2.0	.004	41x40	310	300	195	195	CROWFOOT
350	120	1.7	.0037	34x34	240	240	195	195	PLAIN
351	220	2.2	.0046	22x22	294	298	380	380	PLAIN
352	281	5.2	.010	17x17	624	643	1140	1140	PLAIN
353	285	5.15	.009	17x17	623	635	1140	1140	CROWFOOT
354	500	4.8	.010	13x13	550	550	1420	1420	PLAIN
357	540	5.2	.010	11x17	440	700	1420	1420	PLAIN
358	243	6.6	.011	38x18	1483	227	1140	380	CROWFOOT
372		3.8	.007	73x72	525	550	195	195	4x4 TWILL
383	900	8.9	.014	16x16	920	974	2160	2160	5H SATIN
384	1050	10.7	.019	28x28	1368	1309	1420	1420	BASKET 4x
386	1350	13.6	.025	27x22	1826	1473	2160	2160	BASKET 4x
388	1033	15.0	.026	40x40	1850	1790	1420	1420	BASKET 8x

*ALL VALUES ARE BASED ON CS-800 (SCOURED) FABRICS. DATA IS TO BE USED AS A GUIDE ONLY AN ARE NOT GUARANTEED VALUES.

-5-

KEVLAR IS A REGISTERED TRADEMARK OF E. I. DUPONT DE NEMOURS & CO., INC.

Table III

Typical Technical Data

	Product	Filament		Yarn			Package[a]	
	Denier g/9000 m	Number Per Yarn	Cross Section Area 10^{-7} in^2	Nominal Break Strength lb	Nominal Diameter[b] 10^{-3} in.	Approximate Yield[c] yd/lb	Nominal Yarn Weight lb	Nominal Outer Diameter in.
KEVLAR* 29								
Type 960	1500	1000	1.8	75.0	17	2642	10, 17.8	8.25, 10.25
	3000	1333	2.7	146.0	24	1321	22	11.25
	15000	10000	1.8	620.0	54	264	10	6.8
Type 961	1000	666	1.8	50.7	14	4198	10	8.25
	1500	1000	1.8	76.0	17	2802	13, 22	9.1, 11.25
	3000	1333	2.7	154.0	24	1401	22	11.25
	4500	3000	1.8	226.0	29	934	10	6.8
	15000	10000	1.8	628.0	54	280	5, 16.6	4.1, 11.5
Type 962	1500	1000	1.8	71.0	17	2828	22	11.25
KEVLAR* 49								
Type 968/989	195	134	1.8	10.1	6.2	21470	5	6.5
	380	267	1.8	20.5	8.7	11018	5	6.5
	1140	768	1.8	59.3	15	3672	10	8.25
	1420	1000	1.8	75.1	17	2948	10, 11.9, 22	8.25, 8.75, 11.25
	2160	1000	2.7	102.5	21	1938	10, 11	8.25, 8.5
	2840	1333	2.7	135.0	24	1474	10, 22	8.25, 11.25
	4320	2000	2.7	205.0	29	969	9.5,10, 15	6.6, 6.8, 7.9
	5680	2666	2.7	267.0	33	737	–	–
	7100	5000	1.8	360.0	38	590	10, 11.5, 15	6.8, 7.1, 7.9
	8520	4000	2.7	402.0	40	491	–	–
Type 978	2160	1000	2.7	104.5	21	1822	10	8.25
KEVLAR* 68								
Type 989B	1420	1000	1.8	73.0	17	2921	10	8.25
	2160	1000	2.7	113.1	21	1920	11, 21.5	8.5, 11.2
	2840	1333	2.7	148.0	24	1460	10, 13.5	8.25, 9.2

Finish Types

Cordage finish (used for Types 960, 978) is a high-lubricity finish for improved abrasion resistance.

Standard finish (used for Types 961, 968, 989, and 989B) is a standard-lubricity finish.

Type 962 has no finish applied to it.

[a] In addition to standard package weights, KEVLAR 49 and KEVLAR 68 are also available on tailored-length packages. Types 989 and 989B are recommended for fiber optic cable applications which require metered length and/or improved package stability on rolling take-off serving equipment.

[b] Assumes 80% packing factor.

[c] Takes into consideration respective moisture and finish levels.

* Du Pont Registered Trademark

Table 1 **Comparative Properties**

	Tensile Strength lb/in² (MPa)*	Tenacity g/den (dN/tex)	Modulus lb/in² (MPa)	Elongation at break	[illegible]
YARN — tested per textile test (ASTM D885)					
KEVLAR 29	400,000 (2 760)	22 (19.4)	9,000,000 (62 000)	[illegible]	[illegible]
KEVLAR 49	400,000 (2 760)	[illegible] (19.4)	[illegible]	[illegible]	[illegible]
Du Pont Nylon (Type 728)	143,000 (985)	[illegible]	[illegible]	[illegible]	[illegible]
DACRON** Polyester (Type 68)	162,500 (1 120)	9.2 (8.1)	2,000,000 (13 800)	[illegible]	[illegible]
Stainless Steel	250,000 (1 720)	2.5 (2.2)	29,000,000 (200 000)	[illegible]	[illegible]
REINFORCING FIBERS — tested per resin impregnated strand test (ASTM D2343)					
KEVLAR 29	525,000 (3 620)		12,000,000 (83 000)	[illegible]	[illegible]
KEVLAR 49	525,000 (3 620)		18,000,000 [illegible]	[illegible]	[illegible]
High Strength Graphite	450,000 (3 100)		32,000,000 (221 000)	[illegible]	[illegible]
"E" Glass	350,000 (2 410)		10,000,000 (69 000)	[illegible]	[illegible]
Asbestos	100,000 400,000 [illegible]		23,200,000 (160 000)	0.4-[illegible]	[illegible]

*MPa = MN/m² = lb/in² x 6.895 x 10^{-3}

**DACRON is DuPont's registered trademark for its polyester fiber.

Table 2 **Comparative Properties for Rubber Reinforcement (Dipped Belt Cords)**

	Cord Size Denier (dtex)	Construction	Breaking Strength lbs (N)	Tenacity g/den (dN/tex)	Elongation at Break %	Modulus g/den (dN/tex)	Loop Tenacity g/den (dN/tex)
KEVLAR®	4,500 (5 000)	1500/1/3	180 (800)	18 (15.9)	4	[illegible]	[illegible]
Wire	17,500 (19 400)	1x5x[illegible]	139.0 (618)	3.6 (3.2)	2.1	[illegible]	[illegible]
Glass	12,100 (13 400)	15/3/0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

updated Table For page 8 A Lee

Table II-2 compares the properties of KEVLAR 29 and KEVLAR 49 to other yarns, such as glass, steel wire, nylon, polyester, polyethylene and carbon. Compared to KEVLAR, nylon and polyester have relatively low moduli and intermediate melting points. Polyethylene has a high initial modulus, which is offset by its relatively low melting point.

TABLE II-2. Comparative Properties of KEVLAR® vs. Other Yarns

	"Customary" (inch-pound) Units							
	Specific Density lb/in.^{3}	Tenacity 10^3 psi	Modulus 10^6 psi	Break Elongation %	Specific Tensile Strength* 10^6 in.	CTE** 10^{-6}/°F	Decomposition Temperature °F	(°C)
KEVLAR 29	0.052	424	10.2	3.6	8.15	-2.2	800-900	(427-482)
KEVLAR 49	0.052	435	16.3	2.4	8.37	-2.7	800-900	(427-482)
Other Yarns								
S-Glass	0.090	665	12.4	5.4	7.40	+1.7	1,562†	(850)
E-Glass	0.092	500	10.5	4.8	5.43	+1.6	1,346†	(730)
Steel Wire	0.280	285	29	2.0	1.0	+3.7	2,732†	(1,500)
Nylon-66	0.042	143	0.8	18.3	3.40	—	490†	(254)
Polyester	0.050	168	2.0	14.5	3.36	—	493†	(256)
HS Polyethylene	0.035	375	17	3.5	10.7	—	300	(149)
High-Tenacity Carbon	0.065	450	32	1.4	6.93	-0.1	6,332	(3,500)

*Specific tensile strength is obtained by dividing the tenacity by the density.

**CTE is the coefficient of thermal expansion (in the longitudinal direction).

†Melt temperature.

cross-section area per yarn

a): Dupon Kevlar -49 Fabrics. Denier 195.

$$195 \text{ denier} = \frac{195 \text{ gram}}{9000 \text{ m}} = 2.1667 \times 10^{-4} \frac{g}{cm}$$

$$\rho = 1.44 \frac{gram}{cm^3}.$$

$$W = A \cdot L \cdot \rho = A * 1 cm * 1.44 \frac{g}{cm^3} = 2.1667 \times 10^{-4}$$

$$A = \frac{2.1667 \times 10^{-4}}{1.44} = 1.5046 \times 10^{-4} \text{ cm}^2 \text{ or } 2.33 \times 10^{-5} \text{ in}^2$$

$$d = \sqrt{\frac{A \times 4}{\pi}} = 0.0138 \text{ cm} \text{ or } 5.4492 \times 10^{-3} \text{ in}$$

b): Based on Dupont Technical Data.

$$A = 134 \text{ filament/yarn} * 1.8 \times 10^{-7} \text{ in}^2/\text{filament}$$

$$= 2.412 \times 10^{-5} \text{ in}^2.$$

$$d = \sqrt{\frac{A \times 4}{\pi}} = \sqrt{\frac{2.412 \times 10^{-5} \times 4}{\pi}} = 5.541 \times 10^{-3} \text{ in}.$$

Diff% $\leq 2\%$

Take: $d = 5.541 \times 10^{-5}$ in OR $A = 2.412 \times 10^{-5}$ in^2.

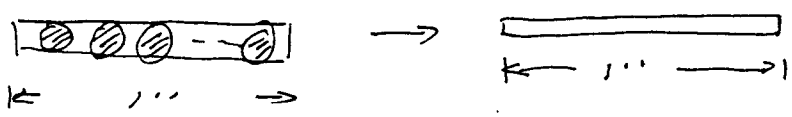
For single yarn:

$$A = 2.412 \times 10^{-5} \ in^2 .$$

per inch Base:

$$A = 2.412 \times 10^{-5} \ in^2/yarn \ * \ 34 \ yarn/IN$$

$$= 8.2008 \times 10^{-4} \ in^2/$$

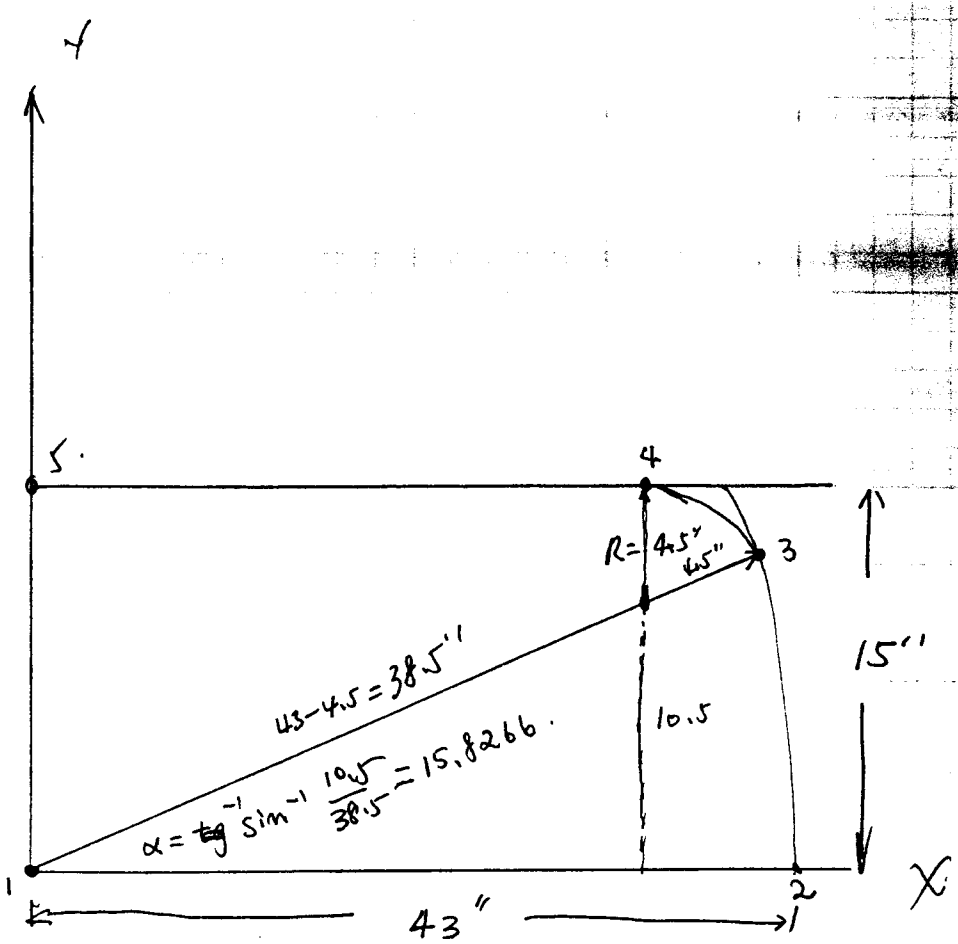


$= t_{eff}$.

$$t_{eff} = A = 8.2008 \times 10^{-4} \ in^2$$

E-781 counter.

$\Delta p = 2$ psi



Fermilab
PPD/MD/Engineering Analysis Group

MSG-EAR03-340

The Stress Calculation for the Phototube Plate__(E781)

Ang Lee & Jim Kilmer
Oct 9th , 2003

Introduction

The phototube plate used in E-781 consists of many small holes where the glass plate will be installed as shown in drawing #9213.150-ME-285771. This "hollow-like" aluminum plate will be subjected to a 3 psi operation load. In order to qualify for that, a calculation for the plate subjected to a lateral load is done to make sure that the working stress is limited or below to its allowable stress.

Modeling & Criteria

Several calculations have been done. First one is to use a simple model based on the equivalent bending stiffness following by a formula from "Roark's Formulas for Stress & Strain"[1]. Both second and third calculations are FEA approaches to model the whole plate with many small holes as is to check the maximum stress. The final study is to use ASME code ligament calculation to check the working stress. The plate material is Al 6061-T6. ASME Section 2 ,Part D, gives its allowable

$$\sigma(allowable) = 10{,}500 psi$$

Result and Discussion

The simple model calculation shows that the maximum stress is about 1,536 psi as shown in Appendix A. The result from a FEA thick plate model shows the maximum stress is about 1,333 psi. It is not far away from first calculation. As a further cross check, a 3-D solid FEA model also shows the maximum stress is around 1,400 psi. It is very consistent with the earlier result. Then, ASME Section VIII, Div 1, UG-53 & Appendix 13 for ligament efficiency have been also shown that the current design is satisfied with the code requirement as seen in Appendix B. The result is summarized in Table 1. Therefore, we have concluded that the plate is adequate for 3 psi operating load.

Table 1 Summary of Calculation Result

	$\sigma_{(\max)(psi)}$	$\sigma_{(allowable)(psi)}$	t (min)"	t(design)"	adequate
1) Simple Model	1,536	10,500	N/A	3"	Y
2) FEA thick plate	1,333	10,500	N/A	3"	Y
3) FEA solid element	1,400	10,500	N/A	3"	Y
4) ASME UG-53	N/A	10,500	1.68"	3"	Y
5) ASME App 13	1,547	10,500	N/A	3"	Y

Reference:

(1) W.C. Young, "Roark's Formulas for Stress & Strain", Sixth Edition, McGraw-Hill, pp 464.
(2) ASME Boiler and Pressure Vessel, Section VIII, Div I, 1992 ED.

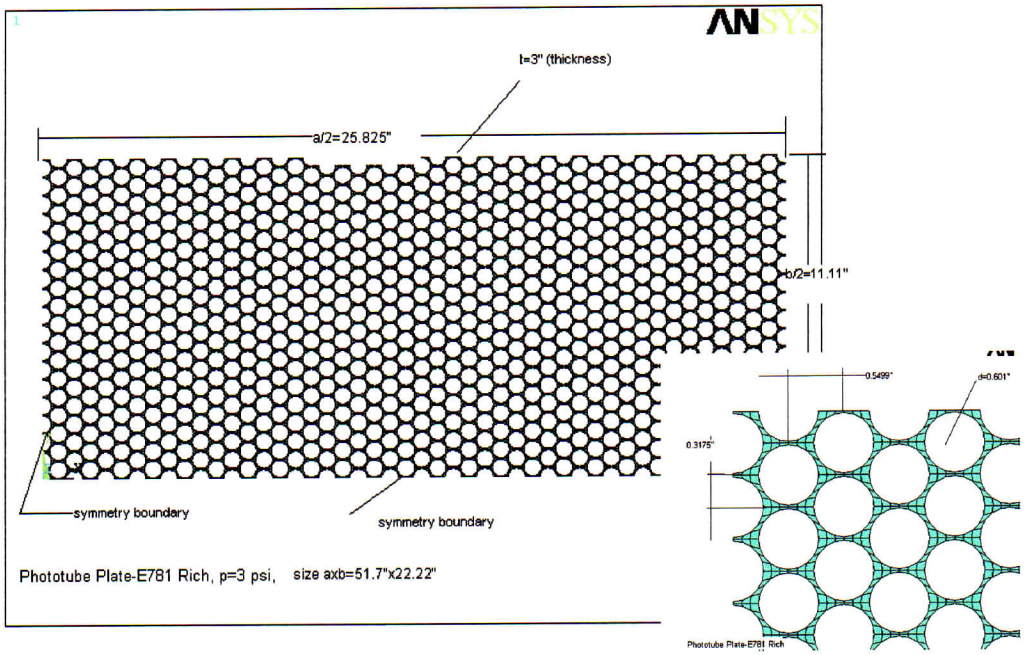


Figure 1 The FEA Model

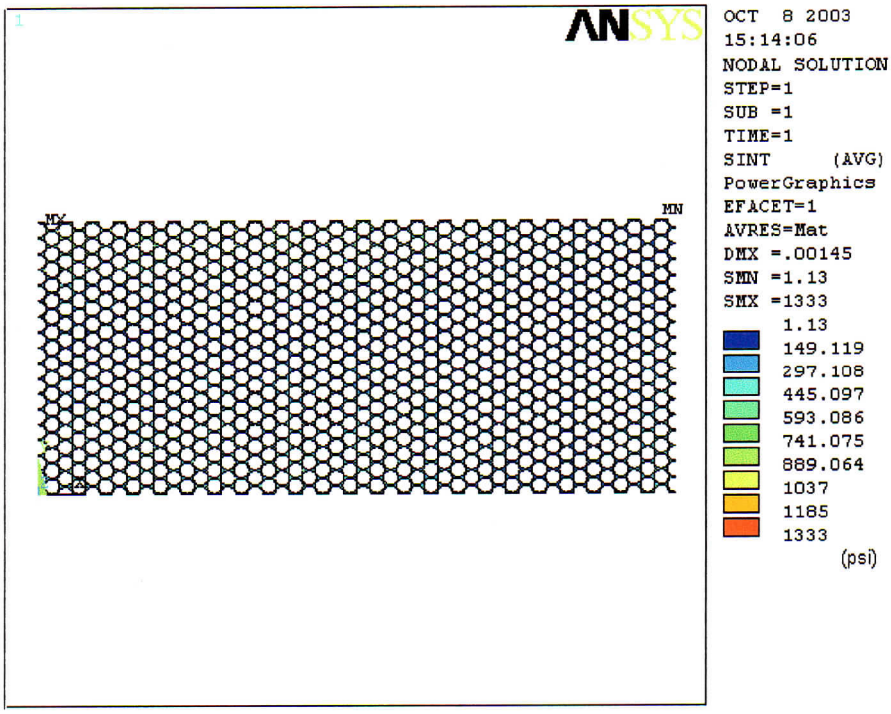


Figure 2 The stress based on the thick plate model

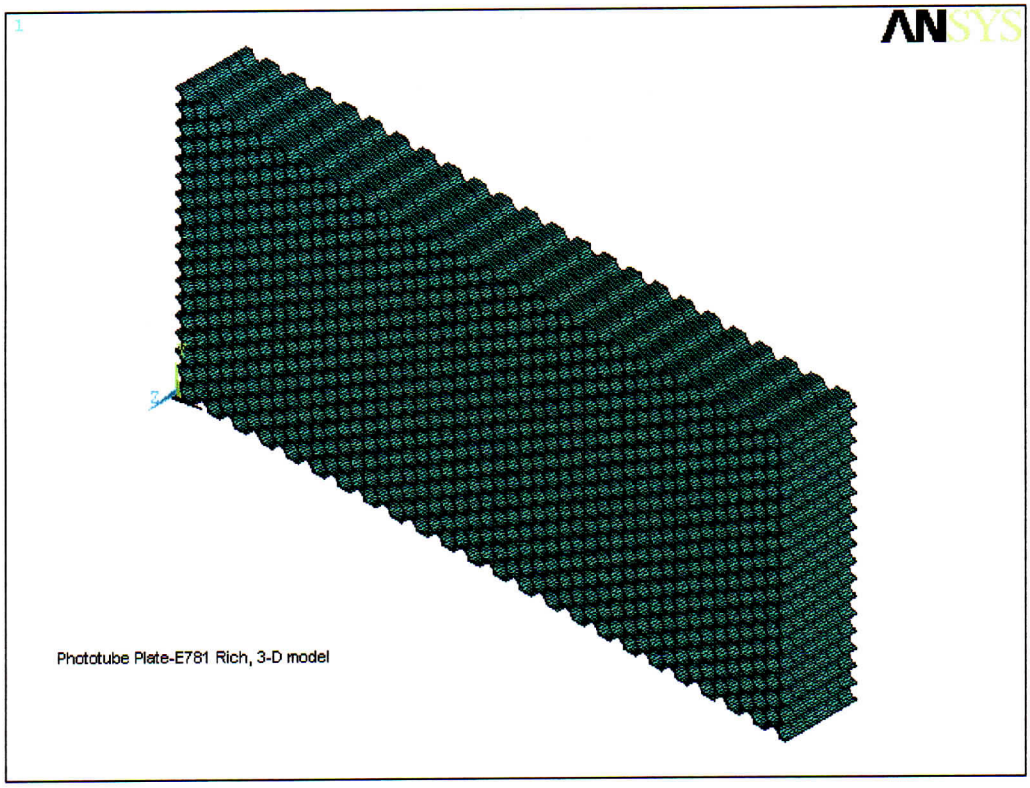


Figure 3 The FEA 3-D solid element model

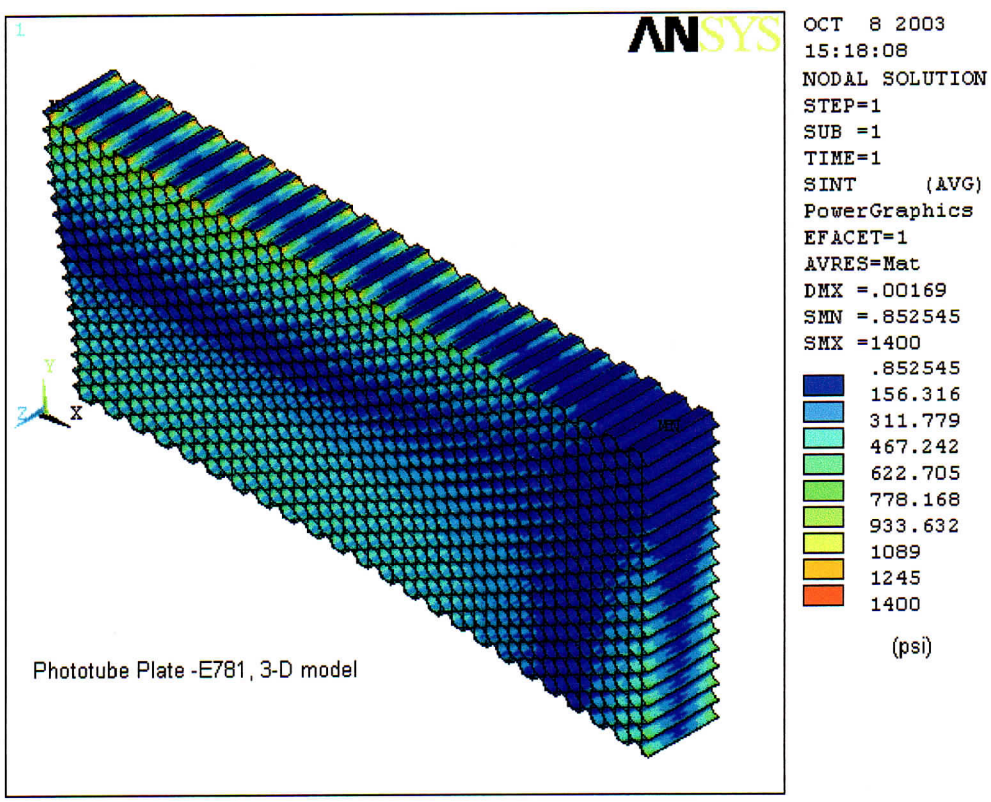
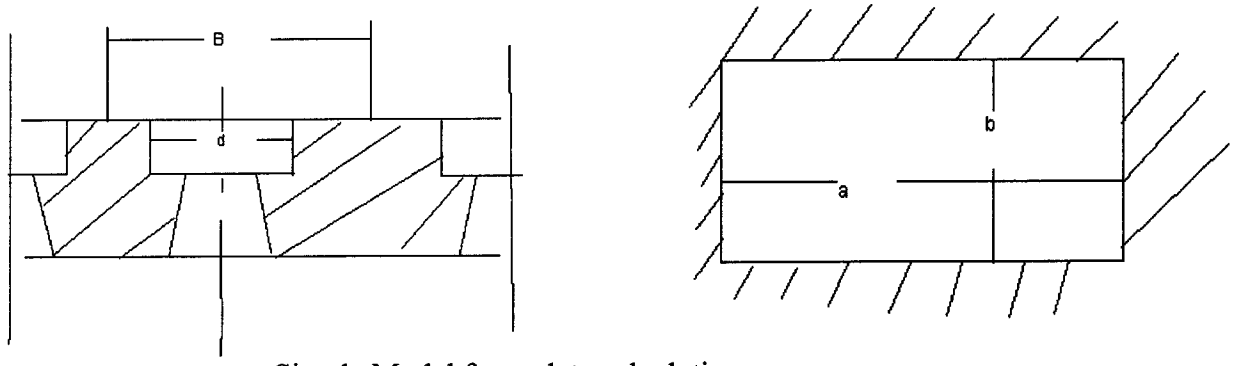


Figure 4 The stress plot for 3-D model

Appendix A



Simple Model for a plate calculation

Where
B=0.3175"*2=0.635"
d=0.601"

Material: Al 6061T-T6

$$\sigma(allowable) = 10{,}500(psi)$$

The inertial moment for the hollow plate I_h with a unit width: $I_h = \dfrac{(B-d)*t^3}{B*12}$

The equation from reference 1 for the solid plate subjected to lateral load shows

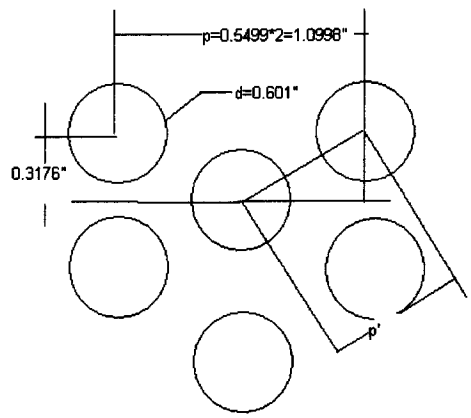
$$\sigma_{\max} = \frac{\beta*q*b^2}{t^2} = \frac{\beta*q*b^2*\frac{t}{12}}{t^2*\frac{t}{12}} = \frac{\beta*q*b^2*\frac{t}{6*2}}{\frac{t^3}{12}} = \frac{\frac{\beta*q*b^2}{6}*\frac{t}{2}}{I}$$

For the hollow plate, we substitute I_h for I in above equation, and then the maximum stress for the hollow-like plate will be

$$\sigma_{(\max)} = \frac{\frac{\beta*q*b^2}{6}*\frac{t}{2}}{\frac{(B-d)*t^3}{B*12}} = \frac{\frac{0.5*3*22.22^2}{6}*\frac{3''}{2}}{\frac{(0.635''-0.601'')*3^3}{0.635''*12}} = 1{,}536(psi) << 10.5ksi(allowable)$$

Appendix B ASME code ligament calculation

1)Per UG-53 ,ASME Section VIII, Div II,



p=0.5499"*2=1.0996"
p'=$(0.5499^2+0.3176^2)^{0.5}$=0.635"
p_1=p
E (long)=(p-d)/p=(1.0998-0.601)/1.0998=0.453
Ratio p'/p_1=0.635/1.0998=0.577

It is off the Fig UG-53.5, and then use following equation per UG-53

$$\text{Diagonal Efficiency \%}=\frac{J+0.25-(1-0.01Elong)*\sqrt{0.75+J}}{0.00575+0.005J}$$

Where J=$(p'/p_1)^2$=$(0.635/1.0998)^2$=$(0.577)^2$=0.3329
E=100*(p_1-d)/p_1=100*0.453=45.3

So, diagonal efficiency %

$$=\frac{0.3329+0.25-(1-0.01*45.3)*\sqrt{0.75+0.3329}}{0.00375+0.005*0.3329}=\frac{0.5839-0.5692}{0.005415}=2.51\%$$

Per UG-27, for a cylindrical shell subject to the internal pressure, code gives

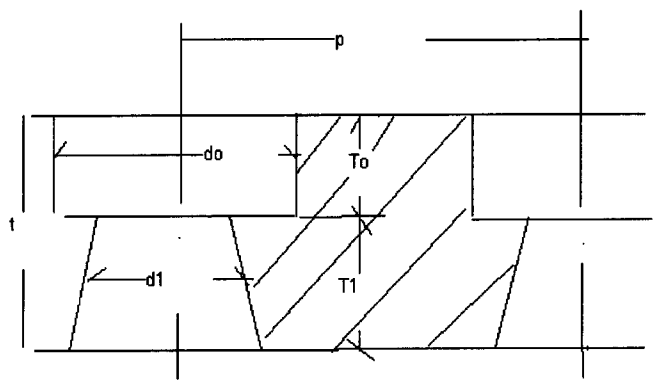
t min=PR/(SE-0.6 P)

The allowable is multiplied by ligament efficiency E to count for the hole effect. For the same reason, the plate, subjected to a lateral load, can be calculated by using reference 1 as following:

$$t_{\min} = \sqrt{\frac{\beta * q * b^2}{S * E}} = \sqrt{\frac{0.5 * 3 * 22.22^2}{10{,}500 * 0.025}} = 1.68" < t_{design} = 3"$$

The code requirement UG-53 is satisfied.

2) Per ASME Section VIII, DIV II, Appendix 13



Per 13-6(b)

Ligament efficiency of plate with multidiameter hole subjected to the bending stress can be found as

Ligament Efficiency e_b=(p-De)/p

Where De=p-6I/(t^2*c)
For the simplicity, we have assumed all holes will have only one size d_o Then, equation (5) gives

$$I = \frac{1}{12} * b_0 * T_0^3 + b_0 * T_0 (\frac{T_0}{2} - \overline{X})$$

$$where T_0 = t, b_0 = p - d_0$$

$$\overline{X} = b_0 * T_0 * \frac{T_0}{2} * (b_0 * T_0)^{-1} = \frac{T_0}{2}$$

$$c = \overline{X} = \frac{T_0}{2} = \frac{t}{2}$$

So,

$$I = \frac{b_0 * t^3}{12} + b_0 * t * (\frac{t}{2} - \frac{t}{2}) = \frac{b_0 * t^3}{12}$$

then

$$De = p - \frac{6 * I}{t^2 * c} = p - \frac{6 * b_0 * \frac{t^3}{12}}{t^2 * \frac{t}{2}} = p - b_0 = p - (p - d_0) = d_0$$

So, the ligament efficiency e_b

$$e_b = (p - De)/p = (p - d_o)/p = (0.635 - 0.601)/0.635 = 0.053$$

It is interested to note it is the exact same number used by simple model approach (appendix A) for the reduction factor of I. The maximum stress can be found based on reference 1 without hole

$$\sigma_{\max}^{solid} = \frac{\beta * q * b^2}{t^2} = \frac{0.5 * 3 * 22.22^2}{3^2} = 82(psi)$$

Then, the maximum stress for the hollow plate is

$$\sigma_{\max}^{hole} = \frac{\sigma_{\max}^{solid}}{e_b} = \frac{82}{0.053} = 1{,}547(psi) << 10{,}500(psi) = allowable$$

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT

NAME

DATE

REVISION DATE

$$A = \frac{V\sqrt{MTZ}}{6.32\, C K P_1}$$

(CONVERT REGULATOR FLOW RATE FROM AIR → CO_2 USING FLOW FORMULA FOR FLOW FROM ANDERSON GREENWOOD CATALOGUE.)

$$\frac{V_{AIR}\sqrt{M_{AIR}\cancel{T}\cancel{Z}}}{\cancel{6.32}\, C_{AIR}\, \cancel{K}\cancel{P_1}} = \frac{V_{CO_2}\sqrt{M_{CO_2}\cancel{T}\cancel{Z}}}{\cancel{6.32}\, C_{CO_2}\, \cancel{K}\cancel{P_1}}$$

$$V_{CO_2} = V_{AIR}\sqrt{\frac{M_{AIR}}{M_{CO_2}}}\,\frac{C_{CO_2}}{C_{AIR}}$$

$$V_{CO_2} = V_{AIR}\left(\sqrt{\frac{29}{44}}\right)\left(\frac{345}{356}\right)$$

$$= V_{AIR} \times .787$$

FROM THE REGULATOR FLOW GRAPH USE MAXIMUM POSSIBLE AIR FLOW EVEN THOUGH CO_2 BOTTLE PRESSURE WILL BE LESS

$$\Rightarrow V_{CO_2} = (1750\ \text{SCFH})(.787)$$

$$= 1380\ \text{SCFH OF } CO_2 = 23\ \text{SCFM OF } CO_2$$

COMPARE WITH RELIEF VALVE FLOW RATE

$$V_{REQ} < V_{PROVIDED}$$

$$23\ \text{SCFM OF } CO_2 < 267\ \text{SCFM OF } CO_2 \text{ FROM AG VALVE}$$

RELIEF VALVE PROVIDED IS OK.

Jim Kilmer

From: "Terry Tope" <tope@fnal.gov>
To: "Jim Kilmer" <kilmer@fnal.gov>
Sent: Wednesday, August 13, 2003 4:51 PM
Attach: 041_65-2007.pdf
Subject: RICH CO2 regulator

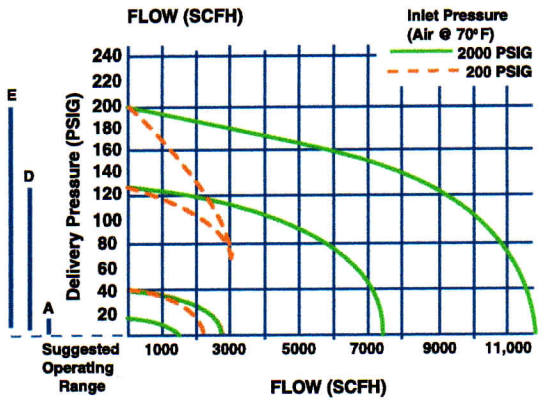
Hi Jim. We will use a Victor VTS 453-D-320 regulator. Its delivery pressure range is 4-50 psi and the maximum flow is 1750 SCFH. The 750 SCFH figure I gave you is for a 0-15 psi delivery range regulator which usually gets used on flammable gas. See attached sheet if you want to include the regulator flow curve in your document. Its the middle chart in the right hand column. And the flow is actually a little less than that because the CO2 bottles are only 830 psig (versus the 2000 psig on the plot) so they don't become liquid.

Regards,

Terry Tope
Fermi National Accelerator Laboratory
630.840.2666

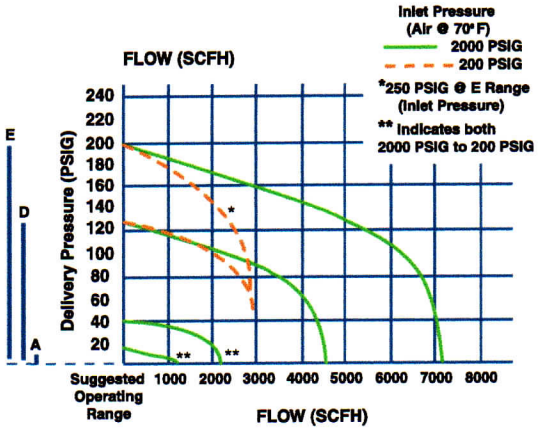
Regulator Flow Data (SCFH)

SR 700/Single Stage - Extra Heavy Duty



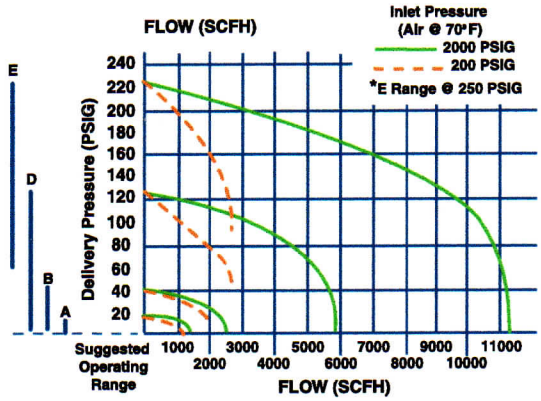
Reference: SR 700 Series - Section A, Page 6

VTS 700/Two Stage - Extra Heavy Duty



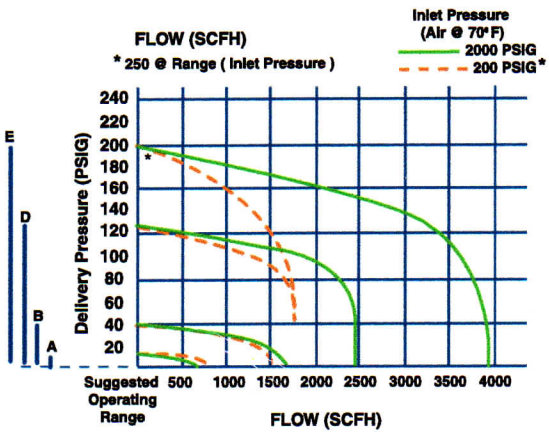
Reference: VTS 700 Series - Section A, Page 7

SR 450/Single Stage - Heavy Duty



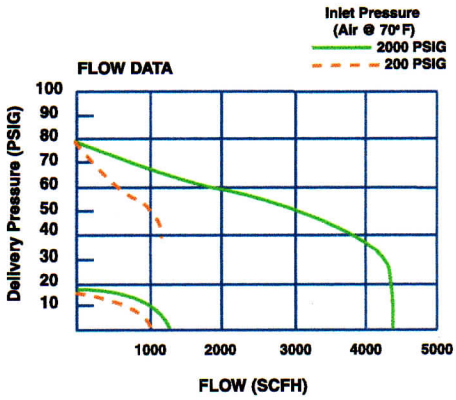
Reference: SR 450 Series - Section A, Page 8

VTS 450/Two Stage - Heavy Duty



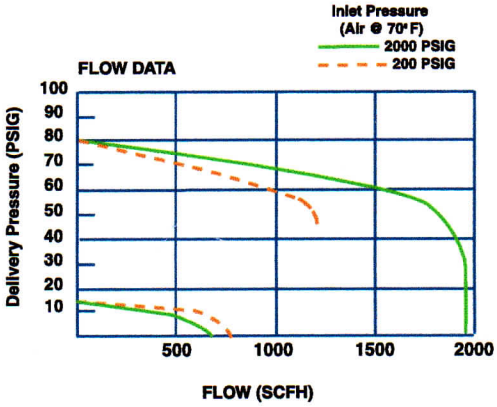
Reference: VTS 450 Series - Section A, Page 9

VGS 450/Gaugeless Regulator - Heavy



Reference: VGS 450 Series - Section A, Page 10

VGT 450/Gaugeless Two Stage Regulator Heavy Duty



Reference: VGT 450 Series - Section A, Page 10

Status	Input	Name	Output	Unit	Comment
					This calculates relief valve flow on E-907 Rich vessel.
					Formulas are from the Anderson Greenwood catalogue for Type 93 piloted relief valves.
		P2pr	15.615144		
	16.7	P1			Valve inlet in psia
	14.7	P2			Valve outlet in psia
		Fpr	.245017366		Factor based on ratio of specific heats and valve pressure dro
	1.28	k			Carbon Dioxide Specific Heat Ratio
		V	267.630655		Valve flow in SCFM of Carbon Dioxide
	2.29	A			Orfice Area (sq in) for Type 93 valve
	.939	Kd			Nozzle coefficient for Type 93 valve
	44	M			Carbon Dioxide Molecular weight
	530	T			70 degrees F in Rankine
	1	Z			Compressibility factor

Status	Rule
Satisf	P2pr=P1-0.55*(P1-P2)^0.98
Satisf	Fpr=SQRT((k/(k-1))*((P2pr/P1)^(2/k)-(P2pr/P1)^((k+1)/k)))
Satisf	V=4645*A*Kd*P1*Fpr/(SQRT(M*T*Z))