EC Vacuum Vessel Finite Element Analysis

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A handwritten signature in black ink, appearing to read "RD Luther", is positioned to the right of the printed name "Originator: Dave Rudland/Rick Luther".

EC Vacuum Vessel Finite Element Analysis

Dave Rudland/Rick Luther

This Note contains a summary of the results of the finite element analysis of the EC Cryostat vacuum vessel performed by Dave Rudland in 1987. The results are used in the structural evaluation of the EC cryostats presented in Engineering Note 194. It should also be noted that the adequacy of the design of the vacuum vessels was reviewed and verified by the Battelle Memorial Institute. Battelle used a shell of revolution program to essentially duplicate the FEA analysis with similar results.

It should be noted that no plots of the finite element mesh were retained from the analysis, and these can not be easily reproduced due to a change in the version of the ANSYS computer program shortly after the analysis was completed.

Various Local Analysis - Check of Stress Points

- ① Membrane hoop stress should not exceed $1\frac{1}{2}SE$
- ② Membrane longitudinal stress - Bending should not exceed $4SE$

A. Outer Ring 1.5, $E = .65$

$$S = 18,800$$

$$1.) 1\frac{1}{2}SE = 18,300 \text{ psi}$$

$$2.) 4SE = 48,880 \text{ psi}$$

Code Allowables

Section = ① Membrane Hoop Stress (psi) ② Membrane Longitudinal + Bending Stress (psi)

	2.5 inner Ring	1.5 inner Ring	2.5 inner	1.5 inner
1	-4181	-4174	21940	21940
2	-2005	21612	-27100	-27100
3	2261	2264	-19600	-19600
4	3055	3057	-13110	-13110
5	-17130	-17130	7785	7781
6	-16060	-16060	8008	8119
7	-15460	-15460	5961	5948
8	-12280	-14740	4324	4348

Vacuum Vessel Stiff ring Buckling

Outer Ring

F_1 = Force due to hoop stress on Vessel

$$L = \frac{1}{2} \text{ Ring Length} + \text{Shell Length} + \frac{1}{3} \text{ head depth.}$$

$$= 2 + 65.335 + 11.4073 = 78.742 \text{ in}$$

$$F = \sigma \cdot A$$

$$\sigma = \frac{PR}{t} = \frac{15 \text{ psi} (102)}{.62} = 2467.7419 \text{ psi}$$

$$A = \left(\frac{L}{2} - 2 \right) t = \left(\frac{78.742}{2} - 2 \right) (.62) = 23.17 \text{ in}^2$$

$$F_1 = 2467.7419 \text{ psi} \cdot 23.17 = \underline{57177.63 \text{ lbs}}$$

F_2 = Force due to hoop stress on Ring

from Area - Average Membrane hoop stress

$$\text{is } 11542.65 \text{ psi}$$

$$\text{Area of ring} = 2.5 \times 4 = 10 \text{ in}^2$$

$$F_2 = 115426.5 \text{ lbs}$$

F_3 = Force on Window section $\frac{1.1 \sqrt{D_o t}}{2}$

$$\text{Say } D_o = 408''; t = .625$$

$$D = \frac{1.1 \sqrt{D_o t}}{2} = \frac{.55 \sqrt{408 (.625)}}{2} = 8.783$$

STRESS From ANSYS

$$\text{AVERAGE HOOP STRESS (MEMB.)} = 15852.5 \text{ psi}$$

$$A = Dt = 8.783 (.625) = 5.489 \text{ in}^2$$

$$F_b = \sigma A = \underline{87014.37 \text{ lbs}}$$

$$F_T = 57177.63 + 115426.5 + 87014.37 = 259618.5 \text{ lbs}$$

NOW THE AREA TAKING THIS LOAD

$$A = 4(2.5) + 8.783 (.625) + .55 (\sqrt{204 (.62)}).62$$
$$= 19.32 \text{ in}^2$$

$$\bar{\sigma} = \frac{F_T}{A} = \frac{259618.5}{19.32} = 13434.2 \text{ psi}$$

From JAWAD & FARR

STRUCTURAL ANALYSIS AND DESIGN OF
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$$B = \frac{\sigma (\text{F.S.})}{\bar{\sigma}} \quad \text{Try F.S.} = 3$$

$$= \frac{3}{2} \sigma = \frac{3}{2} (13434.2) = 20151.3$$

$$A \geq 1.0$$

$$I \geq \frac{B^2 (\text{AREA}) A}{10.9} = \frac{(204)^2 (19.32) (1.0)}{10.9}$$

$$= 73763.4 \text{ in}^4$$

Diagram of a stepped cantilever beam fixed to a wall. The beam consists of a vertical section (labeled 2) and a horizontal section (labeled 1). The vertical section has a height of 2.5. The horizontal section has a length of 6.18. A diagonal section (labeled 3) is attached to the bottom of the vertical section at an angle of 29° to the horizontal. The diagonal section has a length of 8.783. A downward point load of 0.62 is applied at the free end of the horizontal section. The beam is fixed to a wall on the left.

	A	$\bar{y}$	$A\bar{y}$	Ad^2	I
1	5.4894	5.8409	32.063	66.21	35.87
2	10	1.25	12.5	12.497	2.667
3	3.8316	.31	1.1878	16.2266	.1127
	<u>19.321</u>		<u>45.7508</u>		<u>38.65</u>

19. 321

$$\bar{y} = \frac{\sum A \bar{y}}{\sum A} = 2.3679 \text{ in}$$

$$I_{rot} = \sum A d^2 + EI$$

$$= 133.59 \text{ m} < 73763.4 \text{ No Good.}$$

Assume that Angles serve as stiffeners for most of the she!

THIS RING IS SURE
FOR SECOND HAND
FOR 3X3

$$F_{FEA} = 203725.48 \text{ lbs}$$

$$F_R = 15 \left(\frac{201}{2} \right) (3.21) = 2.48 \text{ kips}$$

$$F_{\text{Total}} = 206205.48 \text{ lbs}$$

$$\bar{\sigma} = \frac{206205.48}{19.321} = 10672.6 \text{ (psi)}$$

$$\text{Assume F.S.} = 2.$$

$$\sigma = B - 10672.6$$

$$A = 0.0015$$

$$I_{req} = \frac{(201)^2 (19.321) (0.0015)}{10.9}$$

$$= 110.45 \text{ in}^4 < 133.59 \text{ OK!}$$

ANSYS 4.2B
JUL 7 1987
9:31:10
PLOT NO. 3
POST1 ELEMENTS

ORIG SCALING
ZV=1
DIST=4.94
XF=100
YF=102

B) Inner Ring

Section #	① Membrane Hoop Stress (psi)		② Radial Long. + Bending (psi)	
	2.5 in Ring	1.5 in Ring	2.5 in	1.5 in
1	8,779	13,770	-6,356	-10,420
2	7,663	12,090	-10,440	-16,460
3	6,665	10,550	-10,630	-16,590
4	5,716	9,096	-10,770	-16,630
5	9,718	14,560	9,791	13,570
6	9,288	13,240	14,060	19,080
7	8,236	13,130	14,610	19,100
8	8,372	12,400	13,850	18,950

Conclusion - All ANSYS results are within stress limits of ASME code

Inner Ring

Average Stresses (ANSYS)

- ① 9053.5 psi
- ② 13820.124 psi
- ③ 7205.75 psi

AREAS

- ① 5.4894 in²
- ② 10.625 in²
- ③ 2.117 in²

Total 18.2314 in²

Forces

- ① 49698.28 lbs
- ② 146838.82 lbs
- ③ 15254.57 lbs

TOTAL - 211791.67 lbs

$$\sigma = \frac{F_T}{A_T} = \frac{211791.67}{18.2314} = 11616.863 \text{ psi}$$

$$\sigma = \frac{F_T}{A_T} = \frac{211791.67}{18.2314} = 11616.863 \text{ psi}$$

$$B = \frac{\sigma (F.S.)}{2} = \frac{3\sigma}{2} = 17425.295 \text{ psi}$$

$$A = .25$$

$$I_{reg} = \frac{D_o^2 (AREA) A}{10.5} = \frac{(104.934)^2 (18.2314) (.25)}{10.9} = 4604.325 \text{ no good!}$$

	<u>A</u>	<u>$\bar{y}$</u>	<u>$A\bar{y}$</u>	<u>$A\bar{d}^2$</u>
①	5.4894	13.0375	71.568	133.75
②	10.625	6.725	71.453	20.488
③	2.117	2.21	4.678	73.478

$$\bar{y} = \frac{\sum A\bar{y}}{\sum A} = 8.1014$$

$$\text{① } \bar{I} = 36.738 \text{ in}^4$$

$$\text{② } 15.998 \text{ in}^4$$

$$\text{③ } 4.587 \text{ in}^4$$

$$I_{\text{tot}} = \sum I + \sum A\bar{d}^2$$

$$I_{\text{tot}} = 284.675 \text{ in}^4 < 4604.325 \text{ in}^4 \quad \text{no Good}$$

Find Allowable pressure for F.S. of 3 : 2

$$I = \frac{D_o^2 (\text{AREA}) A}{10.9} = 284.675$$

$$A = \frac{284.675 (10.9)}{(12.9)^2 + (2.23)^2} = 0.154$$

$$B = 14,500 = \frac{(F.S.)\sigma}{2} \quad \text{if } F.S. = 3$$

$$\sigma = 9666.667$$

$$\text{if } F.S. = 2$$

$$\sigma = 14,500$$

for F.S. 3

$$\frac{\sigma}{\sigma_{15}} = \frac{P}{15 \text{ psi}}$$

$$\frac{9666.667}{15} (15) = P_{\text{all}}$$

$$P_{\text{all}} = 12.48 \text{ psi for F.S. of 3}$$

For a F.S. of 2 - by observation - 15 psi is safe pressure. (14,500 is larger than 11,616.8)

4 1/4 x 1 1/2 inner Ring buckling

$$D_o = 104.934$$

Average Stresses

$$\textcircled{1} 13482.5 \text{ psi}$$

$$\textcircled{2} 15391.043 \text{ psi}$$

$$\textcircled{3} 11367.5 \text{ psi}$$

Areas

$$\textcircled{1} 5.4894$$

$$\textcircled{2} 6.375$$

$$\textcircled{3} 2.117 \text{ in}^2$$

$$\text{Total} = 13.9814 \text{ in}^2$$

Forces

$$\textcircled{1} 74010.84 \text{ lbs}$$

$$\textcircled{2} 98117.9$$

$$\textcircled{3} 24064.99$$

$$\text{Total} = 196193.74 \text{ lbs}$$

$$\bar{\sigma} = \frac{196193.74}{13.9814} = 14032.482$$

$$B = \frac{\sigma(3)}{2} = 21048.722$$

$$A \geq 1$$

$$I_{reg} = \frac{D_o^2 (13.9814) (1)}{10.5}$$

$$= 14662.02 \text{ no Good!}$$

Calculate Actual I

	<u>A</u>	<u>$\bar{y}$</u>	<u>A$\bar{y}$</u>	<u>Ad²</u>	<u>I</u>
①	5.4894	13.0375	71.555	112.042	36.738
②	6.375	6.725	42.872	20.5335	9.596
③	2.117	2.21	4.678	84.2826	4.587

$$\bar{y} = \frac{\sum A\bar{y}}{\sum A} = 8.5197$$

$$I_{tot} = \sum I + Ad^2 = 267.7788 \text{ in}^4$$

Find Allowable Pressure for F.S. of 3 & 2

$$I = \frac{D_o^2 (AREA) A}{10.9} = 267.7788$$

$$A = \frac{267.7788 (10.9)}{(204.9)^2 (13.9814)} = .01897$$

$$B = 15,000 = \frac{Fs(\sigma)}{2} \quad \text{if F.S.} = 3$$

$$\sigma = 10,000$$

$$\text{if F.S.} = 2$$

$$\sigma = 15,000$$

for F.S. = 3

$$\frac{\sigma}{\sigma_{15}} = \frac{P}{15}$$

$$P = \frac{10,000}{14032.48} (15)$$

$$= 10.69 \text{ psi for F.S.} = 3$$

For F.S. = 2 - by observation 15 psi is safe pressure (15,000 is larger than 14,032.482)

ANSYS 4.2B
JUL 7 1987
13:14:33
PLOT NO. 1
POST1 ELEMENTS

ORIG SCALING
ZV=1
DIST=3.59
XF=50.6
YF=87.6