HOM DAMPERS AND WAVEGUIDES FOR THE SHORT PULSE X-RAY (SPX) PROJECT*

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Abstract

The production of HOM dampers for the superconducting SPX cavities has been undertaken at the Advanced Photon Source. The dampers are vacuum compatible WR284 waveguide loads that utilize a four wedge design. The rf lossy material consists of hexoloy silicon carbide (SiC) due to its suitable mechanical and electrical material properties. Issues regarding the manufacturing of the dampers consist of initial SiC material failure due to fabrication stresses as well as substandard soldering bonds of the SiC to the copper damper bodies. The integration of the dampers into the cryomodule with the HOM waveguide assembly consists of rf, thermal, and mechanical design considerations. An analysis of the manufacturing and integration issues and remedies are discussed in this paper.

INTRODUCTION

The SPX cryomodule is designed for installation into the APS storage ring with deflecting-mode cavities operating at 2.815 GHz [1]. Passive damping of the lower-order mode (LOM) and higher-order modes (HOMs) for each cavity is achieved by a single LOM waveguide damper and two HOM dampers [2]. A total beam-induced power of 1.25 kW is expected for a 150-mA beam current with approximately 150 W absorbed by each HOM damper and 850 W absorbed by the LOM damper.

The HOM waveguide and dampers are located entirely within the cryomodule and, due to broadband damping requirements up to 6 GHz, share the ultra-high vacuum environment with the cavity. As a result, the waveguides and dampers are designed to be compatible with the superconducting cavity as well as satisfying mechanical and thermal considerations.

The damper material must be cleanable using high-pressure rinsing, suitable for UHV, and resistant to particulate generation. The HOM waveguide must also be suitable for achieving standards appropriate for its use near a superconducting cavity. In addition, the HOM waveguide assembly is required to span from 2K to room temperature entirely within the confines of the cryomodule with minimum heat leak and adequate mechanical compensation for thermal motion.

DAMPER MANUFACTURING

The dampers consist of iso-pressed silicon carbide (SiC) material from St. Gobain due to its rf, mechanical, and vacuum properties. It is a lossy ceramic material with an average loss tangent of approximately 0.1 and average relative permittivity of 11.5 across the SPX frequency band, see Fig. 1(a) [3]. Variations in the electrical properties shown in the plot are due to material inhomogeneity as well as to tolerances in the fabrication of test samples for the rf analysis. Due to the commercial applications of SiC, the material manufacturing was assumed to be reasonably well established and repeatable. Electrical material properties that were evaluated from various vendors, manufacturing methods, and fabrication batches were found to be consistent.

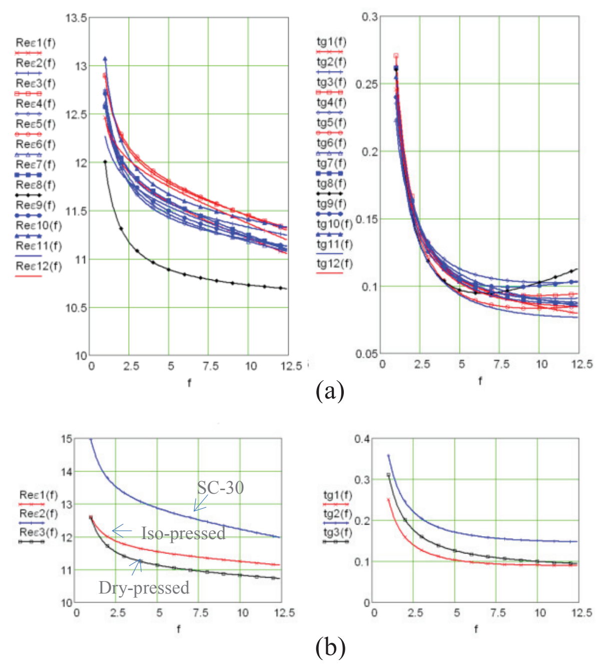

Figure 1: SiC electrical parameters: (a) permittivity and loss tangent for St. Gobain iso-pressed SiC, where the out-lying black line represents a sample with the largest dimensional deviation, and (b) averaged permittivity and loss tangent for St. Gobain iso-pressed, Coorstek SC-30, and St. Gobain dry-pressed SiC.

During the fabrication of the dampers, slabs of SiC were intended to be cut into multiple 50-mm wedge-shaped tiles for soldering onto the copper waveguide bodies, as shown in Fig. 2. Although it had been accomplished many times previously, the cutting operation failed during the production of the SPX damper tiles. As shown in Fig. 3(a), a representative SiC slab fractured into multiple pieces during the first cutting pass,

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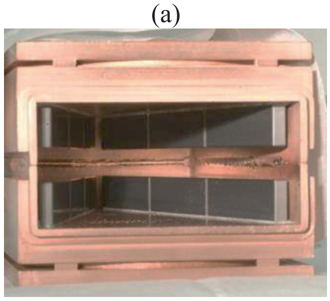
with additional fracturing evident on the surface. Not surprisingly, tomography scans, using 1-µm resolution performed at an APS beamline, showed volumetric sub-surface fractures in the material. The cause of the failure is unknown, but may be the consequence of uneven cooling after firing or issues with the uniformity of the material density during hydrostatic compression.

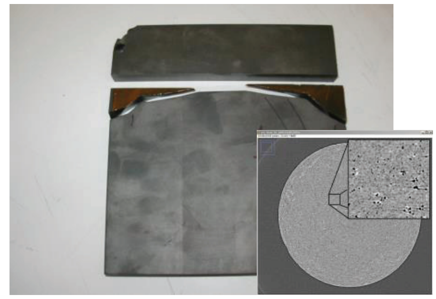
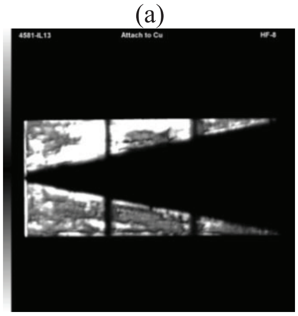

(a)

(b)
Figure 2: HOM damper assemblies: (a) copper damper half with soldered SiC tiles and (b) ebeam welded prototype damper assembly.

As a result of the failure, selected vendors and process variants of SiC were evaluated as substitutes. An additional batch of the nominal St Gobain iso-pressed SiC, as well as St. Gobain dry-pressed and Coorstek SC-30 SiC were analyzed. To ensure their mechanical integrity and rf properties, basic cutting tests, macroscopic density measurements, highly resolved tomography scans, and rf measurements were performed. Each of the materials showed satisfactory results.

Averaged electrical material properties for the test samples are shown in Fig. 1(b) where multiple core samples were extracted from up to ten slabs of each of the materials. It is worth noting that three separate batches of iso-pressed SiC had been fabricated and tested at different times using similar techniques and were shown to produce consistent electrical material parameters. Since iso-pressed SiC had been extensively tested prior to the production of the SPX dampers and had successfully completed additional testing, the latest batch was selected as the lossy material for the SPX dampers.

After completion of the SiC cutting, the tiles were soldered to the copper damper bodies using UHV-compatible Sbond [4]. Graphite spacers were initially used during fixturing to maintain spacing between the tiles as well as with the copper body. Due to residue on the SiC tiles after soldering, the spacers were coated with titanium to reduce the possibility of particulation when installed on the HOM waveguide.

Although soldering of SiC tiles to the damper body had been satisfactorily completed in the past, issues were evident during production of the SPX dampers including lack of containment of the solder and out-of-tolerance gaps. More importantly, the percentage of bonding between the tiles and the damper body was marginal, in some cases, as shown in Fig. 3(b). Due to the possible effect on the mechanical integrity of the tiles, the tiles were unsoldered and subsequently re-soldered by the vendor.


(a)

(b)
Figure 3: Manufacturing issues with HOM dampers: (a) St. Gobain iso-pressed SiC plate failure after single cut - inset shows a topography scan of SiC and (b) ultrasonic image of SiC tiles bonded to copper damper body. White areas denote regions where the solder is dis-bonded.

Following soldering, a cleaning regimen was implemented entailing ultrasonic cleaning for 15 minutes in a solution of citranox followed by high-pressure rinsing. It was found that the initial cleaning created some detachment of the solder. However, it was not evident that repetitions of the cleaning process created any additional effect.

The final manufacturing step required for the SPX damper assemblies is the Ebeam welding of the flange and the damper halves which has not yet been completed.

CRYOMODULE INTEGRATION

The HOM waveguide is attached directly to the cavity flange and transitions to the room temperature WR284 HOM damper located in the warm region of the cryomodule (see Fig. 4(a)). The waveguide achieves a return loss of at least 10 dB from 2.92 to 6 GHz, as seen in Fig. 5(b), as well as rejects the operating deflecting mode due to the natural high-pass filtering of the waveguide. Since the cutoff frequency only exceeds the operating frequency by 2%, the HOM waveguide extends a prescribed length before transitioning to the WR284 waveguide to reduce excessive loading of the damper.

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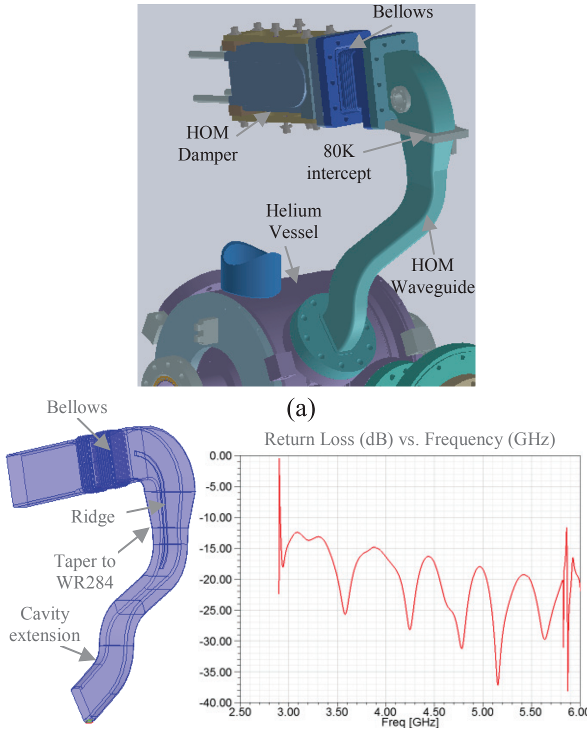
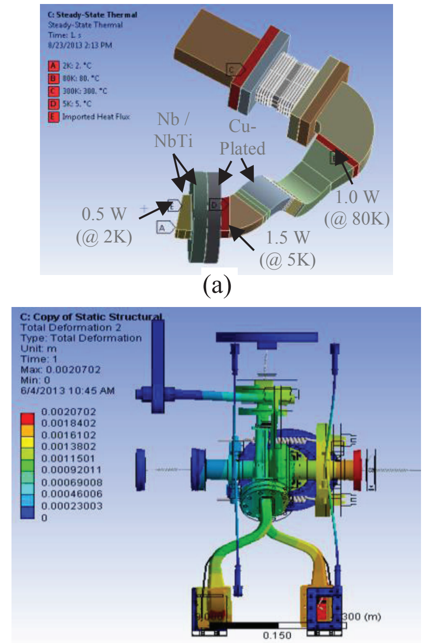


(a)

(b)

Figure 4: HOM waveguide assembly: (a) CAD geometry and (b) RF simulation model with return loss.



(a)

(b)

Figure 5: HOM waveguide thermal simulations: (a) heat load from static and dynamic effects with 5K and 80K thermal intercepts, and (b) displacement of cavity assembly due to temperature cycling to 2K. Bellows are represented as spring forces.

Due to interference issues with the cavity tuner, the HOM waveguide cavity-side flange was located near the helium vessel. In conjunction with the slow decay of the cavity evanescent field, the proximity of the flange to the cavity created a considerable heat load to 2K. As a result, a separate 5K bus was integrated into the cryogenic design, along with the original 80K intercept. The 5K bus extracted approximately 75% of the heat load originally destined for the 2K circuit. The heat load of a 1.5-mm thick stainless steel HOM waveguide with 10-µm copper plating is shown in Fig. 5(a).

A prototype HOM waveguide was fabricated from four laser-cut pieces of sheet metal that were precision bent to the proper shape. The ridge was also cut from sheet metal stock and welded to the interior surface of the HOM waveguide. Positional tolerances of the flanges were held to within 0.5-mm due to the fixturing apparatus, while the envelope of the waveguide centerline was offset by as much as 4-mm. Quality control analysis of the vacuum integrity, mechanical structure, and rf performance showed satisfactory results.

In the cryomodule, the damper will be connected to the HOM waveguide thorough a bellows and will be rigidly mounted to the space frame at room temperature. As a result, thermal motion and assembly offsets will be compensated for exclusively by the bellows. The bellows are anticipated to require a travel of 1.5-mm in the direction of the waveguide H-bend, 1.0-mm in the E-bend direction, and less than 1.0-mm in the longitudinal direction due to thermal cycling.

CONCLUSION

HOM dampers for SPX are in the process of being manufactured. Hexoloy SiC material has been chosen for the lossy damping material based on its vacuum, mechanical, and rf properties, in addition to its repeatable electrical parameters. Manufacturing issues have been resolved regarding structural deficiencies from fabrication stresses in the SiC material and soldering concerns due to the substandard bonding area of the SiC tiles to the copper substrates.

The HOM waveguide and dampers are located entirely within the cryomodule spanning from 2K to room temperature and were designed to satisfy rf and mechanical constraints including low-frequency and broadband performance, layout in the cryomodule, and thermal considerations. The total cryogenic loading and thermal compliance of the HOM waveguide assembly have been quantified.

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