# SUPERCONDUCTING CAVITY DESIGN FOR SHORT-PULSE X-RAYS AT THE ADVANCED PHOTON SOURCE*

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*Abstract*

Superconducting crabbing cavities have been analyzed for the short-pulse x-ray (SPX) project at the Advanced Photon Source (APS). Due to the strong damping requirements in the APS storage ring, single-cell cavities have been selected. Two designs, referred to as the baseline and alternate designs, are being evaluated for their rf performance and damping margins. Various considerations concerning the designs and damping requirements will be discussed.

## INTRODUCTION

The APS is planning to implement superconducting crabbing cavities to generate picosecond x-ray pulses based on the principles described in [1]. Four crabbing cavities will populate a single cryomodule to produce a total deflecting voltage of 2 MV. A portion of the APS users will utilize these short x-ray pulses for the analysis of short time-scale physical processes while the remaining users will continue to operate with the nominal x-ray pulse length. As a result, a second set of four crabbing cavities will be inserted downstream to reverse the effect of the crabbing and return the beam to its nominal orbit with minimal effect on beam quality.

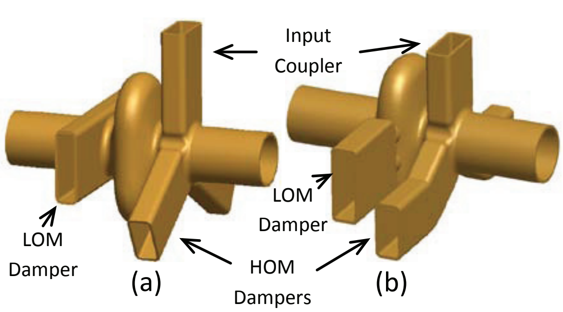


Figure 1: SPX cavity designs: (a) baseline and (b) alternate.

Due to the strict damping requirements, strong coupling from the cavity to the damping waveguide is required. Both SPX single-cell cavity designs use a Y-end group similar to those on the JLAB high-current cryomodules to damp HOMs, see Fig. 1. The LOM damper utilizes a waveguide damper either off the beampipe for the baseline cavity or off the body of the cavity cell for the alternate cavity. The LOM damper on the body of the cavity offers a more compact geometry with enhanced low-order and high-order mode damping. However, the effect of the on-cell damper waveguide on multipacting, and fabrication issues must be determined.

Table 1: Cavity parameters for the baseline and alternate cavity designs

| | Baseline | Alternate | Units |
|---|---|---|---|
| Freq | 2.815 | 2.815 | GHz |
| $Q_u$ | $10^9$ | $10^9$ | |
| $V_t$ | 0.5 | 0.5 | MV |
| G | 225 | 228 | Ohm |
| U | 0.38 | 0.38 | J |
| (R/Q)’ | 18.9 | 18.6 | Ohm |
| $B_{peak}$ | 92 | 100 | mT |
| $E_{peak}$ | 37 | 41 | MV/m |
| $Q_{ext}$ | $\sim 2*10^6$ | $\sim 2*10^6$ | |
| $P_{loss}$ | 7 | 7 | W |
| $I_{beam}$ | 200 | 200 | mA |
| $k_{\|\|}$ ($\sigma$=40ps) | 0.41 | 0.28 | V/pC |

## SPX CAVITY DESIGNS

Multicell cavities have been considered but were found to be either inadequate in achieving the stringent beam stability requirements or were prohibitively difficult to manufacture [2, 3]. As a result, two possible single-cell cavity designs are being considered for installation into the APS storage ring, as shown in Fig. 1. The racetrack cross-section of the cavities were re-optimized based on the KEK crab cavity design in order to minimize the peak surface magnetic field and thereby permit a higher operating gradient [4].

The rf parameters of each cavity are detailed in Table 1 and exhibit similar performance values. The primary distinction between the designs is the coupling of the lower-order mode to the damping waveguide. Both utilize a single waveguide for LOM damping with a shorting stub on the opposite side of the cavity. The stub length in the baseline design has been optimized for the damping of specific parasitic modes, and both stubs are intended to symmetrize the fields in the cavity and reduce any extraneous kick to the beam due to multipole fields.

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The alternate cavity is a novel design with enhanced damping as compared with the baseline cavity. As a result, in order to achieve a reasonable safety margin with the beam stability threshold limit imposed at the APS, the alternate design is the preferred cavity for the SPX project where $Q_{ext}$ on the order of 10's to 100's are typically required for the LOMs/HOMs. However, multipacting and fabrication and processing issues must be evaluated in order to realize a design that operates within performance specifications.

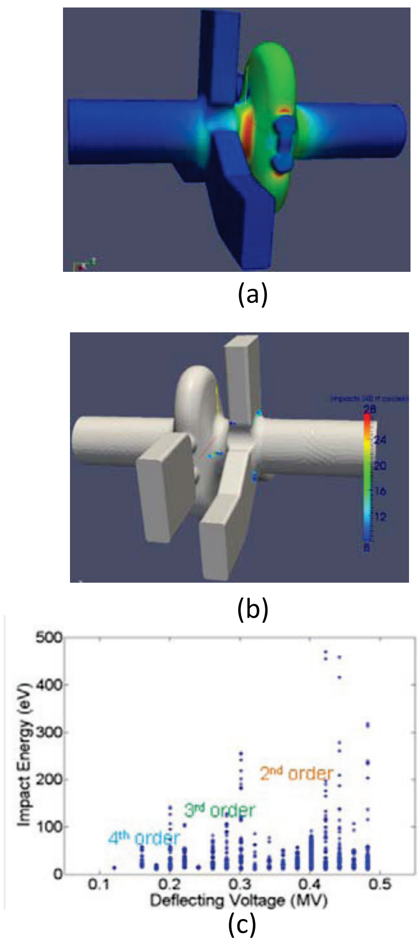


Figure 2: Multipacting simulation results for alternate cavity using Omega3P/TRACK3P: (a) magnetic field magnitude, (b) multipacting sites (color code is based on number of impacts per 40 rf cycles), and (c) impact energy and order number.

Multipacting is known to occur in dipole mode cavities near the high magnetic field regions along the cavity iris, which is especially significant for the alternate cavity since its design introduces a coupling iris and damping waveguide on the cavity body. In order to determine an initial estimate of the significance of multipacting, analysis has been performed using OMEGA3P and TRACK3P from the SLAC suite of ACE3P codes [5].

The magnetic field distribution and multipacting results are shown in Fig. 2 for a simulation run that extended for 40 rf cycles. Multipacting sites are shown in Fig. 2(b) to be clustered near the cavity iris. Interestingly, there are no projected multipacting sites along the LOM waveguide or coupling iris of the alternate cavity. The impact energy distribution and multipacting order shown in Fig. 2(c) exhibit similar tendencies to an identical analysis performed with the baseline cavity. Experimental results of the baseline cavity discussed in [6] have shown little signs of multipacting and have surpassed the design specification for gradient and unloaded quality factor. As a result, higher-order multipacting predicted by TRACK3P does not appear to be a limiting issue in either the alternate or baseline design.

## DAMPERS

The beam loading of the dampers due to broadband impedance for the baseline and alternate cavities with 200 mA beam current is 2.5 kW and 1.7 kW, respectively for a 40-ps beam sigma. The beam loss factor for the alternate cavity is significantly less due to the absence of the perturbation produced by the LOM damper waveguide off the beampipe. Approximately 70% of the beam-generated power is transmitted to the LOM waveguide dampers and is distributed primarily over a narrow bandwidth of less than 100 MHz at about 2.3 GHz. Narrowband impedance effects, on the other hand, are not significant due to the heavy damping levels achieved by the cavities.

Waveguide dampers were chosen based on their proven performance at PEP-II and KEK [7, 8]. At PEP-II, two-wedge waveguide dampers fabricated with AlN doped with 7% SiC have been designed for power levels up to 10 kW. The PEP-II damper frequency range was between 700 – 2500 MHz, which produced a distributed rf load across the material volume.

The rf fields in the SPX LOM damper, on the other hand, couple strongly to the dielectric as a surface wave and become rapidly absorbed in the material for the nominal LOM damper waveguide dimensions of 21 mm × 72 mm. As a result, it was necessary to design the damper assembly to distribute the narrowband load over a large volume to reduce the temperature gradient and the resultant stresses through the damper material.

A four-wedge design is selected for the SPX cavities to reduce the thermal gradient across the material with a lesser material thickness, distribute the load, and supply wideband performance from 2.2 GHz – 8 GHz. The four-wedge design also reduces potential mechanical stresses by producing a symmetric bending force in the waveguide during the critical cool-down after brazing, as well as during operation.

Figure 3(a) shows simulation results from a parametric study to determine the optimal waveguide width for distributing the volumetric power density. The dampers are expected to be cooled at room temperature within the insulating vacuum of the cryomodule, so a compromise was made between the peak power density in the dampers and the waveguide dimension where a 21 mm × 120 mm waveguide cross section was chosen with a peak power density of 42 W/cm$^3$, as shown in Figs. 3(a) and 3(b). The distribution of rf power and the broadband frequency response in the selected four-wedge damper assembly are shown in Figs. 3(b) and 3(c).

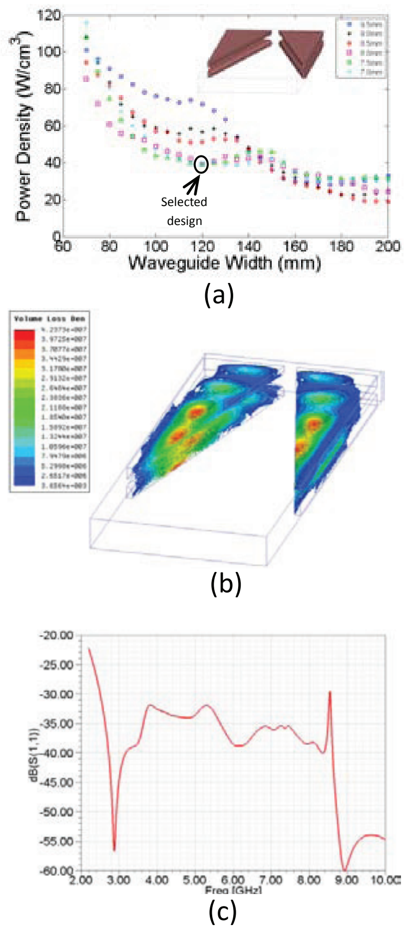


Figure 3: Four-wedge damper rf design: (a) parametric analysis of rf power density peak loading vs. waveguide width for various damper ceramic thicknesses, (b) power density in W/m$^3$ for the selected damper assembly, and (c) broadband return loss for selected damper assembly.

The thermal profile and the equivalent stresses for the damper with 2-kW rf loading at 2.3 GHz are shown in Fig. 4 for the damper wedges. A peak temperature of 42°C was found for the idealized case of solid damper wedges and a solid substrate with a convective film coefficient of 1 W/cm$^2$. It is expected that the dampers will be segmented into blocks, and a copper pin bed may be used as the brazing substrate in order to ensure successful brazing of the damper material.

## CONCLUSION

Single-cell cavities have been selected for the SPX project due to the strong damping requirements of the APS storage ring. The baseline and alternate cavities have similar performance parameters at the operating dipole mode frequency of 2.815 GHz. However, the alternate cavity offers better LOM and HOM damping, performance and has a substantially reduced loss factor which helps limit the power levels in the SPX LOM dampers.

A LOM damper design has been discussed, which distributes the nearly monochromatic rf load produced in the damper throughout the volume of the damper material in order to reduce the thermally induced stresses in the damper assembly.

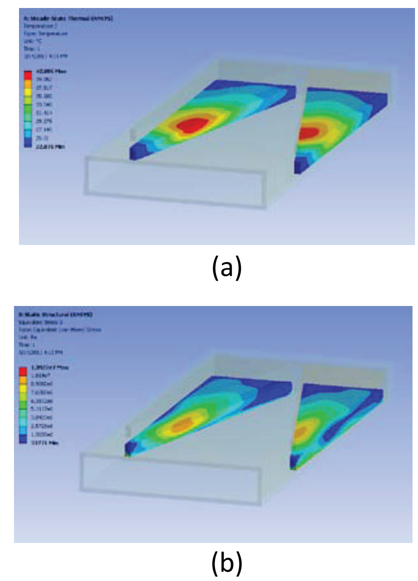


Figure 4: Four-wedge damper mechanical simulation results with 2-kW rf loading: (a) thermal profile and (b) Von Mises equivalent stress.

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