C50 Cold Pressure Test of Cryomodule SL09


Summary

The original CEBAF cryomodules were designed to the intent of the ASME Boiler & Pressure Vessel Code. As part of early testing activities, a venting test was conducted in 1992 to verify the performance of the relief system. In 2000, a series of cryomodules suffered an upset condition that further proved that the relief system performed in a manner that caused no damage to the internal components. However, no actual system pressure test was conducted on a warm or cold cryomodule. A pneumatic pressure test of the primary helium circuit, performed on this particular cryomodule – SL09 dubbed *Fugacity*, was conducted to verify that the original CEBAF cryomodule pressure system performs as intended.

A successful test result, a leak-free pressure test and no detectable change in cavity performance, lends credence to the approach used by CEBAF engineers that was based on sound engineering principles. In the event that a leak develops or the cavity geometry is altered, the result does not adversely impact accelerator operations as this cryomodule is already scheduled for disassembly as part of the C50 refurbishment program.

This cryomodule was successfully pressure tested because the primary circuit was helium leak-tight after pressure testing and the RF parameters of field flatness and external coupling were not altered beyond acceptable limits.

Discussion

A description of the cold pressure test set-up can be found in the TOSP written in support of testing [1]. The test pressure is shown below (Table 1). The pressure boundary for a cryo-unit which contains the cavity and helium vessel assembly is shown in Figure 1. Four of these cryo-units are connected in series within a cryomodule. The entire primary circuit has been pressure tested at 4.2 K on two separate occasions as part of this test program. Electrical measurements of cavity frequency pass-bands and external Q were taken before and after pressure tests to assess changes in RF properties attributable to mechanical distortions of the cavities. In addition, a bead pull measurement was conducted on cavities 5 & 6 after the second pressure test. A helium leak test was conducted after pressure testing was completed to confirm that the entire primary circuit remained helium leak-tight.

*Fugacity as defined at www.meriam-webster.com: ˈfyü-i-ˈga-sa-tē: the vapor pressure of a vapor assumed to be an ideal gas obtained by correcting the determined vapor pressure and useful as a measure of the escaping tendency of a substance from a heterogeneous system. Ironically, this is a fitting name for the cryomodule that endured the first cold pressure test.*
Table 1. Design, Relief and Test Pressures for the Primary Circuit [1]

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Design Pressure</th>
<th>Normal Relief Pressure</th>
<th>Test Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Return – from JT valve to exhaust</td>
<td>4 atm (44 psig)</td>
<td>3.5*/4.1** atm (37/46 psig)</td>
<td>4.4 atm (50 psig)</td>
</tr>
</tbody>
</table>
* without guard vacuum  
** with guard vacuum

Figure 1. Plan/Elevation Views of CM Helium Vessel Assembly [2] illustrating the pressure boundaries including the niobium cavity exterior and the stainless helium vessel interior.
Results

Pressurization

After the first pressure test was complete (Figure 2), it was determined that the low power $Q_{\text{external}}$ measurements taken before the pressure test were invalid. A series of high power $Q_{\text{external}}$ measurements was taken before and after the second pressure test (Figure 3).

In both tests, ~360 Watts of power was applied to the cavity heaters. The cavity temperatures and helium circuit pressure responded similarly when comparing the two tests. Note that the scales are not the same for the two time history plots.

The liquid level probe ceases to function when the bath temperature exceeds the critical point ($T = 5.2 \, \text{K}, P \sim 1750 \, \text{torr}$). When the bath temperature and pressure drop below the critical point, the liquid level probe then functions properly.

The primary circuit was ramped to ~3340 torr (4.4 atm) in about 30 minutes, held for 10 minutes and then de-pressurized in about 45 minutes. As predicted in the TOSP, the pressurization rate increases after the bath temperature and pressure exceed the critical point.

Pass Bands

The pass band frequencies were measured for all cavities before and after both pressure tests. Small geometric distortions in cavity shape can be detected by comparing the relative change in spacing between the pass bands. The relative change between the five pass bands for each cavity, one through eight left to right, are plotted on three different scales (Figure 4).

Six out of eight of the cavities showed little or no change in the relative pass band spacing, less than $\pm 500 \, \text{Hz}$. Cavity 4 showed a change of ~ 5 kHz between $2\pi/5$ and $\pi/5$ modes. Cavity 5 showed a change of ~ 250 kHz between $2\pi/5$ and $\pi/5$ modes. A change of 250 kHz for a single cell cavity corresponds to an elastic displacement of ~ 0.2 mm. This assumes that the tuning sensitivity for a CEBAF 5-cell cavity is ~ 300 kHz/mm.

In general, the cavities experience little or no distortion. Measurement of RF parameters of greater interest are given in the next sections.
Figure 2. Time History of Data from First Pressure Test

Figure 3. Time History of Data from Second Pressure Test
Figure 4. Change in Pass Band Spacing due to Second Pressure Test
The specification for $Q_{\text{external}}$ is $6.6 \times 10^6 \pm 20\% \ (\pm 1.3 \times 10^6) \ [3]$. All cavities were within specification prior to the second pressure test and remained within specification after the second pressure test (see Table 2). It is worth noting that the $Q_{\text{external}}$ for cavity 5 increased by 12.4%, while all other cavities changed at most a few percent. This increase is consistent with a displacement of the broad walls of the cavity FPC body that would result in a reduction of the height of the waveguide. Gussets welded on the FPC body (Figure 5) serve to reinforce the waveguide and minimize changes in $Q_{\text{external}}$ due to operational pressure loads.

<table>
<thead>
<tr>
<th>Cavity #</th>
<th>SN</th>
<th>Before 2nd Test</th>
<th>After Second Test</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IA-180</td>
<td>7.74E+06</td>
<td>7.51E+06</td>
<td>-3.0%</td>
</tr>
<tr>
<td>2</td>
<td>IA-222</td>
<td>7.65E+06</td>
<td>7.84E+06</td>
<td>2.5%</td>
</tr>
<tr>
<td>3</td>
<td>IA-345</td>
<td>6.39E+06</td>
<td>6.25E+06</td>
<td>-2.2%</td>
</tr>
<tr>
<td>4</td>
<td>IA-299</td>
<td>5.61E+06</td>
<td>5.72E+06</td>
<td>2.0%</td>
</tr>
<tr>
<td>5</td>
<td>IA-260</td>
<td>5.33E+06</td>
<td>5.99E+06</td>
<td>12.4%</td>
</tr>
<tr>
<td>6</td>
<td>IA-38</td>
<td>7.28E+06</td>
<td>7.31E+06</td>
<td>0.4%</td>
</tr>
<tr>
<td>7</td>
<td>IA-218</td>
<td>5.83E+06</td>
<td>5.82E+06</td>
<td>-0.2%</td>
</tr>
<tr>
<td>8</td>
<td>IA-280</td>
<td>6.82E+06</td>
<td>6.82E+06</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 2. Change in $Q_{\text{external}}$ After Pressure Testing

Figure 5. Cavity – Last Two Cells and FPC Body
Field Flatness

The specification for field flatness is ± 5% [3]. Bead pulls were conducted on cavities 5 and 6 since cavity 5 showed a change in $Q_{\text{external}}$. The bead pull was done on the cryo-unit as part of disassembly, specifically after the adjacent bridging area components were removed. The field flatness calculated from the bead pull data was 4.6% and 2.6% for cavities 5 and 6 respectively (Figures 6 & 7).

Figure 6. Plot of Field Flatness of 4.6% for Cavity 5 (IA-260)

Figure 7. Plot of Field Flatness of 2.6% for Cavity 6 (IA-038)
Final Leak Check

After warm-up the primary circuit was leak checked with a helium mass spectrometer. The MDL was $2 \times 10^{-10}$ std cc He/sec. The primary circuit was pressurized to 1 atm while pumping on the insulating vacuum space. No leak was found indicating that the primary circuit remained leak tight [5].

Conclusion

This cryomodule was successfully pressure-tested as part of the decommissioning effort for the the C50 Refurbishment Program. There were no significant changes in RF parameters detected that can be attributed to the pressure testing.

Future Work

More pressure tests should be conducted in order to add to this data set and ultimately increase JLAB’s understanding of pressure-related issues in the context of cryomodule construction and operation.

References:

1. TOSP-ENG-07-004-T, “Cold Pressure Test of Original CEBAF Cryomodule”
2. Drawing 11126-E-0001 rev F.
3. CEBAF Design Handbook, Revised 1/14/91, p. 17
4. D. Forehand and R. Overton, taken from data posted at M:\asd\asddata\CavityTuning
5. D. Bigelow, private communication, test conducted on 11-07-07.