SoLID HGC Prototype Vessel Leak Testing

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Abstract

The construction of the SoLID HGC requires a vessel that can withstand pressures of 1.7 atm, or 22.0 psi (absolute) for long periods of time with minimal leaking. These tests sought out to find a method of sealing the vessel so that it doesn't leak. The vessel was sealed using DOWSIL RTV 832 Sealant. When using a good technique to apply the sealant, the vessel's leak rate was as low as $5.6 \times 10^4 \frac{Torr \cdot L}{s}$, or $2.2 \times 10^{-6} \frac{\text{g}}{\text{s}}$ when filled with C_4F_8 gas. This result is from test 6 where vessel was left inflated for 28 days. The RTV sealant performed well, but the performance depends on how well the sealant is applied, so there may be better methods of sealing the vessel.

Introduction

The SoLID Heavy Gas Cherenkov detector (HGC) is a particle detector that will use Cherenkov radiation through C_4F_8 gas for $\pi^{\pm}/K^{\pm}$ separation. The construction of the SoLID HGC requires a vessel that can withstand pressures of 1.7 atm, or 22.0 psi (absolute) for long periods of time without leaking. A prototype of this vessel was machined and assembled by IMM Industrial Machine and Manufacturing Inc [1]. The objective of the tests is to find method of sealing the vessel so that it can hold gases without leak. This report details test using DOWSIL RTV 832 Sealant to seal the vessel.

Construction

All vessel parts except for the windows were machined from 6061 T-651 aluminum alloy and the pieces were dry fit together by the vendor (IMM) to assure a good fit. All parts were fastened together using $\frac{5}{16}$ inch 316 stainless steel hex head fine thread machine screws. Mounting holes for the back windows were not marked, drill or tapped. On March 31, 2020 the partially assembled vessel was transported to the Faculty of Science Machine Shop at the University of Regina, where the holes for the back windows were later drilled and tapped. The back windows were dry fitted and later installed and sealed with DOWSIL RTV Sealant 832. The parts of the vessel are listed in Table 1 and they are labeled as if the vessel were oriented as it is in Fig. 1. Throughout this report, parts will be referred to by their names instead of numbers.

Table 1: Part list for the SoLID HGC Prototype.

Part Number	Part Name
SP-10-01-01	Bottom Center
SP-10-01-02	Bottom Right
SP-10-01-03	Bottom Left
SP-10-01-04	Bottom Extension
SP-10-01-05	Side Plate-Right
SP-10-01-06	Side Plate-Left
SP-10-01-07	Rib-Mid
SP-10-01-08	Rib-Top
SP-10-01-09	Front Plate
SP-10-01-10	Front Plate Extension
SP-10-01-11	Front-Top Plate PMT
SP-10-01-12	Front-Top Plate Blank
SP-10-01-13	Top Plate
SP-10-01-14	Back Plate
SP-10-01-15	Back Plate Extension
SP-10-01-16	Back Window
SP-10-01-17	Back Window Ext
SP-10-01-18	Mount Side
SP-10-01-19	Mount Top
SP-10-01-21	Top Brace
SP-10-02-01	Front Window Frame

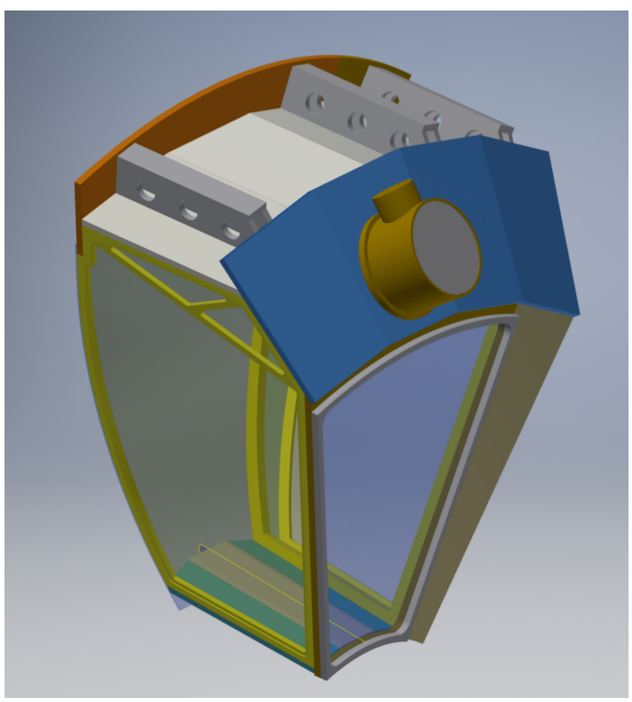


Figure 1: A 3D rendering of the vessel in its vertical orientation.

Test Protocol

Whit Seay, a member of the JLab Hall A engineering staff, has specified that the HGC vessel must have a safety factor of 3× for ultimate strength, demonstrated through engineering analysis. Furthermore, the vessel needs to be pneumatically tested to 1.1× operational (design) pressure for an extended period. An absolute C_4F_8 gas pressure of 1.7 atm implies a differential pressure of 0.7 atm (10.3 psi) across the vessel walls. The testing protocol thus requires the vessel to be inflated to 11.3 psi differential pressure.

Prototype Vessel Volume and Leak Rate

The leak rate of the vessel was estimated by creating an estimate for the volume and multiplying it by the pressure change over time. The volume of the vessel was estimated by simplifying its shape as the frustum of a rectangular-based pyramid. The frustum has a top area is a rectangle 38.437 inches by 49.527 inches, and the bottom area is a rectangle 19.050 inches by 26.612 inches. The height is 60.347 inches. These measurements were obtained from the part construction diagrams.

$$\begin{aligned}
b_1 &= (38.437\ \text{in} \times 49.527\ \text{in}) = 1903.7\ \text{in}^2, \\
b_2 &= (19.050\ \text{in} \times 26.612\ \text{in}) = 507.0\ \text{in}^2, \\
h &= 60.347\ \text{in}, \\
V &= \frac{h}{3} \times \left(b_1 + b_2 + \sqrt{b_1 \times b_2}\right), \\
&= \frac{60.347\ \text{in}}{3} \times \left(1903.7\ \text{in}^2 + 507.0\ \text{in}^2 + \sqrt{1903.7\ \text{in}^2 \times 507.0\ \text{in}^2}\right), \\
&= 68255.15\ \text{in}^3.
\end{aligned}$$

The volume of the vessel is 68255.15 in^3. This converts to 1118.50 L. The leak rate of the vessel can be determined by the volume times the change in pressure over time.

$$L = -V\frac{dP}{dt}$$

Error Calculation

This is an example calculation using the data from the second test. All of the length measurements have an uncertainty of ±0.005 in, as determined from the construction drawing tolerances. The error calculation for the volume is below:

$$V = \frac{h}{3} \times \left(b_1 + b_2 + \sqrt{b_1 \times b_2}\right),$$
$$V = \frac{h}{3} \times (b_1 + b_2 + c),$$
$$V = \frac{h}{3} \times d,$$
$$\delta_{b_1} = b_1\sqrt{\left(\frac{\delta_{s_1}}{s_1}\right)^2 + \left(\frac{\delta_{s_2}}{s_2}\right)^2},$$
$$\delta_{b_1} = 0.31 \text{ in}^2,$$
$$\delta_{b_2} = b_2\sqrt{\left(\frac{\delta_{s_3}}{s_3}\right)^2 + \left(\frac{\delta_{s_4}}{s_4}\right)^2},$$
$$\delta_{b_2} = 0.28 \text{ in}^2,$$
$$\delta_c = \frac{c}{2}\left(\frac{\delta_{b_1}}{b_1} + \frac{\delta_{b_2}}{b_2}\right),$$
$$\delta_c = 0.368 \text{ in},$$
$$\delta_d = \sqrt{(\delta_{b_1})^2 + (\delta_{b_2})^2 + (\delta_c)^2},$$
$$\delta_d = 0.56 \text{ in},$$
$$\delta_V = V\sqrt{\left(\frac{\delta_h}{h}\right)^2 + \left(\frac{\delta_d}{d}\right)^2},$$
$$\delta_V = 12.6 \text{ in}^3.$$

The volume is 68260±10 in^3. When converting to litres, this becomes 1118.5±0.2 L. The error in the change in pressure is calculated as follows:

$$m = \frac{\mathrm{dp}}{\mathrm{dt}},$$
$$\delta_m^2 = \frac{n\delta_p^2}{n\sum_{i=1}^n t^2 - \left(\sum_{i=1}^n t\right)^2},$$
$$\delta_p = 5 \text{ Torr},$$
$$\delta_m = 0.001\frac{\text{Torr}}{\text{s}}.$$

The change in pressure is -0.017±0.001$\frac{\text{Torr}}{\text{s}}$. The error in the leak rate is:

$$\delta_L = L\sqrt{\left(\frac{\delta_V}{V}\right)^2 + \left(\frac{\delta_m}{m}\right)^2},$$
$$\delta_L = 1.11\frac{\text{Torr} \cdot \text{L}}{\text{s}}.$$

The leak rate is 19 ± 1 $\frac{\text{Torr}\cdot\text{L}}{\text{s}}$ for the second test.

Leak Rate When Filled With C_4F_8

The SoLID Heavy Gas Cherenkov detector (HGC) is designed to be filled with C_4F_8 gas, so it is necessary to calculate what the leak rate would be when filled with this gas instead of air. To make the gas loss over time more clear, the leak rate is converted from $\frac{\text{Torr}\cdot\text{L}}{\text{s}}$ to $\frac{g}{s}$. This calculation will be done with the lowest leak rate for the vessel, $0.00054\frac{Torr\cdot L}{s}$, found in test 6.

The leak rate is converted from $\frac{\text{Torr}\cdot\text{L}}{\text{s}}$ to $\frac{g}{s}$ using the ideal gas law. The leak rate is first converted to $\frac{\text{Pa}\cdot\text{m}^3}{\text{s}}$. It is then divided by the ideal gas constant and the room temperature and multiplied by the molecular weight of air, which is 28.97 $\frac{g}{mol}$[7].

$$\text{Leak Rate} = 0.00054\frac{\text{Torr}\cdot\text{L}}{\text{s}} = 7.1\times10^{-5}\frac{\text{Pa}\cdot\text{m}^3}{\text{s}}$$

$$\text{Leak Rate} = \text{M}\left(\frac{PV}{RT}\right)$$
$$\text{Leak Rate} = 28.97\frac{\text{g}}{\text{mol}}\left(\frac{7.1\times10^{-5}\frac{\text{Pa}\cdot\text{m}^3}{\text{s}}}{(8.3145\frac{\text{Pa}\cdot\text{m}^3}{\text{K}\cdot\text{mol}})\,(293\text{K})}\right)$$
$$\text{Leak Rate} = 8.6\times10^{-7}\frac{\text{g}}{\text{s}}$$

After converting to $\frac{\text{g}}{\text{s}}$, the leak rate of the vessel filled with C_4F_8 is found by multiplying the leak rate of air by the square root of the molecular weight of C_4F_8 over the molecular weight of air [2].

$$\text{L}_{\text{C}_4\text{F}_8} = \text{L}_{\text{air}}\sqrt{\frac{\text{M}_{\text{C}_4\text{F}_8}}{\text{M}_{\text{air}}}}$$
$$\text{L}_{\text{C}_4\text{F}_8} = 8.6\times10^{-7}\sqrt{\frac{200.028}{28.97}}$$
$$\text{L}_{\text{C}_4\text{F}_8} = 2.2\times10^{-6}\frac{\text{g}}{\text{s}}$$

The lowest leak rate of the vessel when filled with C_4F_8 is $2.2\times10^{-6}\frac{\text{g}}{\text{s}}$.

Sealant

A RTV sealant was applied to the vessel to try to make it gas tight. This sealant is the DOWSIL RTV 832 Sealant produced by the Dow Chemical Company[4]. It is 100% silcone, low out-gassing and non-corrosive, in 300 mL tubes in the colour black.

Application method 1

The application of the sealant was first practiced on pieces of wood stapled together at various angles. To apply the sealant, a thick bead (about the size of a pea, roughly 0.2 inches in diameter) of sealant should be applied across the seam, pushing the bead away from yourself (see Fig. 2). The caulking gun used to apply the sealant should be at an angle which bisects the angle of the seam. For example, if the angle of the seam was 120°, the nozzle of the caulking gun should be at a 60°. Plastic scrapers made from scrap acrylic (see Fig. 3) were made to scrape off excess sealant and to push the sealant further into the seam (see Fig.4).

Application method 2

On February 22nd, a new method to apply the sealant was used, with it first being tested on scraps of wood (see Fig. 5). The sealant was to be applied with a smaller bead about half the size as the one used in the first method (roughly 0.1 inches in diameter). **First, a small bead of sealant was pushed out from the tube. Then, this bead was pushed into the corner and pulled upward. Another small bead is formed on the tip of the nozzle and pushed into the previous bead, then the bead is pulled**

Figure 2: The first sealant method.

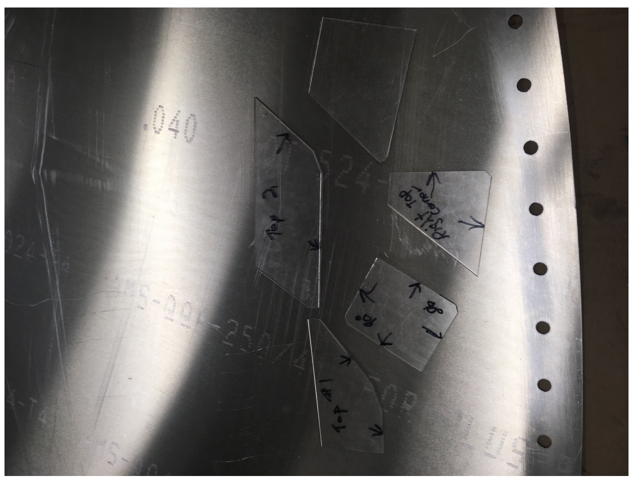


Figure 3: Some scrapers made out of scrap acrylic.

away from the corner in another direction. The bead should be applied away from you. The previous step is repeated for the last seam. The sealant should be smoothed away from the corner. It is very important that the beads always begin in the corner.

Figure 4: A bead of sealant along a test piece of wood. The bead is pushed into the seam and along the side of the wood.

Figure 5: The bead of sealant is smaller than the first method.

Results

Summary

Tests were done on the prototype vessel to see how well it will hold pressure, and how effective the RTV sealant is at keeping the vessel sealed. A summary of the results is in Table 2.

Test 1 - No Sealant, Soapy Water

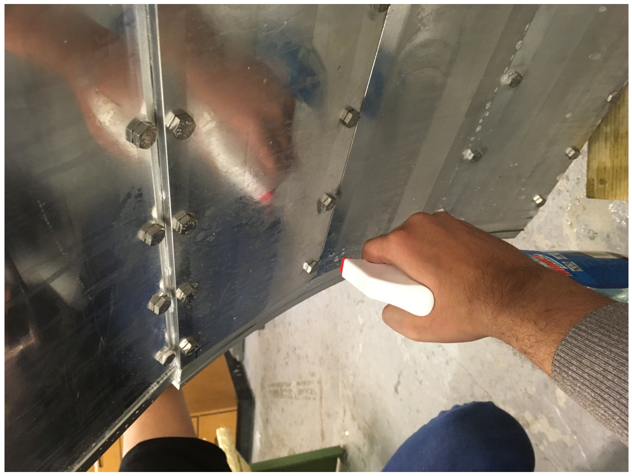


Figure 6: The soapy water test is done by spraying soapy water over the seams.

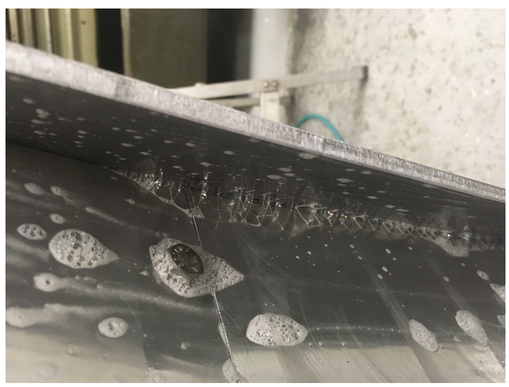


Figure 7: This is what a leak looks like when doing the soapy water test.

On February 8th, the front window with an O-ring was bolted to the vessel. The window's frame was accidentally placed on backwards, so it had to be taken and placed back on again. The vessel had no sealant or epoxy on it at this time. The vessel was pressurized with an air hose, but there were many leaks, enough that no differential pressure could be built up. Soapy water was sprayed onto the vessel to check for leaks (see Fig. 6). If a leak was found, it would bubble like in Fig. 7. Some of the leaks were large enough to feel by hand and to hear. They were located:

- edge of front plate towards the outer radius
- edges of side plate-left, especially where it connects to the back plate extension and the top plate
- between back Window and side plate
- between back window and rib
- a bad leak on the entire seam between the back plate and top plate
- between the top plates
- between front top and top plate

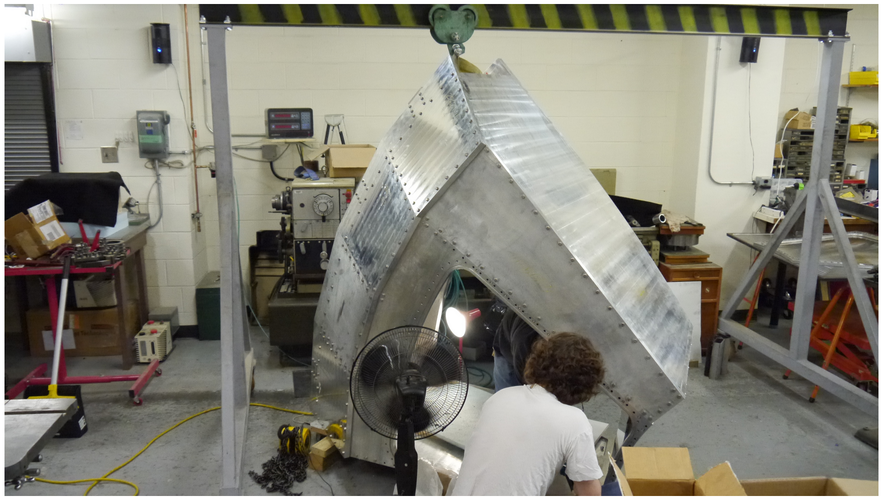


Figure 8: A fan was used to reduce fumes and a foam pad was used for comfort.

- some leaking on the bottom plates
- in the corner where the top plate, back plate and rib meets

Between February 9th–11th, the vessel was cleaned four times to prepare it for the sealant. Ethanol was used to clean most of the vessel and acetone was used to clean difficult areas. Rags were used to clean large areas, kimwipes where used to clean smaller areas and Q-tips where used to clean the seams. The first time, it was cleaned with ethanol using kimwipes. The second time, it was cleaned with ethanol using rags, kimwipes and Q-tips. The third and fourth times, it was cleaned with both ethanol and acetone separately, using rags, kimwipes and Q-tips. The cleaning was done with the vessel back panels removed, to allow for more ventilation, and a fan was used to help with air flow. Due to concerns with fumes while cleaning the vessel, breaks were given at least every hour. Foam was used for padding to protect knees. The setup can be seen in Fig. 8. The sealant was then applied on the 11th and the 12th. The setup was similar to the cleaning setup. A lamp was used to help illuminate the vessel and its heat helped the sealant to cure. Headlamps and flashlights were also used to illuminate the inside of the vessel.

About 7 tubes of RTV sealant were used. There were some challenges when applying the sealant. The sealant formed a skin rather quickly, roughly within five minutes, which made making a continuous seal difficult. If the sealant was applied too thickly, there was a tendency for air bubbles to form in the sealant. The glossy black finish made of the RTV it difficult to see imperfections in the application. On February 16th, the back panels were placed back on the vessel. RTV sealant was sandwiched between the back panels and the vessel (see Figs. 9 and 10). The panels were bolted on with 120 in-lbs of torque, as measured by a torque wrench, and the excess sealant on the inside of the vessel was smoothed down with a wet glove.

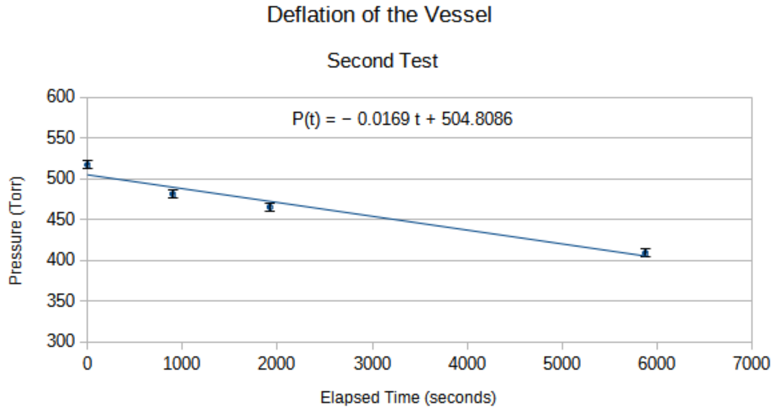
Test 2 - First with Sealant, Soapy Water

On February 19th, after the tank was cleaned and sealant was applied, the tank was tested for leaks. The vessel was inflated to 9.0 psi (relative pressure) and the inflation took roughly 8 minutes. The changes in pressure are listed in Table 3. A graph of the pressure over time is in Fig. 11, this graph was used to calculate the leak rate. The leak rate was $19 \pm 1 \ \frac{\text{Torr}\cdot\text{L}}{\text{s}}$.

Figure 9: Some sealant was used when bolting on the back panel.

Figure 10: The back panel was bolted on.

Figure 11: Result of Test 2. The leak rate of the vessel can be determined from the slope of this graph.



The vessel was checked for leaks using soapy water. The leaks were found:

- the outer radius and inner radius of the vessel
- around the gauge

Most of the leaks were on the top and bottom of the vessel. The front window was deflected when the vessel was inflated to 9.0 psi. The deflection was measured to be 2.125 inches.

Figure 12: The sealant was scraped off with a utility knife.

After the vessel test on February 19th, we decided to scrape off sealant on areas that were most likely causing problems (see Fig. 12). These areas included the joints on the bottom of the vessel, as well as the top of the vessel. The sealant was scraped off with a utility blade and dissolved with ethanol and acetone. Ethanol tended to work better at dissolving the sealant. **Scratches were added to the aluminum near the seams so that the sealant will adhere better. On February 23rd, the sealant was applied to the scraped off areas. The bottom seams were sanded and cleaned. Several holes on the inside radius penetrated through into the vessel. To seal the two rows of holes, thin wood spacers (0.090 inches thick) were stuck to either side of them with double-sided tape (see Fig. 13). The wood spacers were used as screeds to allow a thicker layer of sealant over the holes, they were removed after the sealant cured. This thicker layer of sealant covered up the seams better than before (see Fig.14).**

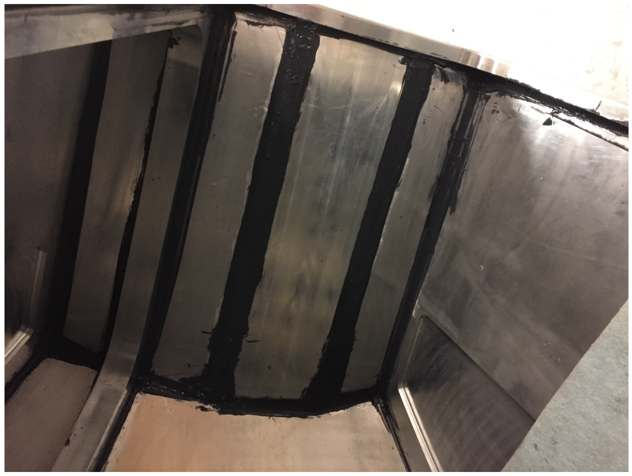


Figure 13: The bottom panel's seam were covered in a thick layer of sealant.

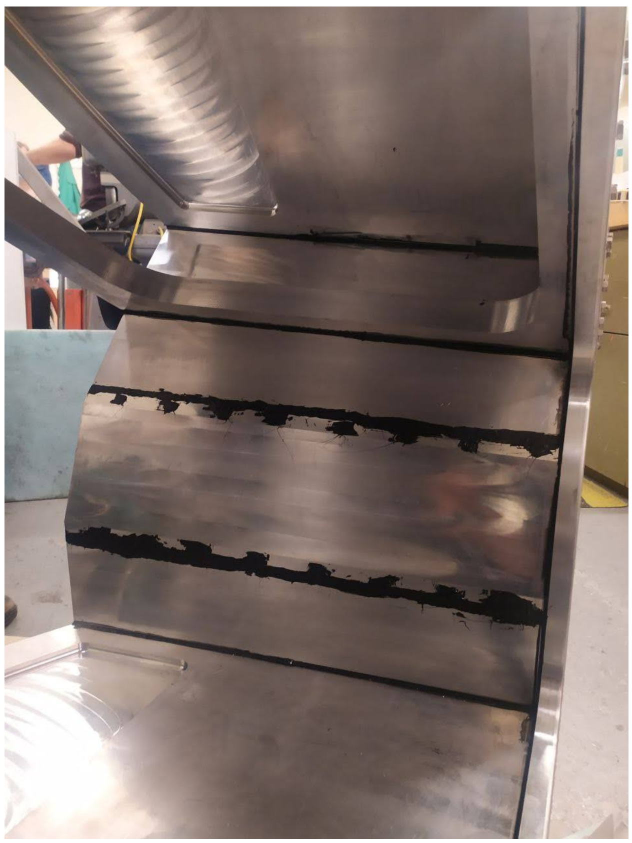


Figure 14: The sealant on the bottom panels before scraping, for comparison.

Vessel Side Panel Deflection Measurement

The deflection of the vessel side panel was measured. Measurements were taken by placing a dial gauge suspended by a steel beam on the panel's estimated high point (see Figs. 15 and 16). The vessel was slowly deflated and the decrease from the gauge measured the panel's deflection. The results are in Table 4 and graphed in Fig. 17.

Figure 15: How the deflection of the side panel was measured.

Figure 16: A closer look at the setup for measuring the side panel.

Table 2: Summary of vessel tests:
Test 1 - The vessel was inflated without any sealant. It did not hold pressure. The vessel was cleaned and RTV sealant was applied.
Test 2 - The vessel was inflated and leaks were found with soapy water. The sealant by the leaks were scraped off and reapplied with a better method. The side of the vessel had its deflection measured.
Test 3 - The vessel was inflated, but the leaks remained. More sealant was applied.
Test 4 - Similar results to test 3.
Test 5 - The vessel was inflated with air and no leaks were found with soapy water. It was inflated with hydrogen gas mixture and small leaks were found.
Test 6 - The vessel was inflated with hydrogen gas and left inflated for a long time. Over that time, the pressure changed very little, but that may be due to an issue with the gauge.

Test	Inflated with	Leak Testing	Leak Rate
1	air	Soapy Water	N/A
2	air	Soapy Water	$18.930 \pm 0.004 \ \frac{Torr \cdot L}{s}$
3	air	Soapy Water	$5 \pm 1 \ \frac{Torr \cdot L}{s}$
4	air	Soapy Water	$19 \pm 2 \ \frac{Torr \cdot L}{s}$
5	hydrogen gas mixture	Soapy Water and Sniffer	$0.03 \pm 0.01 \ \frac{Torr \cdot L}{s}$
6	hydrogen gas mixture	Sniffer	$0.00056 \ \frac{Torr \cdot L}{s}$ (upper limit)

Table 3: Test 2. The deflation of the vessel starting at 9:18. The pressure is measured in psi and listed also in Torr. The error in the pressure is ± 0.1 psi or ±5 Torr.

Elapsed Time (min)	Pressure (psi)	Pressure (Torr)
0	10.00	517
15	9.30	481
32	9.00	465
98	7.90	409

Table 4: Test 2. Deflection of the side panel in imperial units (raw data) and metric units (converted). The pressure has an error of ± 0.1 psi (± 5 Torr), and the deflection has an error of ± 0.001 inches (± 0.003 cm).

Pressure (psi)	Deflection (inches)	Pressure (Torr)	Deflection (cm)
7.0	-0.040	362	-0.102
6.0	-0.064	311	-0.163
5.0	-0.093	259	-0.236
4.0	-0.112	207	-0.285
3.0	-0.144	155	-0.366
2.0	-0.181	104	-0.460
1.0	-0.199	52	-0.506
0.0	-0.255	0.0	-0.648

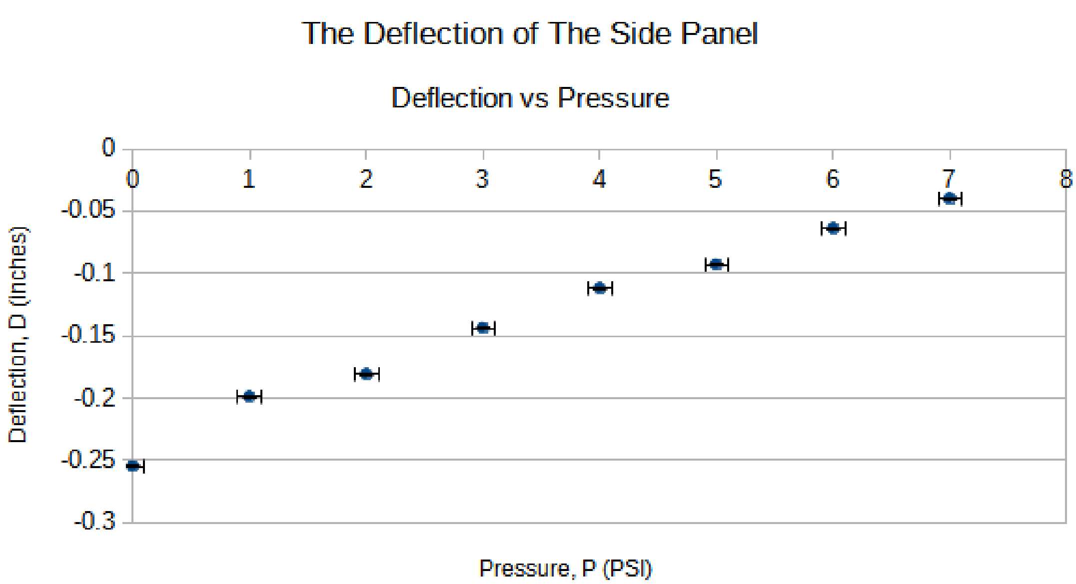


Figure 17: The movement of the side panel while the vessel deflates.

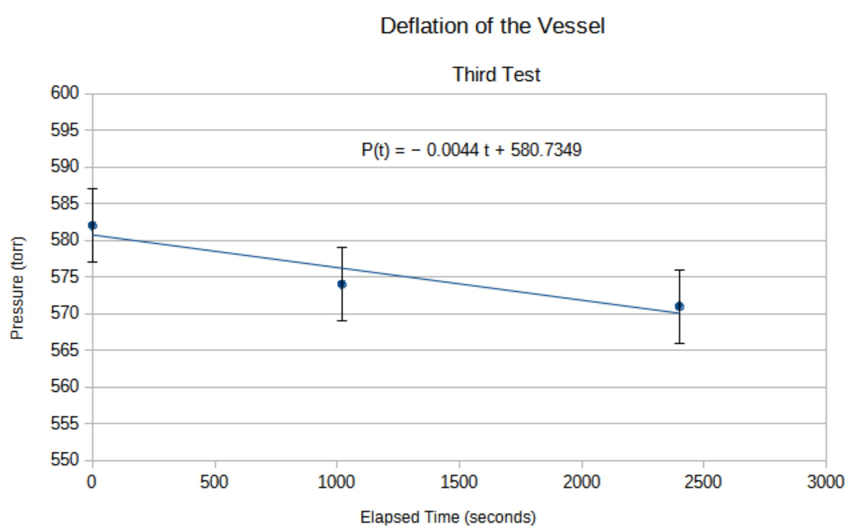
Test 3 - Second with Sealant, Soapy Water

After the second test, some of the sealant was scraped off, reapplied and allowed to cure. On February 26th, the vessel was tested for leaks again with the same methods. The vessel was taken to a higher pressure this time. The results are in Tables 5, and in Fig. 18. The leak rate is 5$\pm$ 1 $\frac{Torr \cdot L}{s}$.

Table 5: Test 3. The deflation of the vessel starting at 13:30. The pressure is measured in psi and Torr. The error in the pressure is $\pm$ 0.1 psi or $\pm$5 Torr.

Elapsed Time (min)	Pressure (psi)	Pressure (Torr)
0	11.25	582
17	11.10	574
40	11.05	571

Figure 18: Result of test 3. The leak rate of the vessel can be determined from the slope of this graph.



The leaks were found using the soapy water test:

- By the front window frame
- Between the joints of top-front plate PMT
- The corner between the top plate and the top plane PMT
- Between the front plate and the top front plate PMT

The leaks by the window frame may be caused by the window's bolt holes being torn.

After the test on February 26th, more sealant was applied to the joint of the right of the window. After the fourth vessel test, we were unsure if sealant alone can make the vessel airtight. Some sealant was reapplied to the joint to the right of the window.

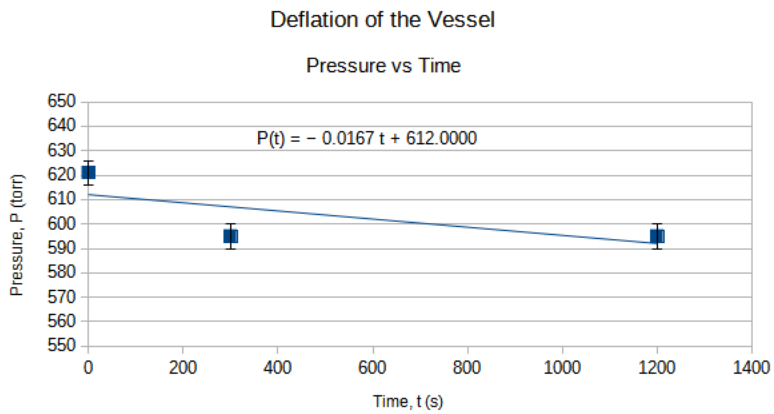


Figure 19: The deflation of the vessel before it was inflated to 15 psi (relative pressure). The change in pressure over time is $0.017 \pm 0.002\ \frac{Torr}{s}$.

Test 4 - Third with Sealant, Soapy Water

Table 6: Test 4. The pressure is measured in psi and Torr. The error in the pressure is ± 0.1 psi or ±5 Torr.

Elapsed Time (min)	Pressure (psi)	Pressure (Torr)
0	12.0	621
5	11.5	595
20	11.5	595
Inflated to 15 psi or 776 Torr at 13:38		
0	14.0	724
10	13.5	698

On March 1st, the vessel was tested again. It was taken to an even higher pressure than before. The results are in Table 6 and Fig. 19. The leak rate before the vessel is inflated to 15 psi is $19 \pm 2\frac{Torr \cdot L}{s}$. There were more leaks discovered during this test than the third test. This may have been due to the higher pressure. On March 5th and 7th, more sealant was applied to the vessel. Extra sealant was applied to the corners of the vessel and to areas where the leaks appeared. The sealant was applied with a silicone trowel scraper with a wide radius (7mm). On the 7th, the second aluminum front window was installed on the vessel.

Other possible methods of sealing the vessel were tested. Araldite epoxy adhesive[5] was tested on scrap aluminum and acrylic to see how well it will hold. The epoxy held aluminum pieces together strongly, but held the acrylic pieces weakly.

Test 5 - Fourth with Sealant, Soapy Water and Hydrogen

On March 8th, the vessel was first inflated with air to 14.0 psi. Soapy water was spritzed on the vessel, but no leaks were found. The vessel was then left for 2 hours and 45 minutes and the pressure dropped to 13.75 psi. The air was released from the vessel and then it was inflated with a mixture of 98.013% dry air and 1.987% hydrogen[6] to 12 psi (relative pressure). The vessel was tested for leaks using with the EZ40: EzFlex™ Combustible Gas Detector [3] natural gas sniffer (see Fig. 20). The sniffer was zeroed outside the room, so that it would tick at a slow rate. The sniffer was then brought into the room and run along the seams of the vessel. If the sniffer is ran by a leak, the tick rate will increase and we'll know that the leak is in that area. The leaks were located:

- By the long sides of the front window frame
- In the corner between the front plate, the front plane extension and the the top front plate PMT
- In-between the bottom plates
- Near the top of the side panel
- Along the seam between back plate and the back plate extension
- Near the valve and the ribs

The vessel was left for two days and a drop in pressure was observed. The results of the pressure over time are in Table 7 and Fig. 21. The leak rate is $0.03 \pm 0.01 \frac{Torr \cdot L}{s}$.

Figure 20: The hydrogen test is done with a natural gas sniffer

Table 7: Test 5. The deflation of the vessel starting at 14:30 on March 8th. The pressure is measured in psi and Torr. The error in the pressure is ± 0.1 psi or ±5 Torr.

Elapsed Time (min)	Pressure (psi)	Pressure (Torr)
0	12.0	621
15	12.0	621
50	12.0	621
68	12.0	621
1,513	11.95	618
2,530	11.95	618

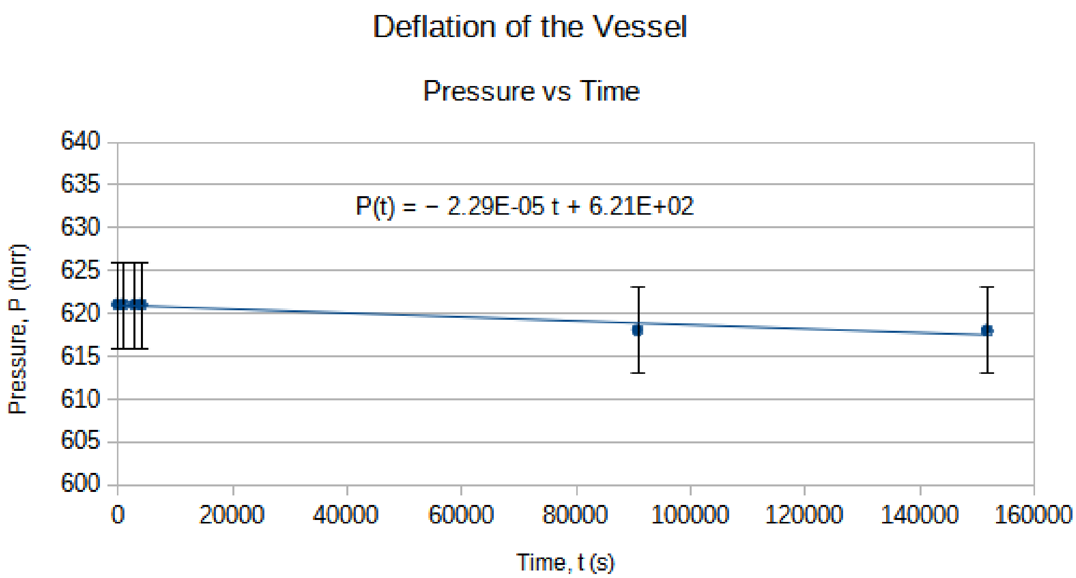


Figure 21: The deflation of the vessel. The change in pressure over time is $(-2\ \pm 1) \times 10^{-5}\ \frac{Torr}{s}$

Figure 22: Discoloured blotches on the top panel.

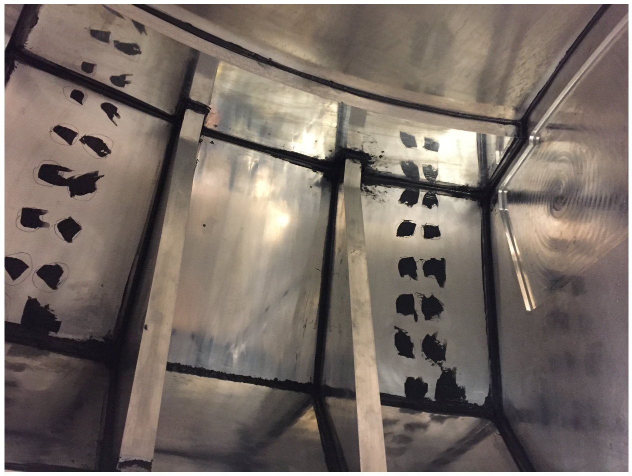


Figure 23: The stressed areas were covered with RTV sealant.

The vessel was depressurized and the window was removed. Some discoloration was found on the inside of the top plate where the rib is bolted (see Fig. 22). This was later investigated and we found that the bolt holes in the top plate were drilled almost all the way through, due to an error in the construction drawings. Extra sealant was applied to these areas (see Fig. 23).

Test 6 - Fifth with sealant, Hydrogen test

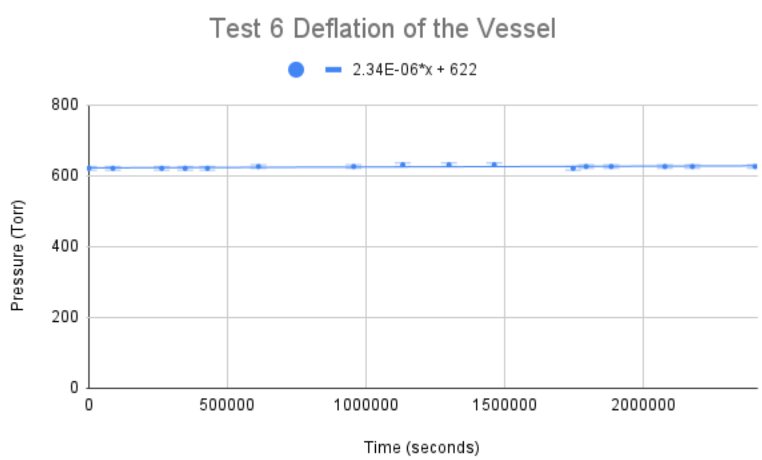


Figure 24: The deflation of the vessel over roughly a month. Assuming the gauge worked properly, the pressure over time was $(2.3 \ \pm 2.8) \times 10^{-6} \ \frac{Torr}{s}$. This rate is positive, but within one uncertainty of zero. The last point in Table 8, which is lower due to the sudden drop in pressure when the valve was opened, is not included in the fit.

On March 11th, the vessel was inflated with the hydrogen mixture to 12 psi (relative pressure). Using the sniffer, leaks were found in the same locations as before, but they seemed smaller. The vessel was left inflated. The next day the same leaks were found, but they were even smaller. There may be some possible issues with this test. It was found that the sniffer can be set off by the ethanol which was used to clean the vessel. It can also be be set of by both cured and uncured RTV sealant. Thus, it is likely that the positive sniffer readings were simply ethanol and RTV residue.

The vessel was left inflated from March 11th to April 8th. The results are in Table 8, and Fig. 24,

Table 8: Test 6. The deflation of the vessel starting at 14:30 on March 11th and ending on April 8th. The pressure is measured in psi and listed in Torr. The error in the pressure is ± 0.1 psi or ±5 Torr.

Elapsed Time (days)	Pressure (PSI)	Atm Pressure (psi)	Relative Pressure (Torr)	Atm Pressure (Torr)
0	12.0	14.88	621	770
1.00	12.0	14.84	621	767
3.04	12.0	14.84	621	767
4.02	12.0	14.62	621	756
4.95	12.0	14.78	621	764
7.08	12.1	14.79	626	765
11.06	12.1	14.78	626	764
13.11	12.2	14.63	631	757
15.04	12.2	14.82	631	766
16.93	12.2	14.71	631	761
20.23	12.0	14.82	621	766
20.77	12.1	14.82	626	766
21.82	12.1	14.71	626	761
24.06	12.1	14.61	626	756
25.21	12.1	14.65	626	758
27.83	12.1	14.69	626	760
27.84	9.8	14.56	507	753

corresponding to an upper limit of the leak rate as $0.00056\frac{Torr \cdot L}{s}$. On April 8th, the valve was opened and the pressure immediately dropped to roughly 11 psi, and then continued to fall normally as the vessel depressurized. The sudden drop to 11 psi may have indicated a problem with the gauge during the long pressurization test, i.e. the needle became stuck after being in a fixed position for too long.

Test 7 - Sixth with sealant, air and a new gauge

On April 21st, the vessel had the second aluminum window attached and was filled with air to 12 psi (relative pressure). The vessel had a different gauge attached to it. The old gauge was a Sioux Chief gauge and the new gauge was the Cole Palmer that was used for testing the thin front windows. The results are in Table 9.

Table 9: Test 7. The vessel was left over a few days starting on April 21st. For the vessel, the relative pressure above atmosphere is listed. The pressure is measured in psi and listed in Torr. The error in the pressure is ± 0.1 psi or ±5 Torr.

Elapsed Time (days)	Pressure (psi)	Atm Pressure (psi)	Pressure (Torr)	Atm Pressure (Torr)
0	12.0	14.66	621	758
0.56	12.0	14.60	621	755
0.93	11.98	14.60	620	755
1.69	11.9	14.66	615	758
2.72	11.9	14.82	615	766
3.54	11.9	14.65	615	758
4.93	12.0	14.61	621	756

On April 23rd, at 13:30 a minuscule leak in the plumbing to the gauge was discovered and repaired. During the repair, the pressure dropped to 11.9 psi. On 19:16 Monday April 26, the pressure increased to 12.0 psi. The cause of this increase is unknown.

Conclusion

In the beginning of these tests, the vessel without any sealant was unable to hold any pressure. Using the DOWSIL RTV Sealant 832 with proper technique, we were able to hold 12 psi of pressure above atmospheric for almost a month with an upper limit on the leak rate of $5.6 \times 10^{-4} \frac{Torr \cdot L}{s}$, or $2.2 \times 10^{-6} \frac{\mathrm{g}}{\mathrm{s}}$ when filled with C_4F_8 gas. While the RTV sealant did seal the vessel, there may be more reliable methods. For the final SoLID HGC vessel, we will likely have the vendor apply epoxy between the various pieces as they do their dry fitment test, and then seal any remaining leaks with RTV upon delivery to JLab.

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