DEVELOPMENT OF WAVEGUIDE HOM LOADS FOR BERLINPRO AND BESSY-VSR SRF CAVITIES*

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Abstract

Two ongoing accelerator projects at Helmholtz-Zentrum Berlin (HZB), bERLinPro and BESSY-VSR (Variable pulse length Storage Ring) upgrade, need to design three variants of SRF cavities, 1.3 GHz cavities for bERLinPro and 1.5 GHz/1.75 GHz cavities for BESSY-VSR. These cavities have adopted waveguide HOM dampers in their design, with a few tens of watts HOM power in each load for bERLinPro cavities and a few hundred watts for BESSY-VSR cavities. Jlab is collaborating with HZB designing and prototyping HOM loads for these cavities. In this paper, we will report on the integrated RF-thermal-mechanical design of these loads, as well as the latest fabrication and testing results of the bERLinPro HOM load.

INTRODUCTION

HZB is developing two high current accelerator SRF projects. One of the projects is bERLinPro [1, 2], a 50 MeV 100 mA single-pass R&D ERL containing one cryomodule with three 7-cell 1.3 GHz TESLA-shape cavities. The other one is BESSY-VSR [3], using two 1.5 GHz (3rd harmonic) cavities and two 1.75 GHz (3.5th harmonic) cavities to shorten some of the bunches in the 300 mA BESSY storage ring. For both projects, supressing beam induced HOM is essential to achieve the design beam current. All of the bERLinPro and VSR cavity variants have Y-shape endgroups on both ends, and each cavity uses one port for a coaxial FPC and the other 5 rectangular waveguide ports for HOM damping.

BERLINPRO HOM LOAD DEVELOPMENT

The first HOM passband in the bERLinPro cavities is a dipole passband at ~1.7 GHz. The dimension of the HOM waveguide is chosen as 105 mm×50 mm, with 1.43 GHz TE10 mode cutoff frequency. The HOM power spectrum spreads in a wide frequency span and a variety of waveguide modes, with the majority concentrates at around 2.6 GHz and 5.2 GHz in TE10 and TM11 modes. From wakefield simulation, the maximum HOM power in one waveguide is 27.4 W including safety margin.

HOM Load Design and Fabrication

The design of the bERLinPro HOM load shares lot of ideas and development efforts with the CEBAF C75 HOM load project [5]. The bERLinPro HOM load uses two ceramic absorber wedges arranged in V-shape, as shown in Fig. 1, left. The pair of wedges are brazed into two pockets in a stainless steel (SS-316L) flange, with a copper pegboard between the absorber and the stainless steel. The pegboard braze concept is based on the experience of PEP-II HOM load development [6]. Multiple compliant pegs with a small contact area mitigates the thermal stress in the braze joints during cool-down. To minimize the stress level, we chose a small peg array of 4×4 pegs, and each peg is a 2.54 mm square, with 2.54 mm spacing between the pegs (Fig. 1, right). A straight water cooling tube is brazed to the back of the stainless steel flange. The water flow rate is set at 0.28 L/min to ensure the flow is laminar, due to microphonics concerns.

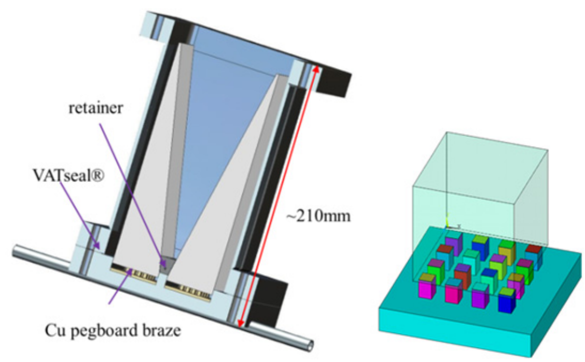

Figure 1: Left: model of the bERLinPro HOM load; Right: "pegboard" brazing concept.

The choice of ceramics material is based on earlier research by F. Marhauser [7]. Initially, we chose Coorstek directly sintered SiC SC-30 for the bERLinPro and VSR HOM loads. With a lower permittivity in the SC-30 absorber, our simulation results found that a pair of wedges with dimension of 152 mm×25 mm×40 mm can achieve 15dB return loss over the required bandwidth. However, test braze of SC-30 failed as a thin layer of ceramics peeled off at the entire braze joint. We then changed the absorber to the stronger AlN based material. Our final choice is Sienna Technologies' STL-100HTC, a high thermal conductivity version of AlN-SiC composite. Due to the higher dielectric constant of the AlN based ceramics, we extended the length of the wedges to 178 mm to get 12 dB absorption in TE10 mode and reasonable performance in other modes. Figure 2 shows the CST simulated return loss of the load with STL-100HTC absorber in the 105 mm×50 mm HOM waveguide.

We successfully brazed our first load, as shown in Fig. 3. The cooling tube was brazed first with higher

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temperature alloy (65% Cu, 35% Au), and then the flange surface was polished to the finish specified for VATseal®, before the absorber was brazed with Cusil-ABA.

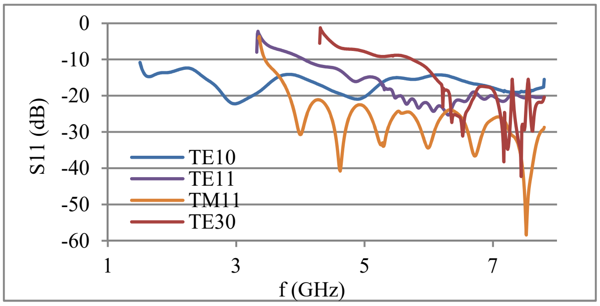

Figure 2: Simulated return loss of the bERLinPro HOM load with two 178 mm STL-100HTC wedges.

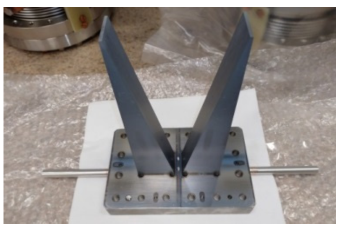

Figure 3: First brazed bERLinPro HOM load.

Thermal Simulation and Optimization

The heat load of each HOM waveguide, including the RF heat from the fundamental mode evanescent field in the normal conducting section and the static heat from the 300 K boundary, are optimized with the 1-D modelling by adjusting the design and length of different section in the waveguide.

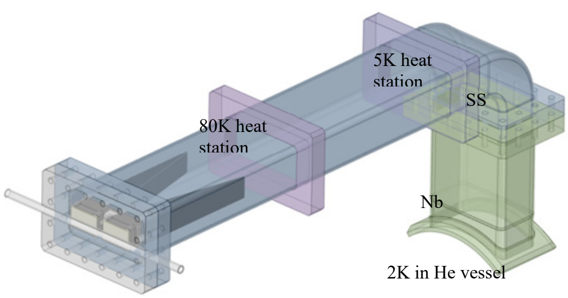

Figure 4: bERLinPro HOM waveguide assembly.

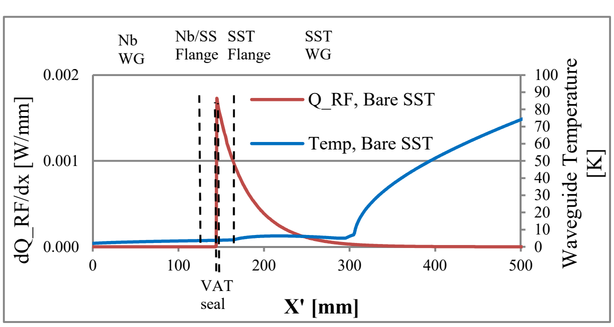

Figure 5: bERLinPro HOM waveguide 1-D thermal optimization results.

The 1D optimization results are shown in Fig. 4 and 5, with ~0.05 W 2 K heat load, ~1 W in 5 K, and ~7 W in 80 K. The temperature in the Nb waveguide is well below 9 K. We also simulated the case with a pair of bellows before and after the 5 K heat station, reducing the heat load further. The boundary for the 1D analysis was provided by a previous 3D RF-thermal analysis of the HOM load waveguide. The 3D results show that the peak temperature in the absorber is 72 °C, using the superposed CST simulated thermal loss density data of the nine most significant modes/frequencies weighted by their ratio of estimated HOM power and scaled to 27 W total power.

RF Test Results

The network measurement of the load is shown in Fig. 6, with comparison to simulation. The measurement was done with TDR (time domain reflectometer) method up to 4 GHz, with a short taper to WR430 waveguide (109 mm width). 4-8 GHz test is delayed due to network analyzer availability.

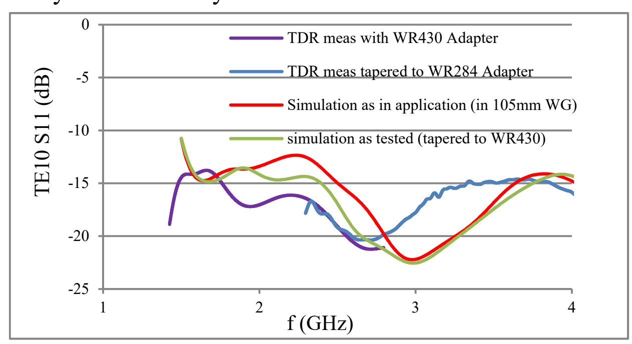

Figure 6: Network analyzer measurement of bERLinPro HOM load.

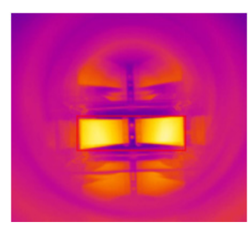

Figure 7: HOM load IR image in 50 W RF test.

The load is tested with 50 W 2.6 GHz RF from a TWT. IR images were taken from a viewport, as seen in Fig. 7. The peak temperature in the absorber measured by the IR camera is 64.9 °C with cooling water, and the load flange temperature was seen at 43 °C. However, the test was done with air in the waveguide, resulting in a much lower temperature than simulation due to convection.

VSR 1.5GHz CAVITY HOM LOAD

For the VSR cavities, we are currently finalizing the design of the 1.5 GHz cavity HOM load. The HOM load for the 1.75 GHz cavity is expected to be a scaled version of the 1.5 GHz load, with minor modifications.

The first HOM passband in the 1.5 GHz cavity starts at around 1.65 GHz, and the first major HOM power

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spectrum appears at 1.75 GHz (~20 W maximum per HOM load). The HOM waveguide dimension is chosen at 88 mm×60 mm near the beampipe to stop the propagation of the fundamental mode, and tapered up to 96 mm× 62 mm at the load side to enhance HOM propagation. HZB simulated the wakefield in 15 waveguide modes up to 12 GHz [4], and found the maximum total HOM power in a waveguide is ~460 W with overhead.

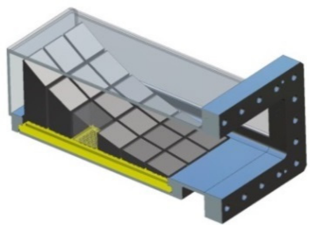

Figure 8: VSR 1.5GHz cavity HOM load design.

Even after tapering up the waveguide to 96 mm, the frequency of the first HOM is still close to TE10 cutoff. As a result, we chose a load design that tapers the absorber material in the height side of the waveguide (Fig. 8) to reduce TE10 mode reflection close to cutoff frequency (and also for other modes like TE30). The absorber is divided into 25.4 mm×25.4 mm blocks in 3 columns and 6 rows, so each block can be brazed onto a 4×4 pegboard like the bERLinPro load. The ceramics columns/rows are separated by 2.54 mm for brazing clearance. Each row of ceramics block has different slope, forming a curved taper. The front row has a gentler slope to enhance the absorption of TE01-like modes at frequencies close to cutoff; the slope goes steeper in the back of the waveguide, so the absorber can fill the waveguide in a shorter length. The front row ceramic tiles also have a very thin front edge, which sinks into the stainless wall. Fig. 9 shows the simulated S11 in 96 mm waveguide for the modes with significant HOM power.

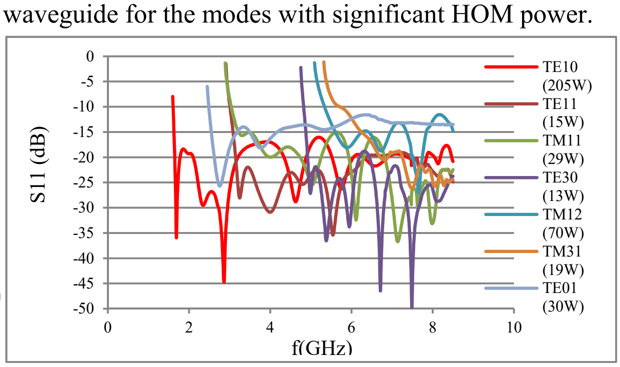

Figure 9. Return loss of VSR 1.5GHz cavity HOM load simulated in CST.

The RF loss density in estimated by superposing the CST simulation results of 11 modes/frequencies with significant HOM power, as shown in Fig. 10, left. The loss is concentrated in the front row absorber, but the peak temperatures for the absorber tiles do not vary much and are all in the 80-91 °C range (Fig. 10, right), due to the shorter thermal path of the front row. The peak temperature is 91.1 °C in the back row. Due to the laminar flow requirement the layout of the cooling channel (Fig. 11) is optimized to first provide cooling to the high-temperature front and rear rows to assure an even temperature distribution. With a 0.36 L/min flow of 30 °C water, the water temperature rise will be 17 °C.

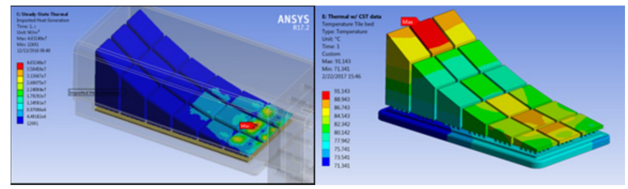

Figure 10: Left: absorber RF loss density rendered in ANSYS by superposing CST results; Right: absorber temperature simulated in ANSYS.

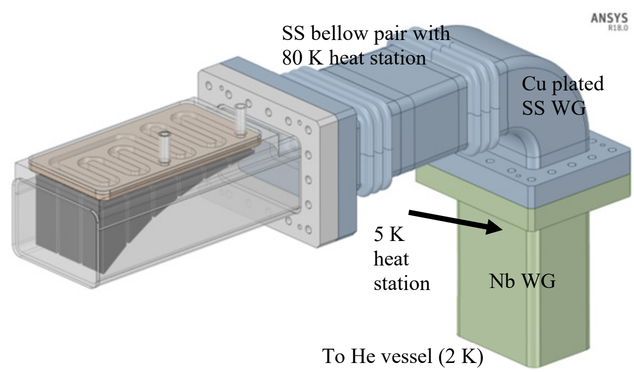

Figure 11: VSR 1.5 GHz HOM waveguide assembly.

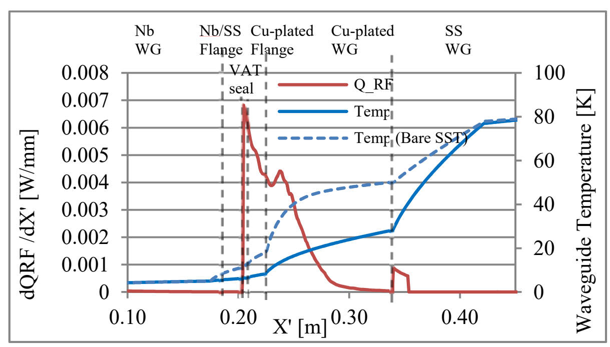

Figure 12: VSR 1.5 GHz HOM waveguide 1-D thermal optimization results.

The 1-D optimization results are shown in Fig. 11 and 12. The heat load is ~0.1 W in 2 K, ~0.6 W in 5 K, and 3.4 W in 80 K, with the Cu-plated waveguide section between the bellow and the Nb flange. Without the Cu-plating in that section, the Nb flange will quench, and the RF heat dQ_RF/dX' will be off the chart in Fig. 12.

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