HEAT TRANSFER IN CRYOGEL® Z UNDER COMPRESSION FOR USE IN THE ULTRA TRANSPARENT CRYOSTATS OF FCC DETECTOR SOLENOIDS

VERONICA ILARDI


Contents:
1. Introduction
2. Cryogel® Z specification
3. Compression test of Cryogel® Z
4. Heat transfer analysis of a large scale Cryogel® Z sample
5. Conclusion
Conventional designs for FCC detector magnets show the superconducting solenoid around the inner tracker detector and calorimeter.

Magnetic field is required in the tracker and in the muon chambers, not in the calorimeter.

Most of the stored magnetic energy (~80%) is wasted in the calorimeter.

Placing the solenoid inside the calorimeter, it is saving:

- factor $\approx 4$ in stored energy,
- factor $\approx 2$ in cost.

The same concept can be applied to the more demanding FCC-hh, with a 4T/4m bore main superconducting solenoid.
Highly particle radiation transparent cold mass and cryostat: \( X_0 \leq 1 \) in radial direction

Lowest possible thickness and density:
Radial envelope < 300 mm

Structure of very thin metallic vacuum vessel walls, supported by an insulation material with sufficient mechanical resistance
CRYOGEL® Z SPECIFICATION

- Manufactured by Aspen Aerogels Inc.
- Shaped as a flexible aerogel composite blanket, with a layer of aluminum on top
- Combines silica aerogel with reinforcing fibers
- Density of 160 kg/m³

Composition:

<table>
<thead>
<tr>
<th>CHEMICAL NAME</th>
<th>PERCENTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic amorphous silica</td>
<td>25-40%</td>
</tr>
<tr>
<td>Methylsilylated silica</td>
<td>10-20%</td>
</tr>
<tr>
<td>Polyethylene terephthalate (PET or polyester)</td>
<td>10-20%</td>
</tr>
<tr>
<td>Fibrous glass (textile grade)</td>
<td>10-20%</td>
</tr>
<tr>
<td>Magnesium hydroxide</td>
<td>0-5%</td>
</tr>
<tr>
<td>Aluminum foil</td>
<td>0-5%</td>
</tr>
</tbody>
</table>

The exact percentage (concentration) of composition has been withheld by Aspen Aerogels Inc. as a trade secret.
A compressive mechanical load equivalent to 1 bar is applied to a stack of 10 samples of Cryogel Z.

The dimension of the stack is 100 mm x 100 mm x 100 mm.

The measurements are taken for 10 compressive cycles.
- Maximum compression ranging from 29.0% of the initial thickness at the first cycle and 29.8% at the last cycle.

- Compression hysteresis: percentage of material recovered ranging from 20% of the initial thickness at the first cycle and 17% at the last cycle.
COMPRESSION TESTS OF CRYOGEL® Z

THERMAL SHRINKAGE TEST OF COMPRESSED CRYOGEL Z

- A G10 cylinder of 484 mm is vacuum pumped and placed in liquid nitrogen.
- 280 mm of Cryogel Z blankets of 155 mm diameter filling the cylinder.
- A stainless steel piston with an O-ring seal is ensuring the leak tightness of the setup.
- The O-ring is kept at room temperature by using two electric heaters on the piston and a 210 mm G10 insert between the O-ring and the stack of Cryogel Z.
- A Pt100 temperature sensor is placed on top of the Cryogel discs.
Compression result consistent with the previous result: compression of the 29% over the initial height, 24% recovered material.

The pressure, decreasing at the first pumping cycle shows a clear holding level at 2.2 mbar, indicating outgassing of the material.

No relevant displacement of the piston observed, given the accuracy of ± 0.5 mm. The contraction of G10 parts is 0.5 mm.

Thus, thermal shrinkage of Cryogel Z may occur within our measurement accuracy of 0÷1 mm (0÷0.5% of the compressed height of Cryogel Z stack).

First pump down of a stack of Cryogel Z compressed layers at 293 K, pressure versus time.
HEAT TRANSFER IN A LARGE-SCALE CRYOGEL® Z SAMPLE

GOAL

To analyse the heat load expected in a large cryostat when using Cryogel Z as thermal insulator.

Heat load measurements from 4 K to room temperature while compressing Cryogel Z by 1 bar, corresponding to the differential pressure of the cryostat under vacuum.
HEAT TRANSFER IN A LARGE-SCALE CRYOgel® Z SAMPLE

(a) cryocooler cold head
(b) cryostat wall
(c) cryostat top flange
(d) flexible thermal links
(e) thermalized copper plates
(f) O-ring
(g) Cryogel Z stacks

Main dimensions:

- Vacuum vessel: 800 mm diameter, 293 mm height
- Thermal shield: 660 mm diameter
- Cold mass: 620 mm diameter
- Cryogel stacks: 600 mm diameter, 4x70 mm height
From the heat flow values obtained for various combinations of temperature on the first and second stages, we determined the thermal conductivity of Cryogel Z in this large scale setup assumed representative for a real cryostat.
We can justify the different thermal conductivity values between the small scale and large scale tests by considering that:

- The small sample dimensions of the first (22 mm diameter, 10 mm thickness) radically increase the measurement error (maximum 30%).
- The heat transfer analysis takes into account the various interfaces between Cryogel Z blankets, copper plates and vessel.

The thermal conductivity data between 150 and 200 K are fairly consistent with the one provided by Aspen Aerogels Inc. (acquired according to ASTM C177, under 140 mbar compression) despite the different test conditions.
HEAT LOADS IN THE CRYOSTAT OF THE 4 m BORE, 6 m LONG FCC-ee+ SOLENOID

- Cryostat’s total thickness: 250 mm
- Thermal shield at 70 mm from the cold mass.
- $T_{\text{SHEILD}} = 40 \, \text{K}$
- $T_{\text{COLD\_MASS}} = 6 \, \text{K}$

Fourier law for a steady-state one-dimensional conduction in a cylindrical layer:

$$Q = 2 \cdot \pi \cdot \lambda \cdot L \cdot \frac{T_1 - T_2}{\ln\left(\frac{r_2}{r_1}\right)}$$

Heat load on the thermal shield:

$$Q_1 = 13 \, \text{kW}$$

Heat load on the cold mass:

$$Q_2 = 900 \, \text{W}$$
CONCLUSION

- Cryogel Z shows fairly stable mechanical behavior under 1 bar mechanical pressure with some 30% height reduction.

- Thermal conductivity for Cryogel Z, measured on a small-scale setup, is 0.2 mW/mK@10 K to 50 mW/mK@273 K.

- Thermal conductivity results in the 150-200 K range are comparable to the data given by Aspen Aerogels Inc.

- For the FCC-ee^+ solenoid, a 250 mm thick cryostat with 13 kW on the shield and 900 W on the cold mass would work.

- Cryogel Z is a promising insulation material for ultra-thin cryostats of the previously mentioned FCC detector magnets.