Team 513 V.O.L.C (Valve Operated Low-Leakage Cryogenic Connector)

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I. Introduction

This document is an overview of the validation for the reusable cryogenic connector. It will include the methods of validation, the results, and a summary of the overall success of our design.

II. Methods of validation

For the design to be validated, the targets set must have been met or exceeded. To ensure that the design meets the targets, tests were developed and conducted for the purpose of testing all targets and functions. To confirm that our connector is ergonomic for astronaut use, the procedure will test tactility when manipulating our connector. Space gloves will be used during this test to ensure that the diameter of the connector is large enough to allow smooth operation. To validate the diameter of the connector, vernier calipers, which have an accuracy of up to one thousandth of an inch, will be used. The force required to operate the ball valves will be tested using an electronic scale. This will simulate a load cell that will output the mass required to open the connector's ball valve. The permissible leakage and volumetric flow rate will be tested at the National High Magnetic Field Laboratory under Dr. Vanderlaan's supervision. The leakage will be measured by inducing a vacuum inside the connector and spraying gaseous helium on different locations on the outside of the connector interface with higher risk of leakage. It will measure the Helium particles that are entering the system. Before connecting our unit, an initial vacuum measurement reading is recorded to indicate our benchmark. Any change of the measurement of Helium detection will indicate leakage. This will give us a value that can be converted to SCIM which can be compared with our permissible rate. Once the results of this test returned a vacuum value of within 10 times the magnitude of the benchmark, the team can proceed with cryogenic testing. While flowing LN2 through the connector the flow rate target was validated by measuring the change in height of both the dewar as well as the storage tank. The temperature target is validated by flowing a cryogen at a temperature less than 90 kelvin through the connector with no failure.

III. Results

A. Ergonomics

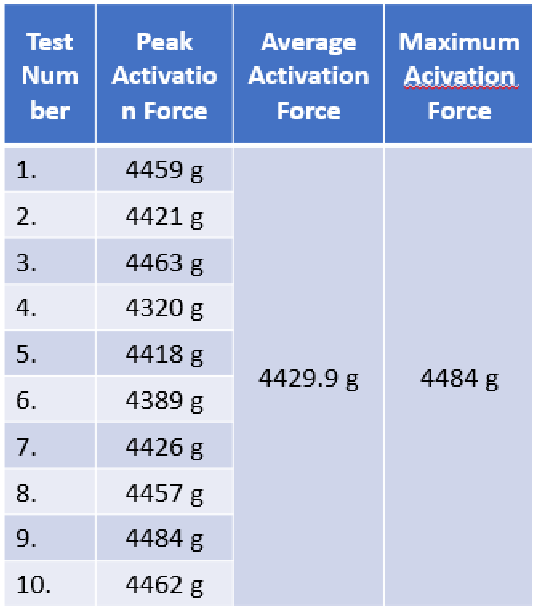
Astronaut gloves for operation were unable to be obtained. Therefore, cryogenic protective gloves used in the National High Magnetic Field Laboratory as personal protection equipment (PPE) were used to estimate the dexterity that astronauts have. These gloves are 12 inches long, 5 inches wide, and 0.5 inches thick. The clearance to operate the connector interface, predominantly the latches and ball valves, was sufficient for the operation while wearing the gloves. Figure 1 shows a picture of the glove used for this test.

Figure 1 Cryogenic Safety Gloves

B. Activation Force

To measure the minimum activation force for the ball valves in our design we used an electronic scale to weigh the equivalent weight needed to turn the valve open. This value was recorded in grams.

Table 1 Ball Valve Activation Force (grams)



Test Number	Peak Activation Force	Average Activation Force	Maximum Acivation Force
1.	4459 g	4429.9 g	4484 g
2.	4421 g		
3.	4463 g		
4.	4320 g		
5.	4418 g		
6.	4389 g		
7.	4426 g		
8.	4457 g		
9.	4484 g		
10.	4462 g		

Once these measurements were tabulated the maximum activation force needs to be converted to Newtons for comparison to the target which is an activation force less than 48 N. This conversion is shown using the calculations shown in Figure 2. After the conversion the maximum activation force was found to be 14.3 N which is significantly less than the target.

Acceleration

- $a = \frac{(x - x_0 - V_0 * t)2}{t\text{^}2}$
- $a = \frac{\left((\frac{1}{4} * 2\pi r.) - x_0 - V_0 \right)2}{(t)\text{^}2}$
- $a = \frac{\left(\frac{1}{4} * 2\pi * 8\ in - 0 - 0 \right)2}{(0.4\ s)\text{^}2}$
- $a = 125.6\ \frac{in}{s^2} = 3.19 \frac{m}{s^2}$

Maximum Activation Force

- $F = ma$
- $m = 4484\ g$
- $a = 3.19 \frac{m}{s^2}$
- $F = (4.484\ kg)\ *(3.19 \frac{m}{s^2})$
- $F = 14.3 \frac{kg * m}{s^2}$
- $1\ N = 1 \frac{kg * m}{s^2}$
- $F = 14.3\ N$

Figure 2 Conversion from Grams to Newtons

C. Permissible Leakage

The leakage test was setup by connecting the connector interface to the Adixen ASM 142, as seen in Figure 3. As said before, this machine is used by applying a vacuum to a system and then detecting the number of particles of Helium that enters the system in Torr*L/s.

Figure 3 Leakage Test Experimental Setup

Before attaching the connector, a full vacuum benchmark was found by closing off the system. At the full vacuum, the detection was 3.2e-10 Torr*L/s. With the connector interface attached, the benchmark was determined to 2.1e-9

Torr*L/s. Helium was then pumped through a nozzle at the critical points, and it was found that there were 3 locations of failure. This can be seen in Figure 4 where the numbers are in red circles.

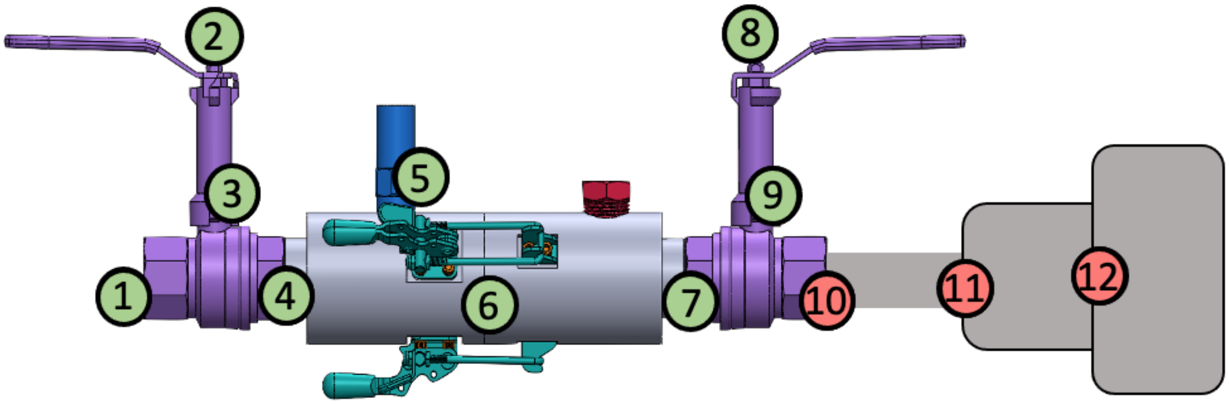


Figure 4 Leak Check Locations

The following table shows the values that were recorded at each location. There was no change to the benchmark for locations 1-9. Locations 10-12 showed an increase in helium detection. The failed locations would be detached and replaced for the next test; therefore, it was sufficient results to proceed with testing to the liquid nitrogen. Helium has a smaller atomic size and would indicate that more particles could enter besides liquid nitrogen. All results were also less than permissible leakage rate in SCIM that was determined for the target.

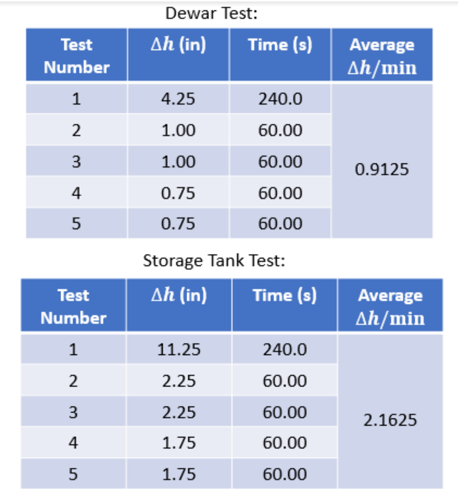
Table 2 Leak Check Values

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Torr*L/s	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	7.6e-8	5.2e-7	4.3e-8
SCIM	3.6e-10	3.6e-10	3.6e-10	3.6e-10	3.6e-10	3.6e-10	3.6e-10	3.6e-10	3.6e-10	1.3e-8	8.8e-8	7.3e-9

D. Flow Rate

The empirical data measured from the flow rate experiment are tabulated in Table 3. With this data, the flow rate was determined using the geometries of the tanks. It was found that the flow rate of LN2 through the connector was 346.7 in^3/min. The target for the volumetric flow rate is 0.1 in^3/min. Therefore, our design exceeded the expected testing condition given.

Table 3 Flow Rate Data



Dewar Test:

Test Number	Δh (in)	Time (s)	Average $\Delta h/\mathrm{min}$
1	4.25	240.0	0.9125
2	1.00	60.00	
3	1.00	60.00	
4	0.75	60.00	
5	0.75	60.00	

Storage Tank Test:

Test Number	Δh (in)	Time (s)	Average $\Delta h/\mathrm{min}$
1	11.25	240.0	2.1625
2	2.25	60.00	
3	2.25	60.00	
4	1.75	60.00	
5	1.75	60.00	

- $Diameter\ of\ Dewar$: $22\ in$
- $Diameter\ of$ Storage Tank: 14 in

- $volume\ of\ a\ cylinder = \pi r^2 h$
- $v_D = \pi(11.00in)^2(0.9125in)$
- $v_D = 346.70\ in^3$
- $\dot{v_D} = 346.70\frac{in^3}{min}$

- $v_{st} = \pi(7in)^2(2.1625in)$
- $v_{st} = 332.72\ in^3$
- $\dot{v_{st}} = 332.72\frac{in^3}{min}$

Figure 5 Flow Rate Calculations

After calculating the flow rate leaving the dewar, and the flow rate entering the storage tank, there was 13.98 $in^3$of LN2 unaccounted for. This volume is 4% of our initial flow, which is 3% above our permissible leakage rate, however, as there was no visible leakage at the interface of the connector, it is assumed that the missing LN2 is a combination of boil off caused by the ambient temperature of the lab and calculation limits of error.

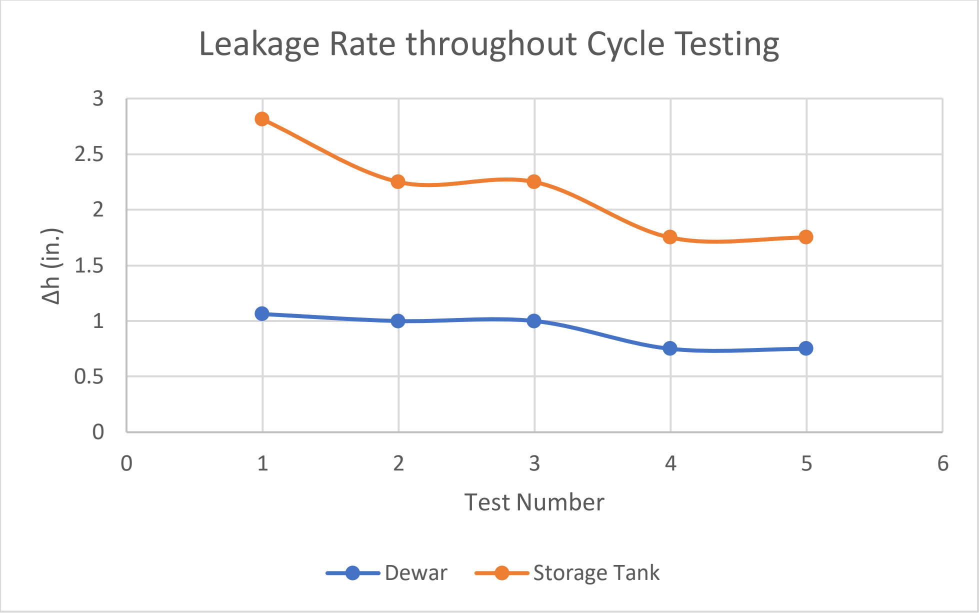
E. Temperature of Cryogen

Pressurized liquid nitrogen was cycled through the connector because it is a safer than liquid oxygen and also readily available at the lab where tests were conducted. Liquid nitrogen boils to a gas at 77 Kelvin and is under the 90 Kelvin temperature target given. Figure 5 shows the experimental setup for flowing pressurized liquid nitrogen through the connector.

Figure 6 Liquid Nitrogen Flow Experimental Setup

When the system was cycled with liquid nitrogen, there was no change in maneuverability and ease of use for the connector interface. There was a slight increase in percent loss as cycling progressed. The initial percent leakage was 4%.

Table 4 Difference in Height During Cycling



IV.Conclusions

After evaluating the various methods of validation, it was determined that our design for a reusable cryogenic connector is validated. An area of concern could be the 4.0% leakage found is higher than the permissible leakage rate target of 1.0 percent of the flow, however, there were no visible leaks at the interface of the connector. Therefore, it is assumed that the unaccounted fluid is due to boil off of the liquid nitrogen. After analyzing the connector's performance during all tests, the prototype has proven to be a success. The significance of the connector is its two key features, the latch sealing mechanism, and the 1" NPT fitting. The latches and hooks are designed with the astronaut's decreased dexterity in mind, as their bulky gloves make it difficult for them to manipulate small objects. The latches are simple and can be operated with ease. The 1" NPT connections are a universal thread that can be adapted to mate with several different fittings. This is significant because it does not limit our design to one single application. Team 513's connector has proven to be seal tight, easily operated, and can successfully transfer pressurized liquid nitrogen from one reservoir to another while undergoing life cycling.

Appendix A: Target Catalog

Function	Target	Metric
Manipulate two connector ends together	2.54 cm – 3 cm	Diameter of connector
Lock two ends together & Unlock	< 48 Newtons	Connection & disconnection force
Seal space between them	< 0.001 SCIM	Permissible leakage rate
Transferring cryogenic fluid	0.1 SCIM	Volumetric Flow rate
Transferring cryogenic fluid	90 K	Cryogenic fluid temperature
Protect from dust and dirt	IP64	Ingress Protection
Mind thermal expansion and contraction	0	Material expansion/ contraction difference
Prevent breaking between uses	500 MPa	Stainless steel ultimate tensile strength
Control Fluid Dynamics	0.0023 SCIM	Liquid Nitrogen boil off rate