CORNELL'S BEAM LINE HIGHER ORDER MODE ABSORBERS

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Abstract
Efficient damping of the higher-order modes (HOMs) of the superconducting cavities is essential for the proposed energy recovery linac at Cornell that aims for high beam currents and short bunches. Designing these HOM beamline absorbers has been a long endeavor, sometimes including disappointing results. We will review the design, the findings on the prototype and the final choices made for the 7 HOM absorbers being built for the main linac cryomodule (MLC) prototype.

INTRODUCTION
The potential for excellent quality of X-ray beams, generated by a low-emittance electron beam, motivated the design of a 5-GeV superconducting energy-recovery linac (ERL) [1] at Cornell University. Starting with 15 MeV beamline electrons produced by a photo-injector with currents of up to 100 mA [2], the beam will be accelerated in two main linac sections to 5 GeV before it enters several undulators feeding the X-ray beamlines. The existing CESR ring is then used to return the beam and inject it into additional undulators, before it gets decelerated to 15 MeV again inside the two main linac sections. A more detailed description can be found in the recently updated project definition design report [3]. Due to the high beam current combined with the short bunch operation, a careful control and efficient damping of the higher-order modes (HOMs) is essential. This paper focuses on the properties of these dampers.

In high current storage rings with superconducting cavities (like CESR @ Cornell) strong broadband HOM damping has been achieved by using beam-pipe ferrite loads operating at room temperature [4]. The ERL will adopt the same damping concept with RF absorbers between the cavities in a cavity string. This will require operating the absorbers at a temperature of about 80 K which has been proven in the injector cryomodule (ICM) [5]. We updated the absorber design for the main linac cryomodule (MLC) [6].

LESSONS FROM THE PROTOTYPE
For the Horizontal Test Cryomodule (HTC) [7], three of these absorbers- as show in Fig. 1 were prototyped. Two of there were mounted into the module and have so far proven to be an efficient RF damper. In the HTC-3 experiment, we measured the higher order mode spectrum of our 7-cell cavity and compared it to a measured spectrum without dampers. Up to 3.7 GHz we found no dipole resonances with Qs above 10^5 indicating the absorber provides suitable RF damping [8]. However, the design issues became visible: during the mounting process we broke one absorber by over-torquing the flange connection as the assembly was leaking. After a careful investigation we found the reason for this leakage: to closely match the thermal expansion coefficient of the absorber material (silicon carbide, SiC), we brazed it to tungsten which also acts as a vacuum barrier and holds the knife edge of the flange transition to the stainless, Originally being tight we discovered that this sintered tungsten material becomes porous under the thermal cycle of the brazing (which is done at 750 C).

For the HTC, the two absorbers were sprayed extensively with vacuum sealant to bring the leak-rate down to an acceptable number- leading however to a beam vacuum to insulation vacuum leakage which complicates future mounting processes.

In addition to these mechanical and vacuum issues we found that the silicon carbide we used (SC-35 from Coorstek) showed a marginally high dc resistivity at 77 K- which remarkably differs from what we measured on small samples. This bears the risk of charging up the material once an electron beam passes through the absorber. This batch to batch variation was also reported by colleagues and seems to be intrinsic to the fabrication procedure.

The redesign efforts therefore concentrated on two: investigating alternative absorber materials and changing the transition to the vacuum barrier.

Figure 1: Cross-section of the HOM absorber currently being installed in the Horizontal Test Cryomodule (HTC). The absorbing material is SiC brazed to tungsten.
RF ABSORBING MATERIAL

The search for a suitable RF absorbing material has been a long endeavour. Initial results have been published earlier [7, 8]. Based on our application, the material should have a broad band of absorption (with frequencies up to 50 GHz) but on the other hand a good DC conductivity to ensure that no charges are collected even if some particles of the beam hit the surface.

So far, the most promising material seems to be a graphite loaded SiC ceramic (Coorstek® SC-35). However, the DC conductivity we measured on a sample ordered a year ago (being some kΩ at 77 K) was not reproducible. We therefore tested the similar material SC-2 which was advertised as low resistivity material. This was confirmed, however, the RF absorption properties described below disqualified the material.

Table 1 summarizes our findings on the DC conductivity measurements, including the AlN based material Ceradyne® CS-137 that will be used in the X-FEL linac.

Table 1: Measured DC Conductivity of the Different Materials (along the 130 mm length)

<table>
<thead>
<tr>
<th>Material</th>
<th>300 K</th>
<th>77 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coorstek SiC SC-2</td>
<td>49 Ω</td>
<td>59 Ω</td>
</tr>
<tr>
<td>Coorstek SiC SC-35</td>
<td>~100 kΩ</td>
<td>Infinite</td>
</tr>
<tr>
<td>Ceradyne AlN CS-137</td>
<td>5.7 kΩ</td>
<td>7 kΩ</td>
</tr>
</tbody>
</table>
permittivity the f and Q curves become parallel, preventing the extraction of this parameter from the measurement.

However, out of this finding one can conclude that the SC-2 silicon carbide is far too conductive and acts more like a bad metal than as a good rf absorber. In practice this would mean that most of the incoming rf is not absorbed but reflected.

Figure 4: Calculated eigenfrequencies (red) and quality factors (blue) of the pillbox eigenfrequencies in the high imaginary dielectric permittivity regime, compared to the measured parameter of the SC-2 material.

**HOM DESIGN FOR THE MAIN LINAC CRYOMODULE**

As a consequence of the data presented above, the only material fulfilling the requirements is the AlN. The production HOM (Fig. 5) design has a titanium cooling jacket and flange that is thermally shrink fit to the AlN absorber. This central flange gives room for 3 convolution bellows on either side, adding flexibility that was needed in the prototype. The central flange is also the mounting place for 8 - 50W heaters and the vertical support that will mount it to the above helium gas return pipe.

The thermal fit has been designed so that all pieces hold together during a bake up to 150°C and all parts have at least a factor of safety of 2 to yield when cooled to 80K. A radial interference of 0.002in between the titanium cooling jacket and AlN absorber meets these parameters. Our calculations are summarized in tab. 2, Fig. 6 shows a picture of the latest shrink fit assembly as it came out of the oven.

Table 2: Working Spread-sheet for the Shrink-fit Parameters, Giving the Formula and the Parameters Used.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
<th>Parameters Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial interference, d</td>
<td>$d = \frac{r_1 - r_2}{2}$</td>
<td>$r_1, r_2$</td>
</tr>
<tr>
<td>Heating temperature for zero dewar, if heavily Ti tube</td>
<td>$\Delta T = \frac{E}{E_0} a_0$</td>
<td>$E, E_0, a_0$</td>
</tr>
<tr>
<td>Heating temperature for zero dewar, if heart both tubes, $\Delta T = \frac{E}{E_0} (a_0 - a_2)$</td>
<td>$E, E_0, a_0$</td>
<td>$a_0, a_2$</td>
</tr>
<tr>
<td>Radial pressure on interfering surface, $P = \frac{E\cdot d^2 \cdot (r_1^2 - r_2^2)}{2 \cdot (r_1^2 - r_2^2)}$</td>
<td></td>
<td>$E, d, r_1, r_2$</td>
</tr>
<tr>
<td>Maximum compressive stress on AlN, $\sigma_{\text{AlN}} = \frac{2PA}{r_2^2}$</td>
<td></td>
<td>$P, A, r_2$</td>
</tr>
<tr>
<td>Maximum tensile stress on Ti tube, $\sigma_t = \frac{P(r_1^2 - r_2^2)}{r_2^2}$</td>
<td></td>
<td>$P, A, r_2$</td>
</tr>
<tr>
<td>Axial holding power, $P\cdot t = 2500$W</td>
<td></td>
<td>$P, t$</td>
</tr>
<tr>
<td>Torque holding power, $25\cdot P\cdot t = 2500$W</td>
<td></td>
<td>$P, t$</td>
</tr>
</tbody>
</table>

Figure 5: Cross section of the Production beam line HOM absorber design.

Figure 6: Shrink fit assembly of the SiC into a Ti-5 cylinder, consisting of two shelves welded together with cooling channels in-between and pipes connected to it.
To test the features, we have built a prototype Ti-SiC shrink fit assembly and done several thermal cycles from room temp to 77K without seeing any signs of deformation or damage. We used the SiC instead of the AlN as the later was not yet available in the final geometry. This approach is justified as the mechanical parameters of both materials are almost equal.

To check the isotropy of the thermal contact a series of heaters were glued to the inner surface of the absorber. Fig. 7 shows the infrared thermometry picture we took, indicating an uniform heat transfer between the ceramics and the titanium shelve which will have internal cooling channels and cooled by 80 K, 3 bar helium.

Finally, we have done vacuum tests of the prototype and see no signs of trapped gas in the shrink fit joint. In our vacuum test we found the SiC to be hygroscopic and that with a bakeout the outgassing rate can be reduced significantly (Fig. 8). In addition, no vacuum bursting could be observed, indicating that there are no trapped gasses at the shrink fit interface.

**SUMMARY**

The design of the higher order mode beamline absorbers for the Cornell ERL main linac module has been revised slightly: The absorbing material will now be AlN instead of SiC shrink-fitted into a Ti-5 cylinder. So far the design has been tested successful. Currently, 8 HOM absorber assemblies are under fabrication.

**ACKNOWLEDGEMENT**

The program is funded by the NSF under grant DMR-0807731. In addition, the authors would like to thank Jacek Sekutowicz for many fruitful discussions.

**REFERENCES**


