AN ALTERNATIVE HOM LOAD DESIGN FOR THE EU HOM DAMPED CAVITY

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Abstract

For the 500 MHz cavities in the main storage ring of SLS 2.0, we plan to manufacture additional spares of the higher order mode (HOM) loads. We saw the current design using ferrite tiles as too risky for us to produce, so we did a redesign using silicon carbide (SiC) blocks, used already with good results for HOM damping in the SLS 2.0 stripline kickers. For good performance specially near cutoff, a prolonged load geometry allows the SiC blocks to taper in smoothly. Up to 1200 W HOM power can be accepted by the load. SiC being quite tolerant to heat up, we rely on black body radiation for cooling resulting in a more homogeneous heat load distribution of the containing waveguide. The load is cooled by water circuits integrated into the waveguide ridges. Two dedicated pumping ports and an optical view port complete the technical design. Even taking into account possible large variations in the RF properties of SiC, we expect a quite satisfactory performance with a RF match better than 10 dB near the waveguide cutoff and even better than 20 dB for frequencies above 1 GHz. A prototype is currently under production and will undergo lab tests under nominal conditions this summer.

INTRODUCTION

The European HOM damped cavity [1] has evolved into a very popular device used in lots of synchrotron radiation facilities. Its special features are its three higher order mode (HOM) couplers allowing stable operation at elevated currents without having to resort to techniques like HOM tuning. Also the recent upgrade of the Swiss Light Source [2] uses four of these cavities for the main RF system, which were produced by RI Research Instruments GmbH.

In order to stay compact and to minimize the interference with the main acceleration mode, the damper couple via ridged waveguides with cutoffs slightly above the fundamental, which connect to a waveguide load. A secondary advantage of the double ridged geometry is its enlarged operating bandwidth compared to standard rectangular waveguide. The standard design [3] of the load uses ferrite tiles brazed to a strongly tapered part of the ridged waveguide. The heat is absorbed via water cooling channels in the backing ridges.

This combination of ferrite with copper makes fabrication a complicated process. The brazing needs to take account of strongly differing thermal expansion of the two materials. In normal operation, all the power absorbed the ferrite tiles need to propagate homogeneously into the copper bulk. Any imperfections in the brazing may lead to localized heat-up and thermal stress. In extreme case, this may cause individual tiles to fall off. In the case of a vertical load, this is a catastrophic event, the tile falls into the cavity itself and may cause discharges and damage on the cavity wall. This led some accelerator facilities to opt for a different strategy. Accepting higher HOM impedances and deteriorated thresholds for coupled bunch instabilities, they use only the two lower dampers, the vertical load is replaced with a metallic short.

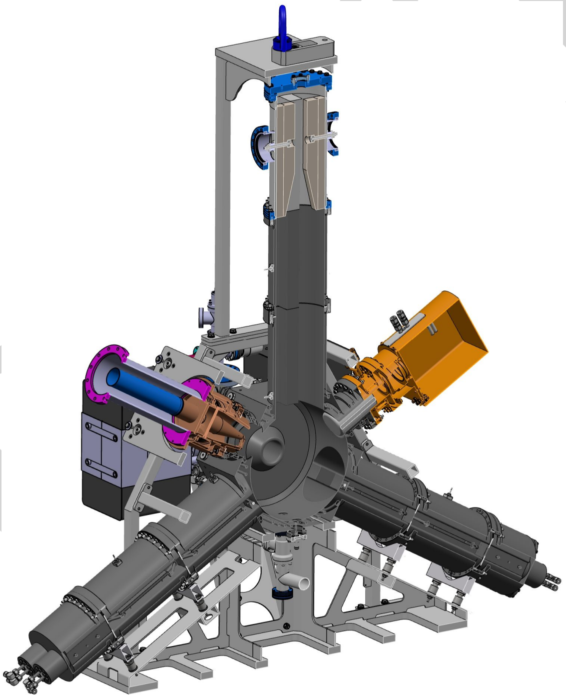

Figure 1: Full cavity layout with the new load design on top. Also visible the lifting device for the full assembly, which was responsible for some mechanical limitations to be observed in the design.

While SLS currently uses all three loads, this risk assessment led to the current development project. The goal is to have a plug in replacement of the ferrite load with similar RF characteristics (Fig. 1), simultaneously avoiding these weaknesses. Cooling should not rely on a defined thermal contacts between damping material and the casing, but be possible even purely via black body radiation. Nonuniform temperature distributions should not cause undue thermal stress. Given previous experiences, we decided to use silicon carbide (SiC), a ceramic able to stand up to 2000 °C heat, as a damping material. Where ferrites have magnetic losses, SiC introduces a dielectric loss, so this required a completely new design.

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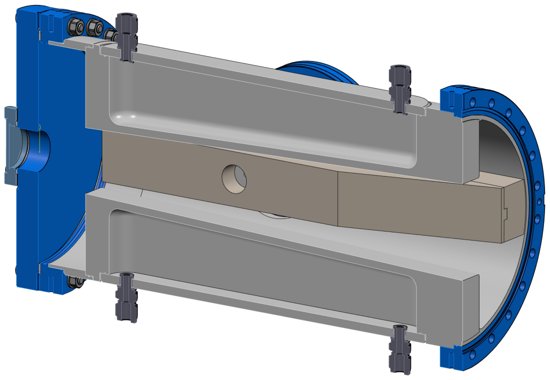

Figure 2: Cut through the load: Ridged waveguide (top, bottom, light gray) with tapered SiC blocks (stone gray) in the back. HOM power enters from the right. Ridge gap and SiC blocks tapering in along the load axis.

DESIGN

Figure 2 shows the layout of the load. Since the electric field is concentrated between the ridges, we have block of SiC slowly tapering in from the side to avoid RF reflections. Also the distance between the ridges is tapering in, smoothly reducing the cutoff frequency along the length of the load and that way improving the performance near cutoff. A short circular waveguide section with a relatively high cutoff frequency combined with the metallic end plate results into a reactive termination of the ridged waveguide/SiC section improving the performance near cutoff further. The large emphasis, we put into the performance near cutoff is due to the fact, that the first longitudinal higher order mode is already near 700 MHz [4]. Visible in the end plate, but not significant in terms of RF performance, is a viewport with a quartz window, which we integrated for visual inspection purposes.

Silicon carbide is not a standardized product. Depending on the supplier and the fabrication process, one can have widely varying electrical properties (see e.g. [5]). For a previous project involving higher order mode damping in stripline kickers [6], we had used already the SiC type SSiC-CS10 produced by Ceramdis [7]. Measurements of this material were performed by Peter Huelsmann from DESY, but not yet published [8]. These show quite a bit of frequency dependency, so the design needs to take account of this. For estimating the match, we used multiple runs with CST [9] allowing the permittivity to vary from $\epsilon_r = 15$ to 18 and the loss angle between $\tan\delta = 0.2$ and 0.4.

The resulting S_{11} values are shown in Fig. 3. Near cutoff, we can expect a match equal or better −10 dB. Further up in frequency, values better than −20 dB can be seen, making this design a valid alternative.

The performance over a super wide band width up to 10 GHz (Fig. 4) is excellent, but must be taken with a grain of salt. Here we are in the overmoded domain of the ridged waveguide. Higher order modes in the cavity would drive not only the fundamental mode but also this higher waveguide modes. Also, the fundamental waveguide mode will partially convert into higher modes, as it propagates into the load. A clean analysis would need to simulate the combined system of cavity and load.

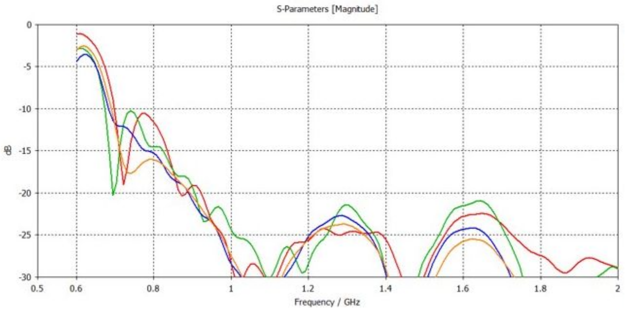

Figure 3: Computed S_{11}. Curves correspond to the following SiC properties ϵ_r, $\tan\delta$: red (15, 0.2), green (18, 0.2), blue (18, 0.4), yellow (15, 0.4).

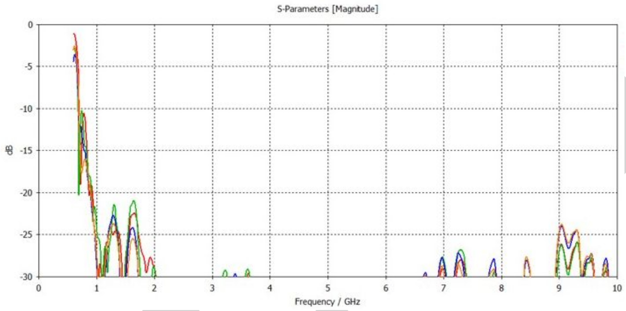

Figure 4: Computed S_{11} up to 10 GHz. Curves correspond to the following SiC properties ϵ_r, $\tan\delta$: red (15, 0.2), green (18, 0.2), blue (18, 0.4), yellow (15, 0.4).

Table 1: Performance comparison between new SiC design (simulated) and standard ferrite load (as measured in [10]).

Frequency Range	**Ferrite**	**SiC**
f_c - 0.8 GHz	−3 to −6 dB	−4 to −8 dB
0.8 - 1.2 GHz	−8.6 dB	−10 to −14 dB
1.2 - 3.2 GHz	−20 dB	−20 to −28 dB
>3.2 GHz	Not measured	<−20 dB

Table 1 compares the match between the new design and measured values from [10]. The SiC load provides equivalent or better matching across the entire measured range. The primary advantage is near cutoff (0.6 - 1.2 GHz), where the most dangerous HOMs reside and where the ferrite load is weakest. At 700 MHz, the resonance frequency of the first and strongest longitudinal higher mode, we expect an improvement of 3 - 4 dB. If all cavity dampers would be upgraded to the new type, this would translate into a roughly 50% improvement in HOM damping!

The loss power distribution in the SiC varies quite a bit with frequency (see Fig. 5 for the behaviour at 0.85 GHz). But SiC being a good thermal conductor, this is not a critical parameter for the performance.

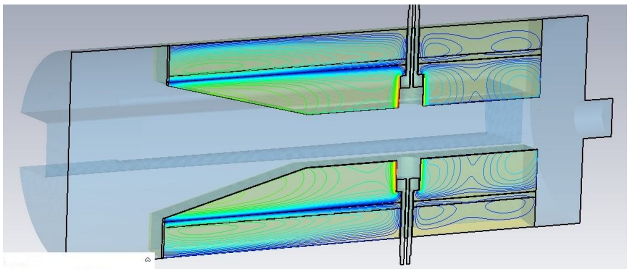

Figure 5: Distribution of loss power density for a frequency of 0.85 GHz.

Mechanical Implementation

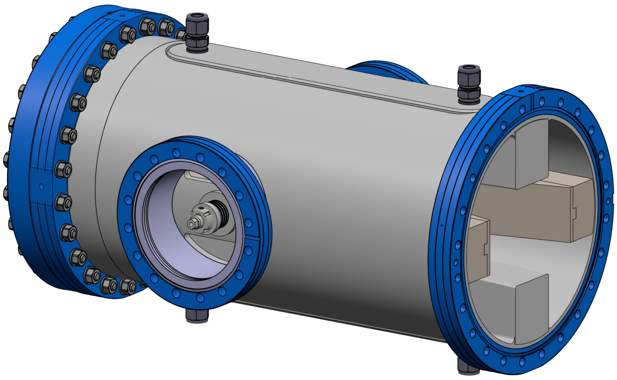

Figure 6: Full mechanical design including pumping ports and connectors for water cooling.

The new design shown in Fig. 6 has a mechanical length of 491 mm, longer than the original at roughly 350 mm but still fitting the available space. Due to fabrication constraints the SiC blocks had to be split. Both SiC parts are fixed laterally by a rail like groove along the longitudinal axis. They are fixed by a spring loaded screw ending in the pumping port seen in front. The blocks are free to thermally expand or contract longitudinally versus the body as they are only fixed in one point. Lateral expansions are small and can be covered by the specified mechanical tolerances.

Outgassing is expected to be most pronounced around the hottest components, the SiC blocks. So pumping the load via the back of the blocks is the most effective approach. Cooling channels are integrated into the waveguide ridges.

Due to the shaping of the SiC blocks versus with respect to the wall of the load, both touch only in places and heat transfer by the classical conduction should be rather negligible, the notable exception being the spring loaded stainless steel bolt holding the assembly. Under these assumptions, the expected temperature distribution is as shown in Fig. 7. A small amount of heat still travels the bolt, but the dominant cooling effect on the SiC block is due to black body radiation. Due to the reflective properties of copper in the infrared, the black body radiation undergoes multiple reflections inside the load leading to a relatively homogeneous heat load on the wall. Cooling circuits don't need to be near to the heat source but can be placed, where they are suitable from the mechanical point of view. As seen in the model, we used the ridges.

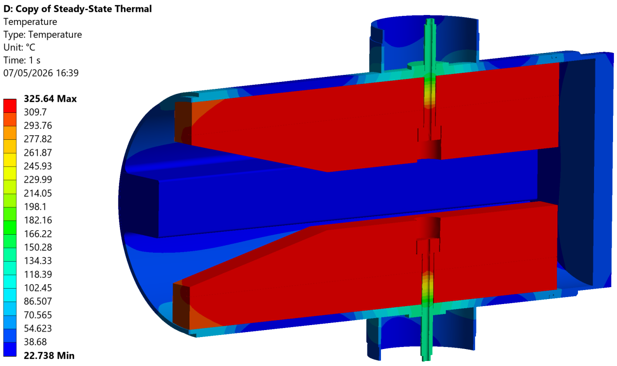

Figure 7: Temperature distribution as computed with ANSYS [11] at a maximum rated HOM power of 12 kW. Peak temperatures are 325 °C in the SiC and 80 °C in the tank.

At the maximum power rating of 12 kW, the SiC dampers heat up significantly to a temperature of 325 °C. The tank itself stays relative cool, only in selected spots can we see 80 °C. In case of significant heat bridges, the SiC temperature should collapse quite a bit, but there will be more heat irregularities at the tank wall. This will be the subject of tests with the prototype.

OUTLOOK

Currently a prototype of this load is in production together with auxiliary test equipment like a coax-to-ridged-waveguide transition and some calibration pieces. We expect the pieces to be ready by late summer (2026). Apart from low power tests measuring the reflection coefficient, we also plan high power tests using a solid state amplifier at 1 kW. The points of interest are the heat up and associated outgassing under vacuum conditions. Furthermore, power cycling tests are required to prove the robustness of design. If these tests are successful, the long winter shutdown of the SLS from November 2026 to Februray 2027 may be a good opportunity to install the load on one of the storage ring cavities and see the performance with beam under nominal conditions.

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