CORNELL'S HOM BEAMLINE ABSORBERS

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Abstract

The proposed energy recovery linac at Cornell aims for high beam currents and short bunch lengths, the combination of which requires efficient damping of the higher-order modes (HOMs) being present in the superconducting cavities. Numerical simulations show that the expected HOM power could be as high as 200 W per cavity with frequencies ranging to 150 GHz. Consequently, a beam line absorber approach was chosen. We will review the design, report on first results from a prototype and discuss further improvements.

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 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 gain. A more detailed description can be found in [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, 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].

GENERAL LAYOUT

The schematic of Cornell's beam line HOM absorber is shown in Fig. 1. The absorbing material is an integral part of the beam pipe vacuum. The absorption of microwaves takes place in the ceramic ring (in our design SiC, currently) which is brazed to a tungsten cylinder. As we expect an average heating of the absorber of 200 W due to higher-order modes, a direct cooling approach was

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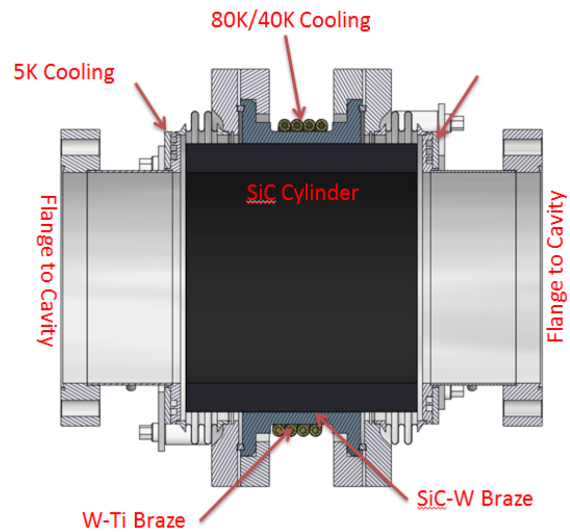

Figure 1: Cross-section of the HOM absorber currently being installed in the Horizontal Test Cryomodule (HTC). The absorbing material is SiC brazed to tungsten.

chosen. The tungsten is cooled by an 80 K, 3 bar, forced flow helium stream through stainless steel pipes. Within the module string, we will have a total of 7 HOM absorbers, individually located between each cavity and at the entrance and exit of the module. Therefore, 5 K intercepts at the flange transitions have been implemented to prevent cavity end-group heating. In addition, the interior of the pipe between the absorber and the cavity has been copper plated to minimize RF heating. The flanged connections have been designed as zero-impedance transitions for the same reason.

Table1: Requirements specified for the Cornell ERL HOM beamline absorbers.

Parameters	Requirement	Notes
Minimum thermal conductivity (at 80K)	≥ 10 W/mK	To support 400 W with no more than 30 K temperature gradient in the full size cylinder
DC conductivity at 80K	>> 10^{-9} Ohm^{-1} m^{-1}	For time constants <1s for discharging
Epsilon (real part)/epsilon_0	≤50	In general, lower is better
Epsilon (imaginary part)/epsilon_0	>-25	In general, higher is better
Mu (real part)/mu_0	>1	Preferable closer to real part of epsilon
Outgassing	< 10^{-12} torr L/s/cm^2	For ultra high vacuum operation; material shall not be porous or absorb water

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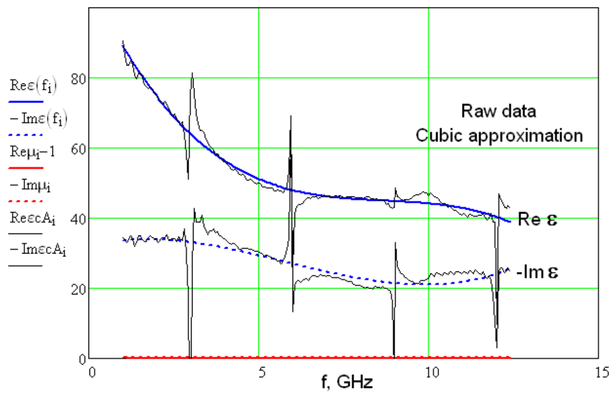

Figure 2: RF parameters of a SiC sample measured at 77 K. Details are described in [7,8]

As a positive side-effect, these absorbers also shield the bellow sections avoiding wake-field heating.

RF ABSORBING MATERIAL

The search for a suitable RF absorbing material has been a long endeavour. Initial results have been published earlier [7,8] but the search for the optimum material is still open. A broadband absorbing material matching most of the requirements summarized in Table 1 is a commercially available, graphite loaded SiC ceramic (Coorstek® SC-35).

Measurements on samples of the dielectric and magnetic permeability, performed at 77 K using a transmission line set-up (see [7] for more details), confirmed the good absorbing properties. The results are shown in Fig. 2. The DC conductivity, mitigating charge-up effects during beam operation was also measured on a sample cooled to 77 K, yielding a resistance on the kΩ scale [9].

PROTOTYPE RESULTS

Following the ERL R&D program manifested in the HTC-1 to HTC-3 testing sequence, two HOM absorbers were prototyped (shown in Fig. 3), revealing mixed results.

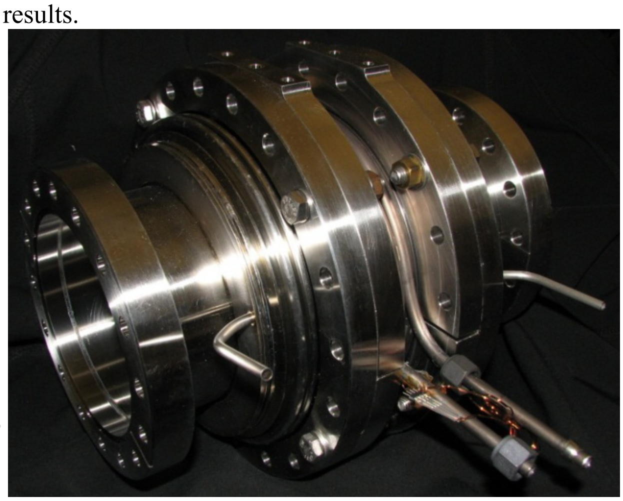

Figure 3: Picture of the HOM beamline absorber prior to installation in the HTC.

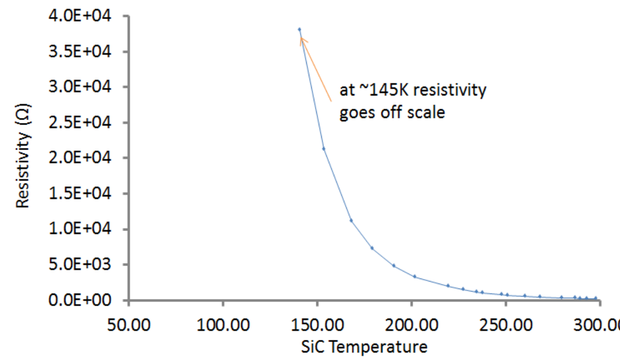

Figure 4: DC conductivity measured during a thermocycle of the SiC ring before brazing, indicating a strong increase with lowering temperatures.

To start with the good news: 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 10^4 indicating the absorber provides suitable RF damping [10].

However, a qualifying test of the full SiC cylinder prior to assembly showed a strong increase of the DC resistance during cool-down, contradicting the results of the sample measurement. This suggests rather unreliable material parameters of the SiC, resulting in batch-to-batch variations. The resistivity as a function of temperature is shown in Fig. 4, suggesting that the material (operated at 80-100 K) has the possibility of being charged by the beam.

There were also mechanical challenges with the HOM load structure. We observed uneven tightening and support of the split-ring rotatable flanges which finally led to cracking of the tungsten flange. A careful investigation revealed a serious problem with the tungsten material itself. Initially, tungsten was chosen to match the rather low CTE (coefficient of thermal expansion) of the SiC. In the pretest, this sintered material was tight and able to hold a tapered sealing surface. However, we found that the material degenerated during the heating cycle caused by the brazing process and eventually became porous.

For the HOM loads installed into the HTC, this was resolved by substituting the aluminum gasket by an indium wire and by spraying the whole set-up with vacuum sealant. Finally, a leak-rate below 10^{-7} mbar L/s was achieved. This is a tolerable leakage from the insulation vacuum to beam vacuum, but indicates the necessity of a redesign.

REDESIGN EFFORTS

The major goal of the redesign effort was to substitute the SiC to Tungsten transitions avoiding a high temperature braze. We discussed brazing at lower temperatures, gluing the materials together with epoxy based resin or shrink-fitting the absorber material to a more decent metallic cylinder. Our calculations showed,

Table2: Working spread-sheet for the shrink-fit parameters, giving the formula and the parameters used.

Inputs	300K	80K	
SiC inner radius, r_i	2.165	2.165	in
SiC outer radius, Nominal radius R	2.362	2.362	in
Ti tube Inner radius, R_{Ti}	2.360	2.356	in
Ti tube outer radius, r_o	2.610	2.606	in
Axial length of contact surface, L	2.421	2.421	in
Coefficient of friction between the two parts, f>	0.1	0.1	
Torsional coefficient of friction between the two parts, f'>	0.1	0.1	
Constants			
Modulus of elasticity, E_{Ti}, Ti Grade 5 Ti-6Al-4V	114	136.8	GPa
Coefficient of linear thermal expansion, α_{SiC}, ceramic SiC	3.8		$\times10^{-6}$/C
Coefficient of linear thermal expansion, α_{Ti}	7.47	4.184	$\times10^{-6}$/C
Outputs			
Radial interference, δ	**0.002**	**0.005**	in
Heating temperature for zero clearance, if heat only Ti tube, $\Delta T = \frac{\delta}{R*\alpha_{Ti}}$	**138**		deg C
Heating temperature for zero cleamace, if heat both tubes, $\Delta T = \frac{\delta}{R*(\alpha_{Ti}-\alpha_{SiC})}$	**256**		
Radial pressure on interfering surface, $P = \frac{E*\delta}{R}\left[\frac{(r_o^2-R^2)*(R^2-r_i^2)}{2R^2*(r_o^2-r_i^2)}\right]$	4	14	MPa
Maximum compressive stress on SiC, $\sigma_{SiC} = \frac{2PR^2}{(R^2-r_i^2)}$	**56**	**181**	MPa
Maximum tensile stress on Ti tube, $\sigma_{Ti} = \frac{P(r_o^2+R^2)}{(r_o^2-R^2)}$	**45**	**147**	MPa
Axial holding power, *F=2πLRP f*>	*10373*	*33514*	N
Torsional holding power, *2πLR^2P f'*>	*622*	*2010*	N-m

that the silicon carbide might be shrink-fitted into a titanium grade 5 cylinder.

The inner diameter of the Ti tube was designed to be smaller than the outer diameter of the SiC tube with a radial interference of 0.002 inch at room temperature. The temperature needed for Ti tube to fit to the SiC tube when heating both tubes together is roughly 300 C. With these parameters we were able to stay below the allowable stresses meanwhile ensuring a good mechanical and thermal contact of the final assembly. Table 2 summarizes the calculation and the parameters used.

Prior to shrink-fitting, the interference of the materials was carefully checked using a coordinate-measuring machine (CMM). The shrink fit was performed at 400 C.

Consequently, we tested the arrangement, a picture of which is shown in Fig. 5. After successfully attaching the SiC to the titanium, the structure was thermally-cycled several times from ambient to 77 K revealing neither visible damage nor loosening.

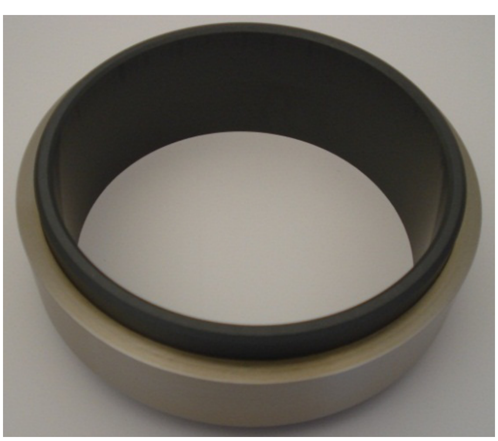

Figure 5: Silicon carbide ring shrink-fitted into a titanium grade 5 cylinder. After 2 thermo-cycles to 77 K neither visible damage nor loosening was observed.

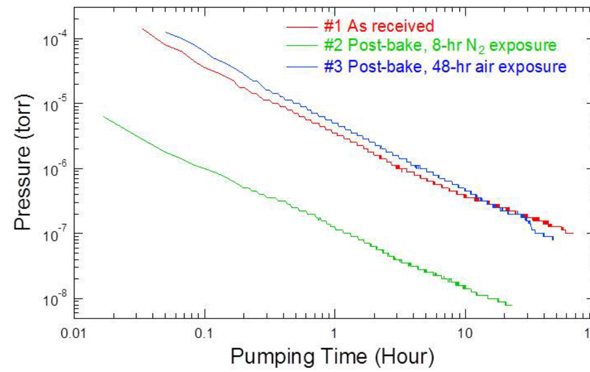

Figure 6: Pumpdown and outgassing test of the shrink-fit assembly. Besides the porous behaviour of the SiC no signs of gas burgs from the shrink-fit could be observed.

As a final qualification step, the vacuum properties of the shrink-fit assembly was tested, results of which are given in Fig. 6. We found no sign of gas-trapping, and the pumpdown pressure was not dominated by air. We saw a small burst during the 1st bakeout being mostly CO, probably caused by slight movements between the titanium and SiC. However, the curves indicate a feature of the absorber material being slightly hygroscopic. With a bake-out, the outgassing rate could be reduced significantly.

Currently, a new version of the HOM load is being built based on this shrink-fit approach. Together with some minor additional changes, this load will be installed into the main linac cryomodule.

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