NCSX Modular Coil Flange Joint Cryogenic Tension Tests Report

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1. Object

The object of these tests was to:

1. Determine deflection of joint under axial preload
2. Confirm Supernut torque-load curve and accuracy of Ultrasonic tester
3. Determine change in preload when cooled to 80K
4. Determine change in preload due to thermal cycling
5. Determine change in preload due to relaxation at room temperature

If there is noticeable relaxation at RT, re-tighten the assembly and determine if there is any subsequent change.

Disassemble and inspect the surfaces and edges of the shims for damage

2. Summary

Sample joints were prepared using the stock parts fabricated for the modular coil joint and surrogate flange sections made from Stellalloy casting material. The parts were tensioned to 80 kips and tension measurements were taken over time and after thermal cycling to LN2 temperature to determine if relaxation of the joint tension occurs.

Tests were also conducted to develop a torque vs load curve for the Supernut fasteners.

3. Introduction

The NCSX Modular Coils are held together using a stud and shim connection. Each of the shims at each stud utilizes a metal core (stainless steel) with a G-10 insulator on each side for electrical isolation. The shear connection requires a tension of 72 kips to ensure that there is compression on the G-10 and stainless steel surfaces to ensure adequate friction forces.

4. Equipment and method

Two stud kits were assembled using the parts shown on drawing SE140-090-r2. All of the parts in the load path were used and the two surrogate flange surfaces were fabricated using 1.5" thick Stellalloy material taken from one of the NCSX Prototype castings. The first two assemblies were tested using alumina coated (by White Engineering) shims. One of the assemblies used a threaded surrogate flange (stud #1) and the other assembly was through bolted using a hexnut on one end and a Supernut on the other (stud #2). All of the washers and shims were production articles. Each stud was fitted with a resistance strain gage to measure the strain directly.

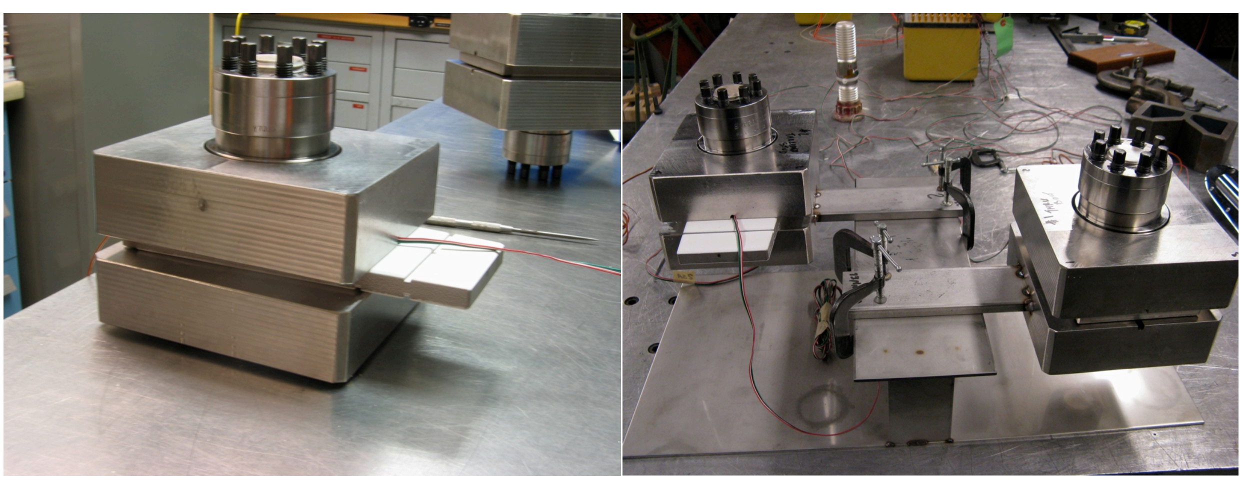


Figure 1: Photo Test Setup

The cryogenic tests were conducted in a foam insulated dewar fabricated especially for these tests. Temperature compensation was accomplished using a thermocouple mounted to a dummy stud inside the dewar cavity. The test articles were mounted about 1-2" above the floor of the dewar.

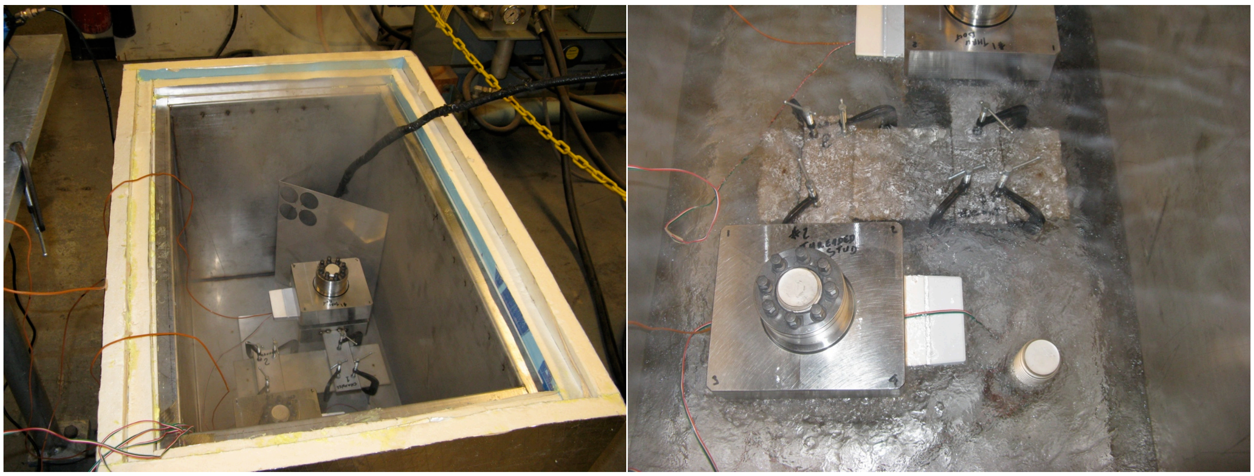


Figure 2: Photo Foam dewar and test specimens

The long stud was tensioned in the 100 kip MTS machine to 80-85 kips to derive the calibration curve (Figure 3) for load vs strain indication on the strain gages. A compensating gage was used on the short stud. The test was conducted by running the load up to 85 kips and back down to zero (0) kips while reading the strain gage values using a bridge.

The stud kits and surrogate flanges were then assembled using the assembly sequence shown on the drawing. The Supernuts were torqued to achieve 80-85 kips and were verified using the calibrated strain gages attached to each stud. Torques were applied using a "click" type torque wrench set to the indicated values. Note that later calibration of the torque wrench against a standard indicated a 4 ft-lb offset. The torquing method used was that specified in the Supernut assembly instructions. Measurments on the outside corners of the surrogate flanges were taken as the parts were tensioned to get an indication of how much the joint compressed under load. The data recorded for each assembly is shown on Tables 1 through 4.

Once the parts were properly torqued they were mounted inside the LN2 dewar as shown in Figure 2 and cooled to 77 K using liquid nitrogen. The first run was cooled by flooding the volume around the test specimens with LN2 to quickly bring the parts down to temperature. For the first run a reference TC junction was not installed so the temperatures recorded for the first test were approximate for indication only.

MTS Machine
MTS Systems Corp.
10 Kip servo-hydraulic tension and compression testing machine
Model 204.61
Serial # 245
Load cell
MTS Systems Corp.

Model 661-21A-02
Serial # 1273
Calibrated 02/12/07

Strain Gage Bridge
Vishay model P-350A portable strain indicator

5. Data and results

The data taken during the test runs is provided in the Appendix. The first Run (Figure 5) was taken using a thermocouple without a reference junction so the temperatures are approx. The pieces were cooled by flooding with LN2. This chilled the parts quickly and provided a worst case scenario. The tension in the studs rose quickly during the transients but returned to near starting tensions once at LN2 temperatures and then again once warmed back up to room temperature. The second test run (Figures 6 & 7) was conducted using a fairly slow cooldown (approximately 8 hrs) to demonstrate a more realistic scenario for the tension in the joint. As expected the tension spike initially but quickly returned to normal values. Upon warming to room temperature the tension returned to the baseline value. The third run (Figures 8 & 9) was a repeat of the second test but was only held conducted using a similar cooldown rate but was held at temperature for 3 days. All of the first 3 runs were conducted with the alumina coated shim. The last 2 runs #4 & 5 (Figures 10 & 11) were conducted using the G-10 / SS sandwich style shims.

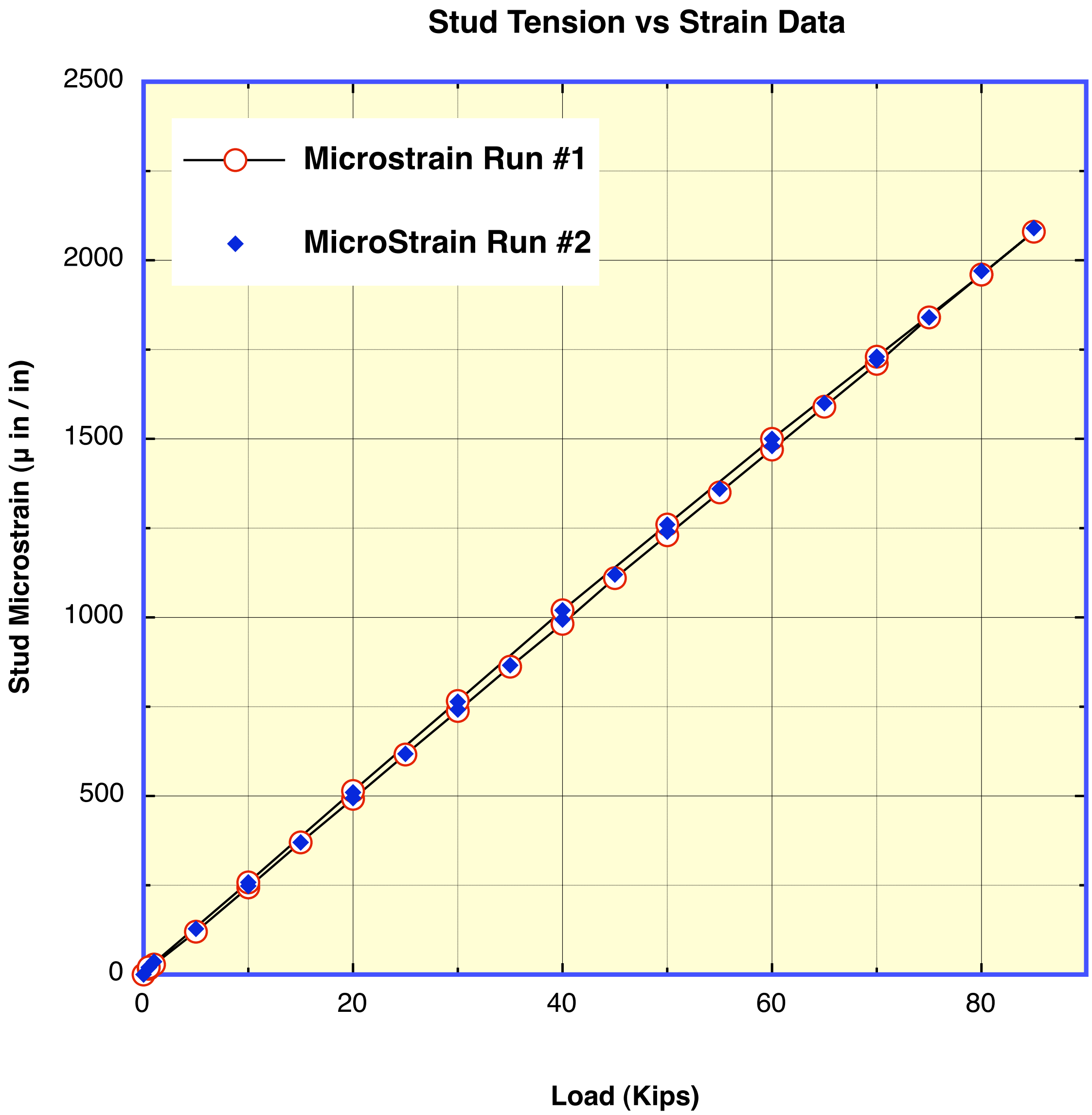


Figure 3 Stud Tension / Strain Data

Torque	Corner 1 (inches)	Corner 2	Corner 3	Corner 4	μStrain	Stud Tension (Kips)
0 ft-lb	4.02	4.018	4.025	4.02	0	0.00
19	4.016	4.017	4.019	4.018	1012	40.80

Torque	Corner 1 (inches)	Corner 2	Corner 3	Corner 4	µStrain	Stud Tension (Kips)
33	4.016	4.017	4.018	4.018	1780	72.07
38	4.016	4.017	4.018	4.018	1968	79.72

Table 1: Stud Tension vs Joint Compression Surrogate 1

Torque	Corner 1 (inches)	Corner 2	Corner 3	Corner 4	µStrain	Stud Tension (Kips)
0 ft-lb	3.764	3.765	3.763	3.765	0	0.00
19	3.762	3.763	3.762	3.762	1038	41.86
33	3.762	3.763	3.762	3.762	1784	72.23
38	3.762	3.763	3.762	3.762	2038	82.57

Table 2: Stud Tension vs Joint Compression Surrogate 2

Torque	Corner 1 (inches)	Corner 2	Corner 3	Corner 4	µStrain	Stud Tension (Kips)
0 ft-lb	4.04	4.042	4.043	4.045	0	0.00
19	4.043	4.042	4.044	4.044	1134	45.77
33	4.042	4.042	4.044	4.045	1714	69.38
38	4.042	4.042	4.044	4.045	1924	77.93

Table 3: Stud Tension vs Joint Compression Surrogate 3

Torque	Corner 1 (inches)	Corner 2	Corner 3	Corner 4	µStrain	Stud Tension (Kips)
0 ft-lb	3.788	3.786	3.787	3.788	0	0.00
19	3.788	3.786	3.787	3.788	1214	49.02
33	3.788	3.786	3.787	3.788	2074	84.03
38	3.788	3.786	3.787	3.788	2324	94.21

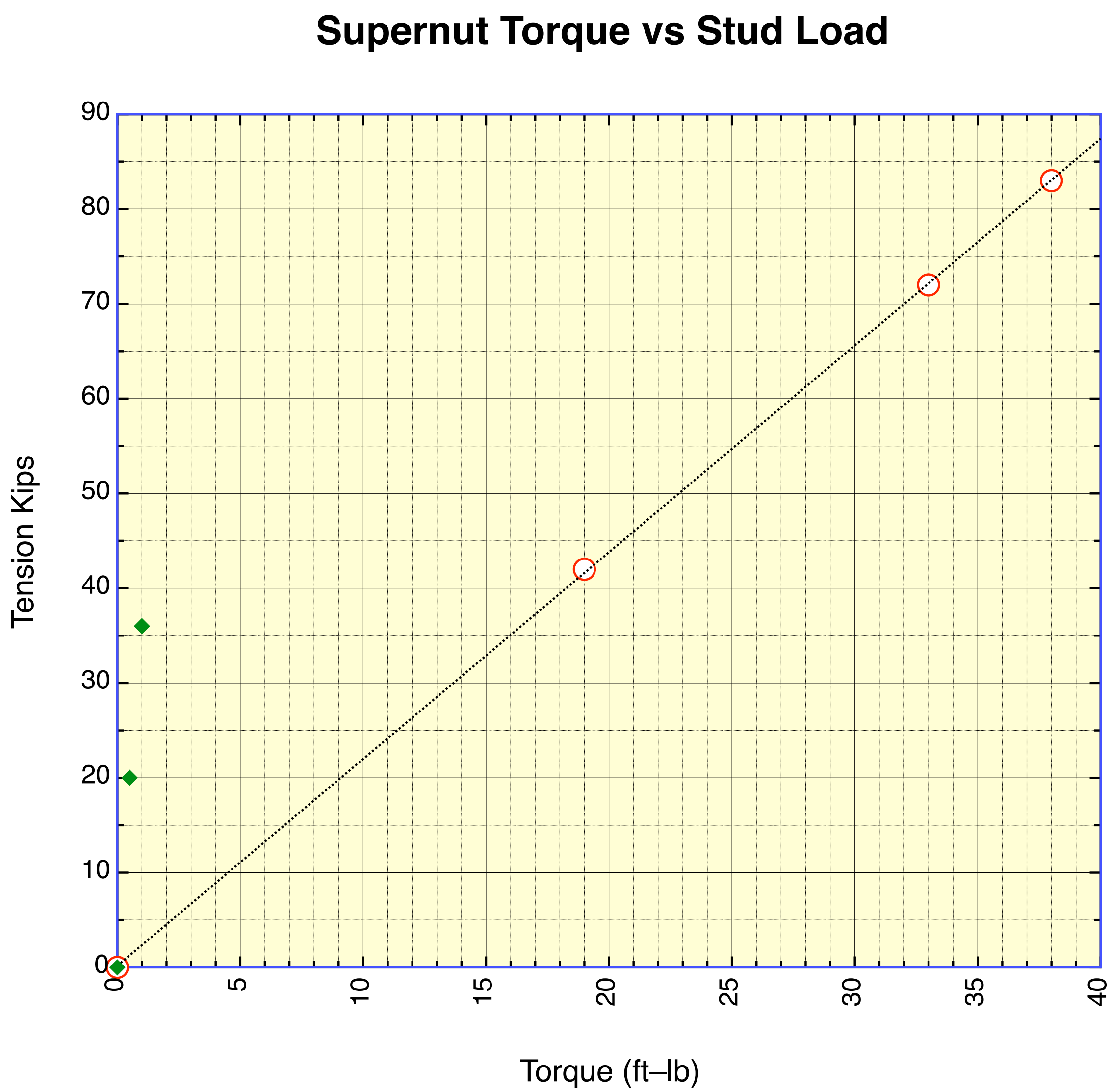


Figure 4: Supernut Torque vs Stud Load

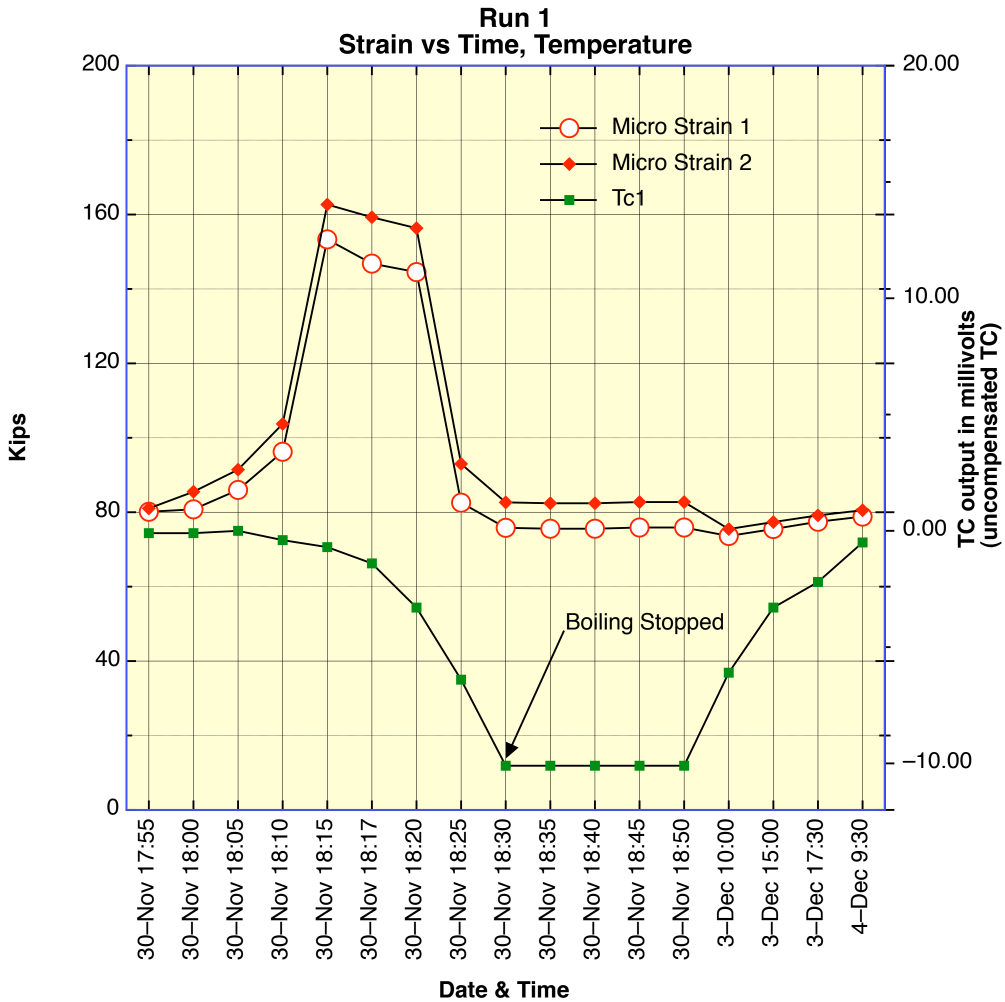


Figure 5: Run 1, Stud 1 & Stud 2 Tension vs Temperature

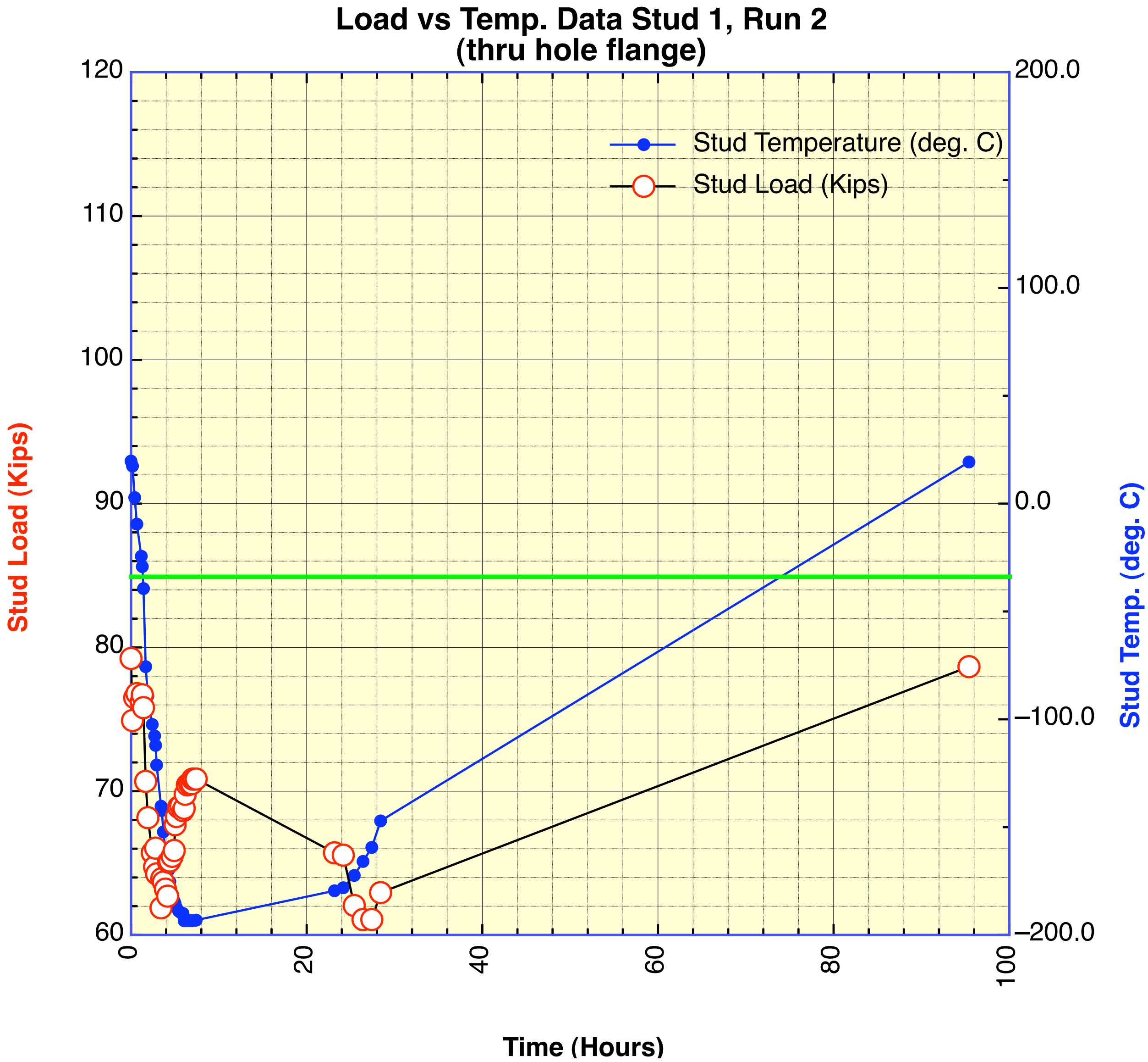


Figure 6: Run 2, Stud 1 Tension vs. Temperature

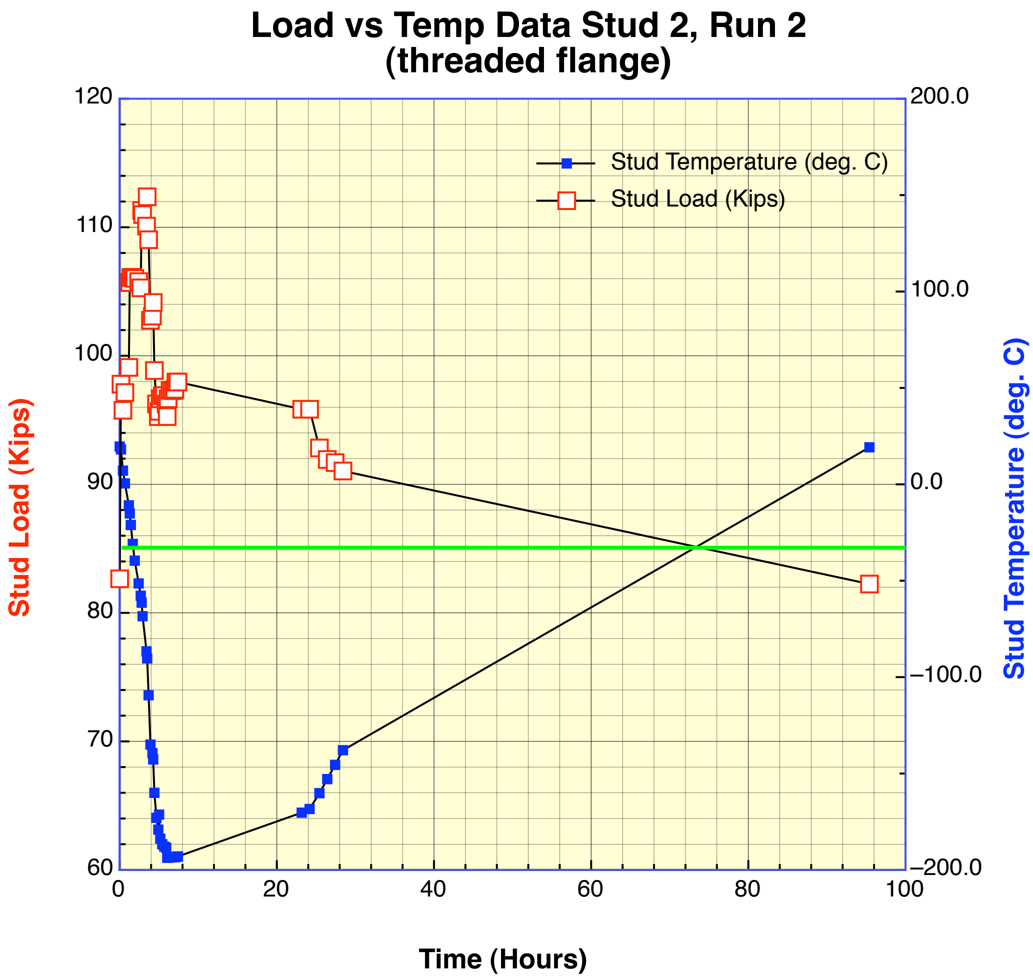


Figure 7: Run 2, Stud #2 Tension vs Temperature

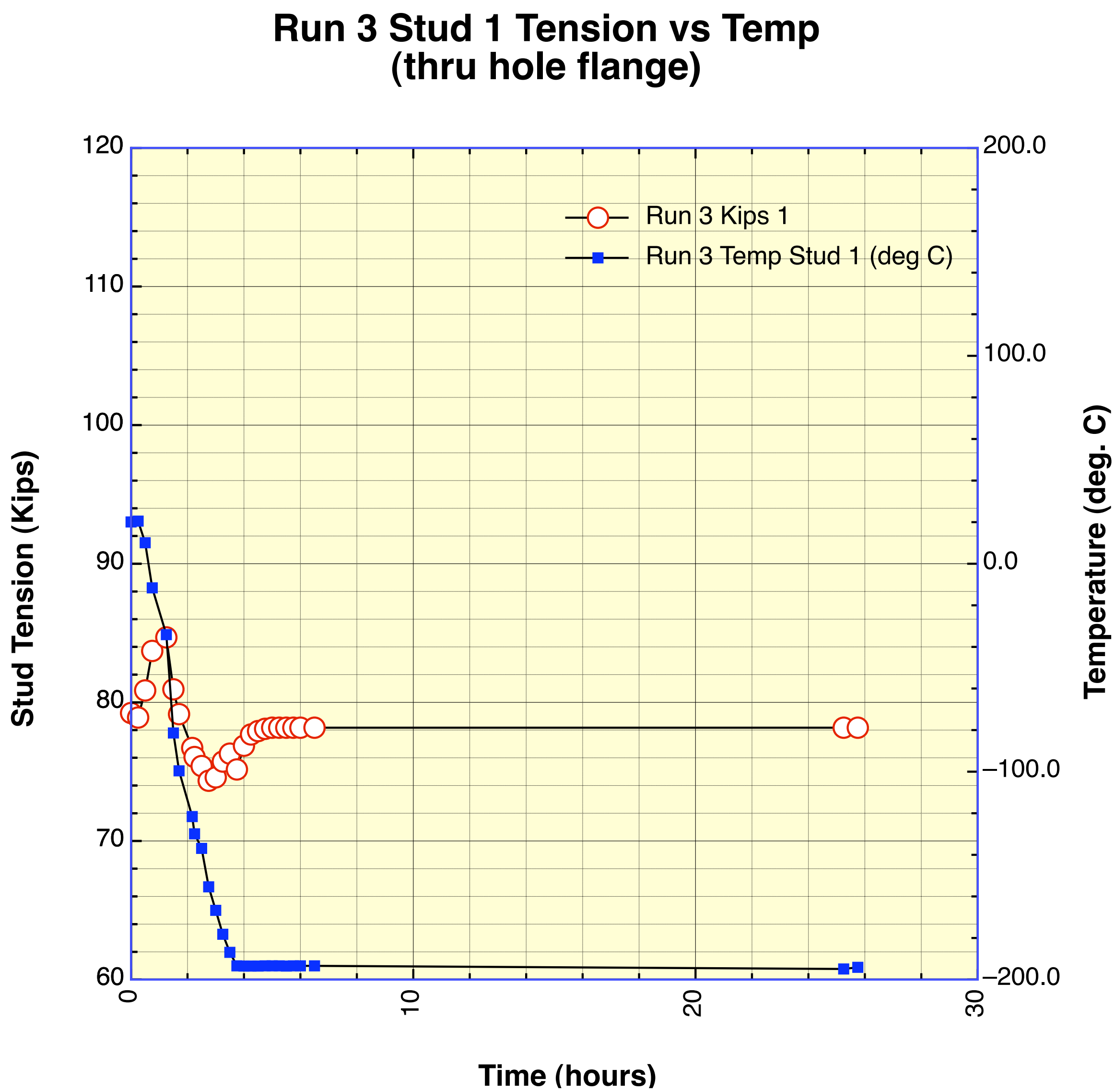


Figure 8: Run 3 Stud 1 Tension vs Temperature

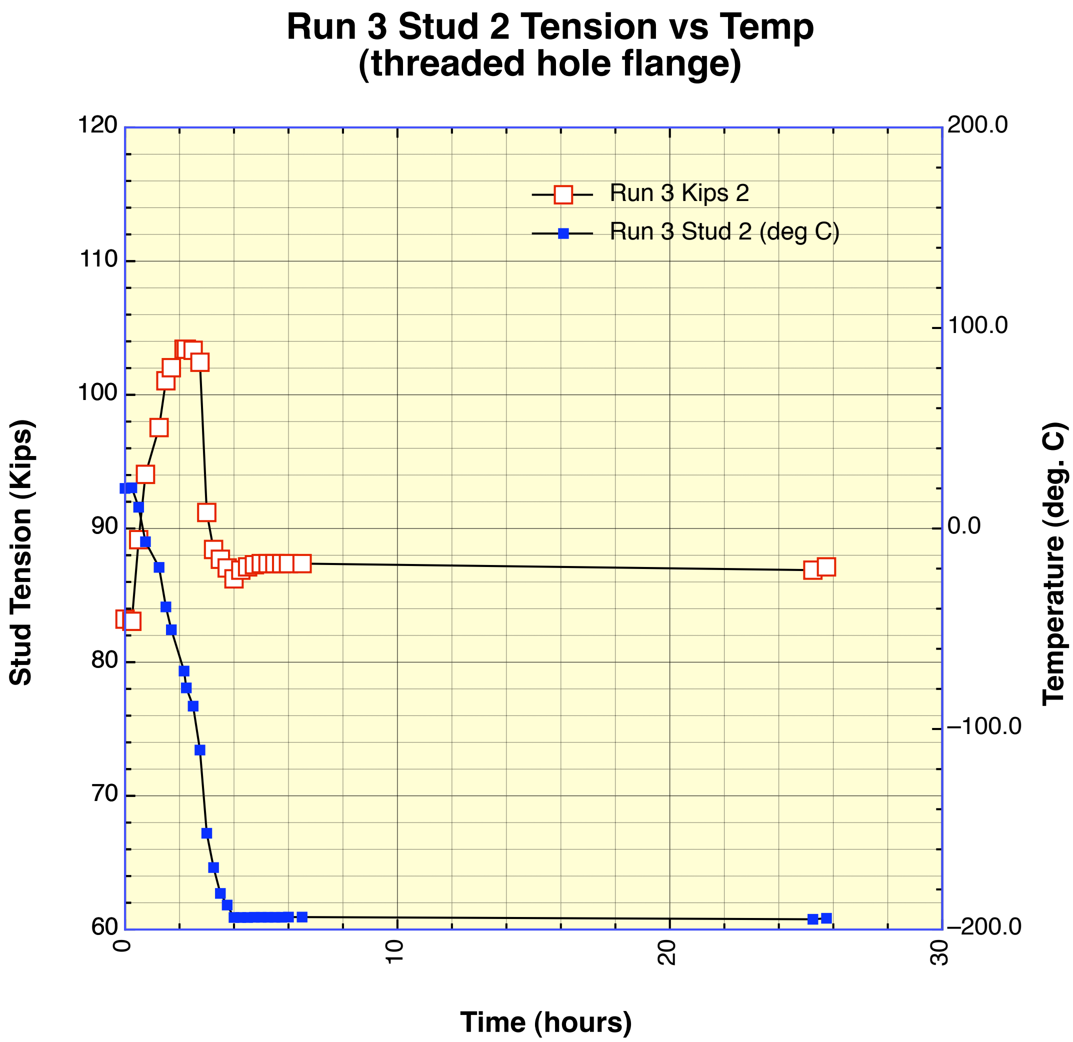


Figure 9: Run 3 Stud 2 Tension vs Temperature

Figure 10: Run 4, Stud 1 & 2, G10 Shims, Tension vs LN2 Level

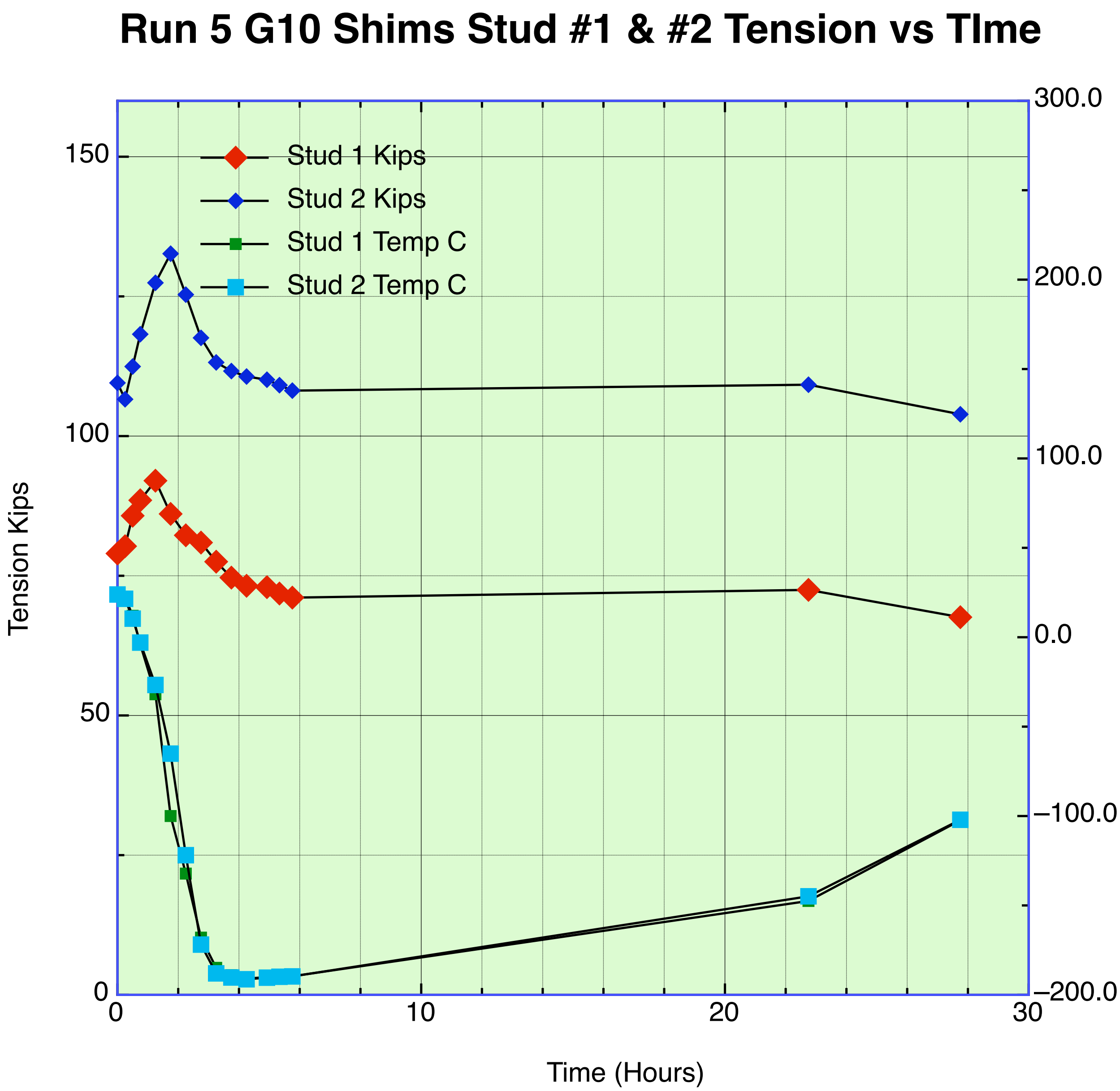


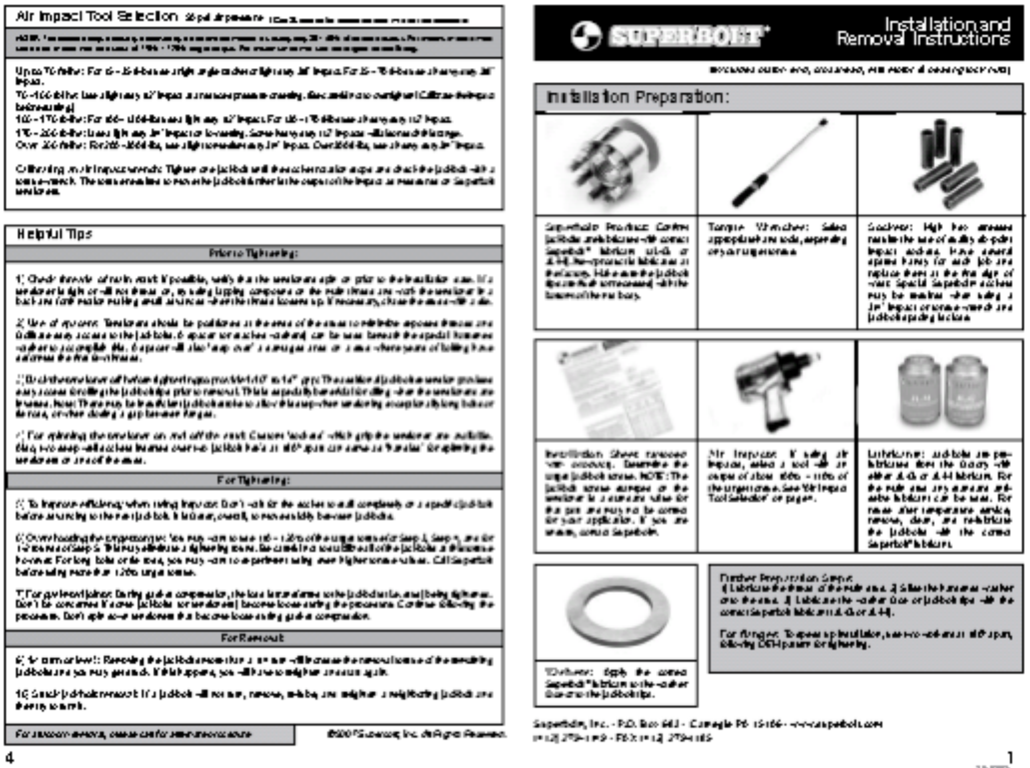
Figure 11: Run 5, Stud 1 & 2, G-10 Shims Tension vs Temperature

6. Conclusions and recommendations

The tests demonstrated that both the alumina and G-10 sandwich style shims maintain tension during a cooldown cycle and return to room temperature. No significant changes in the parts were observed upon disassembly and inspection after completion of the tests.

7. Appendix A

I. Superbolt Instructions


Air Impact Tool Selection

Helpful Tips

Prior to Tightening:

For Tightening:

For Removal:

4

Installation and Removal Instructions

Installation Preparation:

1

II. Data from the Strain Gage Calibration

Load (Kips)	Microstrain Run #1	MicroStrain Run #2	Calculated Kips
0	0	0	-0.40
0.5	16	20	0.41
1	28	36	1.07
5	120	128	4.81
10	244	248	9.70
15	370	370	14.66
20	492	494	19.71
25	616	618	24.76
30	738	742	29.81
35	862	866	34.86
40	982	994	40.07
45	1110	1120	45.20
50	1230	1240	50.08
55	1350	1360	54.97
60	1470	1480	59.85
65	1590	1600	64.74
70	1710	1720	69.62
75	1840	1840	74.51
80	1960	1970	79.80
85	2080	2090	84.69
80	1960	1970	79.80
70	1730	1730	70.03
60	1500	1500	60.67
50	1260	1260	50.90
40	1020	1020	41.12
30	766	764	30.70
20	514	510	20.36
10	258	258	10.10
0.5	20	20	0.41

III. Run #1 Data

Date & Time	Micro Strain Stud 1	Kips Stud 1	Micro Strain Stud 2	Kips Stud 2	Tc1	Tc2	Notes
Nov 30, 2008 5:5	1978	80.13	2000	81.02	-0.1	-0.2	Start of LN2 pour
Nov 30, 2008 6:0	1994	80.78	2110	85.50	-0.1	-0.2	
Nov 30, 2008 6:0	2122	85.99	2256	91.44	0	-0.4	
Nov 30, 2008 6:1	2374	96.25	2558	103.74	-0.4	-0.8	
Nov 30, 2008 6:1	3776	153.32	4006	162.69	-0.7	-1.2	
Nov 30, 2008 6:1	3616	146.81	3922	159.27	-1.4	-1.6	
Nov 30, 2008 6:2	3560	144.53	3850	156.34	-3.3	-3.1	
Nov 30, 2008 6:2	2038	82.57	2294	92.99	-6.4	-10.1	
Nov 30, 2008 6:3	1872	75.81	2040	82.65	-10.1	-10.1	
Nov 30, 2008 6:3	1866	75.57	2034	82.41	-10.1	-10.1	
Nov 30, 2008 6:4	1866	75.57	2034	82.41	-10.1	-10.1	
Nov 30, 2008 6:4	1874	75.89	2042	82.73	-10.1	-10.1	
Nov 30, 2008 6:5	1874	75.89	2042	82.73	-10.1	-10.1	Test Concluded, left in LN2 over weekend
Dec 3, 2008 10:0	1818	73.61	1864	75.48	-6.1	-6.1	In Chamber , warming up
Dec 3, 2008 3:00	1864	75.48	1910	77.36	-3.3	-3.2	Warming up
Dec 3, 2008 5:30	1912	77.44	1954	79.15	-2.2	-2.2	Warming up
Dec 4, 2008 9:30	1946	78.82	1988	80.53	-0.5	-0.5	Warming up

IV. Data from Run #2

Date & Time	Time (Hours)	MicroStrain 1	Kips 1	Microstrain 2	Kips 2	Temp Stud 1 (deg. C)	Temp Stud 2 (deg. C)
Dec 6, 2007 10:0	0	1956	79.23	2040	82.65	19.7	19.6
Dec 6, 2007 10:1	0.17	1850	74.92	2412	97.79	17.4	18.1
Dec 6, 2007 10:3	0.42	1889	76.50	2362	95.76	2.8	7.1
Dec 6, 2007 10:4	0.67	1896	76.79	2396	97.14	-9.5	0.5
Dec 6, 2007 11:1	1.17	1882	76.22	2444	99.10	-24.4	-10.9
Dec 6, 2007 11:2	1.28	1894	76.71	2606	105.69	-29.2	-15.1
Dec 6, 2007 11:3	1.42	1872	75.81	2616	106.10	-39.4	-21.1
Dec 6, 2007 11:4	1.67	1746	70.68	2616	106.10	-75.6	-30.9
Dec 6, 2007 12:0	1.92	1684	68.16	2614	106.02	-89.2	-39.6
Dec 6, 2007 12:3	2.42	1624	65.71	2608	105.77	-102.4	-51.4
Dec 6, 2007 12:4	2.68	1600	64.74	2596	105.29	-107.7	-57.8
Dec 6, 2007 12:5	2.8	1632	66.04	2744	111.31	-112.1	-61.4
Dec 6, 2007 1:00	2.92	1588	64.25	2736	110.99	-121.2	-68.4
Dec 6, 2007 1:30	3.42	1530	61.89	2714	110.09	-140.3	-86.6
Dec 6, 2007 1:35	3.5	1580	63.92	2770	112.37	-142.3	-90.3
Dec 6, 2007 1:46	3.68	1574	63.68	2688	109.03	-152.2	-109.4
Dec 6, 2007 2:00	3.92	1562	63.19	2534	102.76	-161.4	-135.0
Dec 6, 2007 2:15	4.17	1550	62.70	2542	103.09	-167.7	-139.4
Dec 6, 2007 2:21	4.27	1608	65.06	2568	104.15	-170.0	-142.7
Dec 6, 2007 2:30	4.42	1610	65.14	2438	98.85	-175.3	-160.0
Dec 6, 2007 2:46	4.68	1618	65.47	2374	96.25	-180.9	-173.0
Dec 6, 2007 3:00	4.92	1628	65.88	2350	95.27	-184.3	-179.1
Dec 6, 2007 3:06	5.02	1672	67.67	2360	95.68	-185.4	-171.3
Dec 6, 2007 3:15	5.17	1686	68.24	2384	96.65	-187.3	-183.8
Dec 6, 2007 3:30	5.42	1702	68.89	2390	96.90	-188.9	-186.7
Dec 6, 2007 3:45	5.67	1704	68.97	2390	96.90	-189.7	-187.9
Dec 6, 2007 4:00	5.92	1696	68.65	2374	96.25	-190.0	-188.5
Dec 6, 2007 4:08	6.05	1700	68.81	2350	95.27	-193.4	-193.6
Dec 6, 2007 4:15	6.17	1724	69.79	2384	96.65	-193.4	-193.7
Dec 6, 2007 4:30	6.42	1740	70.44	2400	97.31	-193.4	-193.5
Dec 6, 2007 4:45	6.67	1742	70.52	2400	97.31	-193.4	-193.4
Dec 6, 2007 5:00	6.92	1742	70.52	2400	97.31	-193.4	-193.2
Dec 6, 2007 5:06	7.02	1750	70.84	2402	97.39	-193.4	-193.4
Dec 6, 2007 5:15	7.17	1750	70.84	2416	97.96	-193.2	-193.3
Dec 6, 2007 5:30	7.42	1750	70.84	2416	97.96	-193.1	-193.0
Dec 7, 2007 9:15	23.17	1624	65.71	2364	95.84	-179.5	-170.3
Dec 7, 2007 10:1	24.17	1620	65.55	2364	95.84	-178.1	-168.4
Dec 7, 2007 11:3	25.42	1534	62.05	2290	92.83	-172.4	-160.2
Dec 7, 2007 12:3	26.42	1510	61.07	2268	91.93	-165.9	-152.9
Dec 7, 2007 1:30	27.42	1510	61.07	2262	91.69	-159.4	-145.5
Dec 7, 2007 2:30	28.42	1556	62.95	2246	91.04	-147.1	-137.9

Date & Time	Time (Hours)	MicroStrain 1	Kips 1	Microstrain 2	Kips 2	Temp Stud 1 (deg. C)	Temp Stud 2 (deg. C)
Dec 10, 2007 9:3	95.42	1942	78.66	2030	82.24	19.3	19.2

V. Data from Run #3

Date & Time	Time (hours)	MicroStrain 1	Kips 1	MicroStrain 2	Kips 2	Temp Stud 1 (deg C)	Stud 2 (deg C)	LN2 Level
Dec 10, 2007 10:30	0.00	1956	79.23	2054	83.22	20.1	20.0	
Dec 10, 2007 10:45	0.25	1948	78.90	2050	83.06	20.5	20.3	0.0
Dec 10, 2007 11:00	0.50	1996	80.86	2200	89.16	10.1	10.6	0.4
Dec 10, 2007 11:15	0.75	2066	83.71	2320	94.05	-11.6	-6.6	1.3
Dec 10, 2007 11:45	1.25	2090	84.69	2406	97.55	-34.1	-19.4	2.0
Dec 10, 2007 12:00	1.50	1998	80.94	2492	101.05	-81.4	-39.1	2.5
Dec 10, 2007 12:12	1.70	1954	79.15	2516	102.03	-99.6	-50.5	2.8
Dec 10, 2007 12:40	2.17	1894	76.71	2550	103.41	-121.6	-71.1	3.0
Dec 10, 2007 12:45	2.25	1878	76.06	2550	103.41	-129.9	-79.5	3.1
Dec 10, 2007 1:00 I	2.50	1862	75.40	2548	103.33	-136.9	-88.6	3.4
Dec 10, 2007 1:15 I	2.75	1836	74.35	2526	102.44	-155.4	-110.5	3.6
Dec 10, 2007 1:30 I	3.00	1842	74.59	2250	91.20	-166.7	-152.0	3.8
Dec 10, 2007 1:45 I	3.25	1870	75.73	2182	88.43	-178.2	-169.1	4.1
Dec 10, 2007 2:00 I	3.50	1884	76.30	2164	87.70	-186.9	-182.0	4.8
Dec 10, 2007 2:15 I	3.75	1856	75.16	2148	87.05	-193.4	-187.8	5.3
Dec 10, 2007 2:30 I	4.00	1898	76.87	2128	86.23	-193.5	-194.0	5.8
Dec 10, 2007 2:45 I	4.25	1918	77.68	2144	86.88	-193.5	-194.0	6.5
Dec 10, 2007 3:00 I	4.50	1924	77.93	2150	87.13	-193.5	-194.0	7.0
Dec 10, 2007 3:15 I	4.75	1928	78.09	2154	87.29	-193.4	-193.9	7.4
Dec 10, 2007 3:30 I	5.00	1930	78.17	2156	87.37	-193.4	-193.9	8.0
Dec 10, 2007 3:45 I	5.25	1930	78.17	2156	87.37	-193.4	-193.9	8.5
Dec 10, 2007 4:00 I	5.50	1930	78.17	2156	87.37	-193.5	-193.9	9.1
Dec 10, 2007 4:15 I	5.75	1930	78.17	2156	87.37	-193.4	-193.9	9.6
Dec 10, 2007 4:30 I	6.00	1930	78.17	2156	87.37	-193.4	-193.8	10.0
Dec 10, 2007 5:00 I	6.50	1930	78.17	2156	87.37	-193.4	-193.8	20.0
Dec 11, 2007 11:45	25.25	1930	78.17	2144	86.88	-194.9	-194.9	9.0
Dec 11, 2007 12:15	25.75	1930	78.17	2150	87.13	-194.1	-194.4	13.5
Dec 11, 2007 4:00 I	29.50	1930	78.17	2150	87.13	-195	-194.4	14.5
Dec 12, 2007 10:00	47.50	1930	78.17	2150	87.13	-194.1	-195.2	
Dec 12, 2007 10:30	48.00	1926	78.01	2154	87.29	-194.9	-194.4	
Dec 12, 2007 1:00 I	50.50	1924	77.93	2156	87.37	-194.9	-195.0	
Dec 12, 2007 5:00 I	54.50	1930	78.17	2160	87.54	-195	-195.1	
Dec 12, 2007 5:25 I	54.92	1930	78.17	2160	87.54	-194.1	-194.5	
Dec 13, 2007 10:00	71.50	1930	78.17	2160	87.54	-194.9	-195.1	
Dec 13, 2007 11:15	72.75	1930	78.17	2150	87.13	-193.7	-194.0	
Dec 13, 2007 12:00	73.50	1930	78.17	2148	87.05	-193.5	-193.9	
Dec 13, 2007 1:05 I	74.58	1930	78.17	2146	86.97	-193.6	-193.9	
Dec 13, 2007 2:15 I	75.75	1930	78.17	2140	86.72	-193.5	-194.0	
Dec 13, 2007 3:15 I	76.75	1930	78.17	2140	86.72	-193.5	-193.9	
Dec 13, 2007 4:10 I	77.67	1930	78.17	2130	86.31	-193.5	-194.0	
Dec 13, 2007 5:00 I	78.50	1930	78.17	2130	86.31	-193.4	-194.0	

Date & Time	Time (hours)	MicroStrain 1	Kips 1	MicroStrain 2	Kips 2	Temp Stud 1 (deg C)	Stud 2 (deg C)	LN2 Level
Dec 14, 2007 9:15 A	94.75	1610	65.14	1960	79.39	-167.6	-150.7	
Dec 14, 2007 1:00 P	98.50	1694	68.56	1958	79.31	-143.1	-133.7	
Dec 14, 2007 3:30 P	101.00	1722	69.70	1976	80.04	-133.1	-125.1	
Dec 14, 2007 5:15 P	102.75	1676	67.83	1850	74.92	-112.9	-109.2	
Dec 17, 2007 10:00	167.50	1960	79.39	2064	83.63	18.1	18.1	
Dec 17, 2007 1:00 P	170.50	1960	79.39	2056	83.30	20	19.9	