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HIGHER ORDER MODE ABSORBERS FOR HIGH CURRENT ERL APPLICATIONS

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Abstract

Efficient damping of the higher-order modes (HOMs) of the superconducting cavities is essential for any high current linac, especially for the proposed energy recovery linac at Cornell that aims for high beam currents and short bunches. This contribution will present the design and first result on the HOM absorbers built for the Main Linac Cryomodule (MLC).

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., the details of which are summarized in the recently updated project definition design report [2]. 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 at Cornell) strong broadband HOM damping has been achieved by using beam-pipe ferrite loads operating at room temperature [3]. 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 80K which has been proven in the injector cryomodule (ICM) [4]. We updated the absorber design for the main linac cryomodule (MLC) [5].

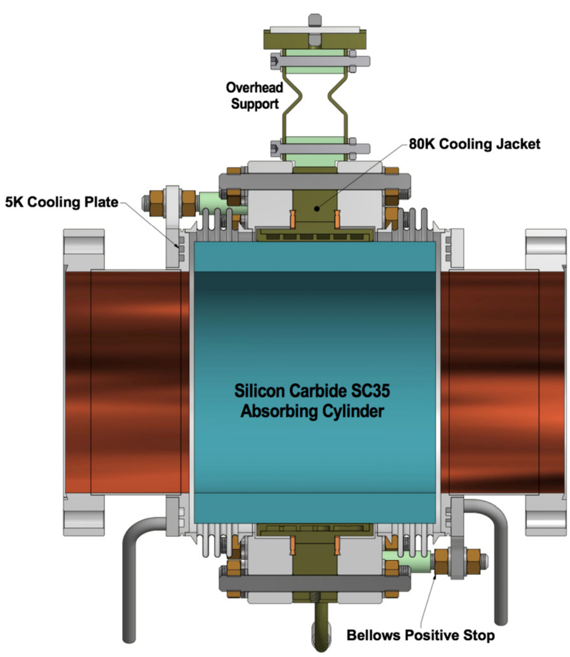

Figure 1: Cross Section view of production HOM Absorber.

DESIGN

The design has been finalized and production of 7 full assemblies was completed. Figure 1 shows a cross section view of the production version of the Cornell HOM Absorber.

The center assembly consists of the absorbing cylinder which is shrink fit into a titanium cooling jacket and flange. The cooling jacket and flange locate, support, and provide cooling at 80 K to the absorbing cylinder using a cooling channel inside the titanium (see Fig. 2). For these production pieces, the absorbing material is Silicon Carbide, SC-35® from Coorstek [6]. The shrink fit is designed so that all materials have a safety factor of at least 2 to yielding at 5 K and the fit will stay tight during a bakeout at 200 C.

The end pieces of the assemblies contain a 3 convolution bellows, a 5 K cooling plate, and taper seal flange to mate with the cavities. The bellows allows for small length variations in the string, small angular misalignments of cavity flanges, as well as adds a long thermal path from 80 K to 5 K. Any rotational misalignment is accounted for in slots in the bolt holes of the central 3 flanges which allow for a few degrees misalignment of the cavity flanges on either end. There are positive stops that prevent the bellows from compressing and closing the gap between the 5 K cooling jacket and the absorbing cylinder to less than 1 mm. This prevents any rubbing of metal to ceramic that could create particles. The beam tubes have a copper plating about 10 micron thick to prevent beam induced heating.

The overhead support is designed to have a similar spring rate to the transverse spring rate of the bellows so that the vertical load is evenly shared between the three springs. The plates are titanium to try to match the thermal expansion coefficient of the vertical supports on the other string components. The G10 pieces are included to reduce the thermal conduction from the 80 K cooling jacket to the helium gas return pipe it is bolted to.

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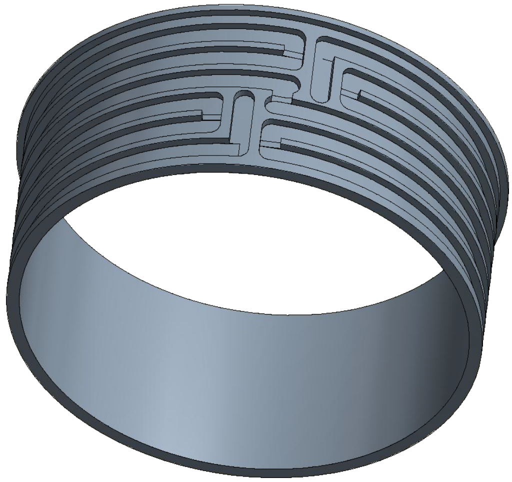

Figure 2: Cooling passage meander within the titanium shelve ensuring an adequate heat transfer from the absorbing ceramic to the helium.

RF ABSORBING MATERIAL

The RF absorbing characteristics, measured on a SC-35 samples are reported in Fig. 3 for reference. However, one should be aware that we found batch-to-batch variations in the material. In addition to that the material has a borderline DC conductivity at 80 K (see also [7]). To mitigate the risk of charge-up during beam operation we tried coating the cylinders with TiN. Even so the results were promising we built the HOM absorbers for the Main Linac Cryomodule without coating but investigations on this will continue.

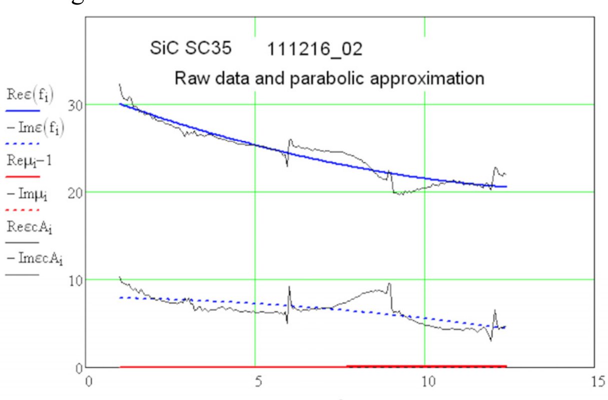

Figure 3: RF absorbing characteristics measured on a SC-35 sample.

PRODUCTION

Seven HOM assemblies have been manufactured for the prototype Main Linac Cryomodule (MLC), built within the R&D phase for the proposed Cornell Energy Recovery Linac (ERL). The 3 pieces of the 80K cooling jacket (one being shown in Fig. 2) were welded together with an electron beam welder in order to ensure the welds will hold the 20 bar helium used for cooling. The final ID bore of the cooling jacket was done after welding to shrink fitting. The shrink fit was done by heating the titanium cooling jacket to 350 C in a nitrogen furnace and then inserting the room temperature absorbing cylinder. match the bore precisely to the absorbing cylinder. The design called for a 0.002 inch radial interference fit. For details see [7].

To assemble the absorber into the cavity string- shown in Fig. 4 - the bellows assemblies are first bolted to the adjacent cavities and then they are slid onto the center absorbing assembly and the center flange connection is made. The center flange has slots for the bolts to allow for rotational misalignment of the adjacent cavities' flanges and the bellows allow for minor length and offset adjustment.

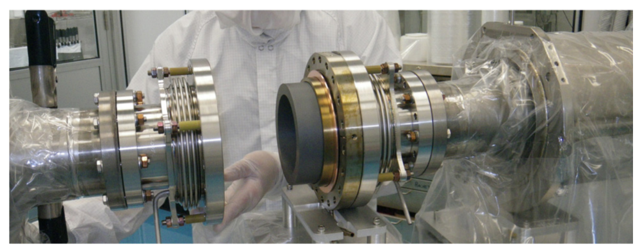

Figure 4: HOM Absorber being assembled into cavity string.

TEST RESULTS FROM THE PROTOTYE

For the HTC cavity testing, 3 prototypes of the HOM absorber have been built with a slightly different design [7]. These prototypes where built using the same absorbing ceramics. Within the HTC, a 7-cell ERL cavity is placed between two HOM absorbers. We achieved an excellent higher order mode damping (as reported in [8]) while preserving the high quality factor of the fundamental mode.

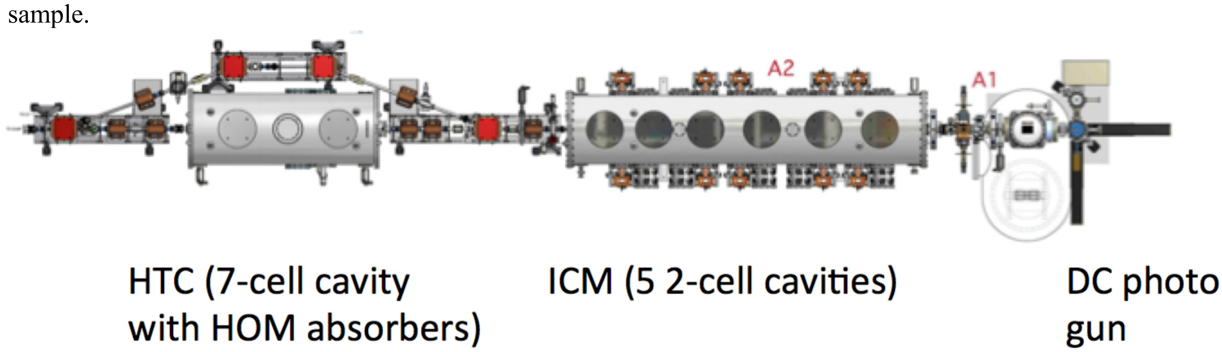

Figure 5: HTC placed behind the photo injector for testing with beam.

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Table1: Results of the HOM absorber beam test. Temperature increase is given in K. The location of the temperature sensors are given in Fig. 6.

Current, bunch length	ΔT (beam pipe behind Abs.) coated/uncoated	ΔT (80K gas temp) coated/uncoated	ΔT (80K absorber temp) coated/uncoated	ΔT (5K flange next to cavity) coated	ΔT, beam pipe to cavity coated/uncoated
25 mA, 3.0 ps	0.075/0.075	1.14/0.82	1.02/0.975	0.007	0.076/-.005
40 mA, 3.4 ps	0.2475/0.335	2.95/2.16	2.72/2.53	0.021	0.179/0.009
40 mA, 2.7 ps	0.2975/0.425	3.00/2.22	2.772/2.63	0.027	0.203/0.014

In the HTC, one of the HOM absorber had copper plated end tubes while the other HOM absorber remained uncoated stainless. This allowed us to balance the pros and cons of a CU-plating, as CU-plating reduces the losses of the higher order modes on the beam pipe while propagating to the absorber, meanwhile increasing the head transfer from the 5K cooling of the HOM absorber towards the 2K cavity end group. Depending on the thickness of the plating, the RRR of the copper and the expected HOM power calculations favour on or the other solution.

BEAM TEST

To test the HOM damping and measure the heating effects, tests with beam were conducted. Therefore, the HTC had been moved to in the photo-injector area, finally being located behind the injector cryomodule. The layout of the beamline is show in Fig. 5.

For the beam test, we ran different beams through the HTC and measured the heating in various locations as indicated by Fig. 6. The results of the runs are summarized in Table 1.

As expected, the heating scaled with beam current, shorter bunches lead to higher heating and the copper coated end groups of the HOMs see less heating. We also learned that the copper coating does not give a significant heating on the cavity end-group. The overall HOM power we saw was about 7 W which we calibrated by electrical heater runs. Scaled to the envisaged 2*100 mA beam current in ERL operation, the scaled HOM power from this measurement is well below our 200 W design assumption.

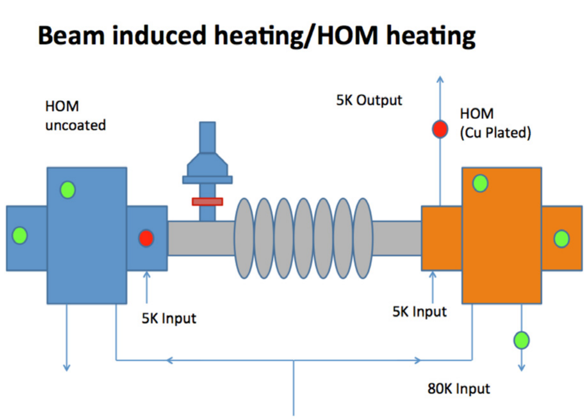

Figure 6: Locations of the various thermometers used to determine the heating under beam operation.

SUMMARY & OUTLOOK

We built a total of 10 HOM beamline absorbers. After some modifications the design is now solid and has proven its performance in beam operation. As the RF absorbing material itself is not a 100% fit for our application, we continue working on engineering a custom adjusted material (see [9]) and on coating .

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