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HIGH-POWER DESIGN OF A CAVITY COMBINER FOR A 352-MHz SOLID STATE AMPLIFIER SYSTEM AT THE ADVANCED PHOTON SOURCE*

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Abstract

A cavity combiner has been designed as part of a solid state amplifier system at the Advanced Photon Source with a power requirement of up to 200 kW for the full system. Peak field levels and thermal loading have been optimized to enhance the rf and mechanical performance of the cavity and to augment its reliability. The combiner consists of 16 rotatable input couplers, a reduced-field output coupler, and static tuning. The power handling capability of the cavity will be evaluated during a back-feed test where an external klystron source will be used to transmit power through the cavity into loads on each of the input couplers.

INTRODUCTION

The Advanced Photon Source is upgrading its facility to a 4th generation multi-bend achromatic light source. Given a reduction of the total beam energy to 6 GeV, the total number of cavities required in the APS storage ring will be reduced from 16 to 12 cavities. However, due to the cost and availability of klystron amplifiers, a solid state amplifier system is being developed and tested.

The 352 MHz solid state amplifier modules will produce up to 2 kW. As a result, combining networks are necessary to produce a total of up to 200 kW. The topology of such a system using cavity combiners is being evaluated at the APS. ESRF and others have previously explored their adoption [1]. An advantage of cavity combiners is the relatively small space consumption and the reduction in the number of external combining networks from large-scale coaxial combiner networks such as at Soleil and elsewhere [2]. Additionally, the number of inputs supported by a single cavity combiner is relatively easily adjusted based on the needs of the overall system.

A single solid state amplifier system producing up to 200 kW will be used for each storage ring cavity in the APS, requiring a total of 12 systems for the full storage ring after final integration. The initial prototype system will be designed with the capability of dynamically adjusting the DC voltage input of each of the amplifiers to optimize the efficiency of the amplifiers, ad hoc, based on changes in the beam loading thereby altering the thermal loading of the cavity combiner. The APS plans to install a prototype solid state amplifier system for a single storage ring cavity before construction of the APS-U begins in 2022.

DESIGN

The geometry of the cavity combiner shown in Fig. 1, focuses on creating a design with reliable, maximal power-handling capability. Particular emphasis was made on reducing the peak electric fields, preventing rf breakdown phenomenon, and minimizing thermal effects. For that reason, the geometry of the output coupler was selected, as well the elliptical shape of the input couplers, the tuner dimensions, surface finish requirements, as well as the integrity of all critical interface joints between components.

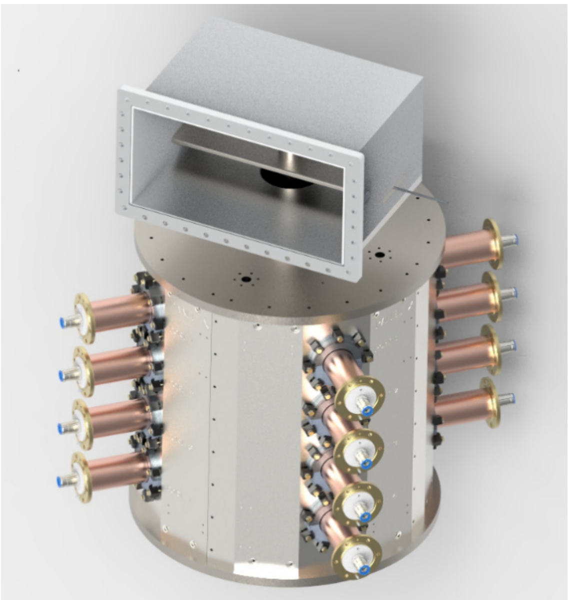

Figure 1: Cavity combiner geometry.

The cavity is monitored for breakdown effects with fast interlocks for arc detectors and on forward and reflected power levels. To ensure breakdown limits are not compromised due to its operation in air, the environmental conditions surrounding the cavity are monitored and interlocked on humidity levels, in addition to the constant circulation of air through the cavity.

The cavity combiner prototype was designed as a flexible platform for evaluating features and performing optimizations for the final combiner. The input couplers are fully rotatable to perform optimal tuning during assembly and account for the longitudinal variability of the cavity field strength. While tuning, the input coupling is adjusted on a single coupler, while all others are terminated with a short circuit, such that the reflection coefficient is fixed at $\Gamma = \frac{-(m-2)-N}{m+N}$, where m=1 is the number of unshorted input ports and N is the total number of inputs. The cavity will

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accommodate up to 16 input couplers and may be reconfigured to allow 4, 8, or 16 inputs.

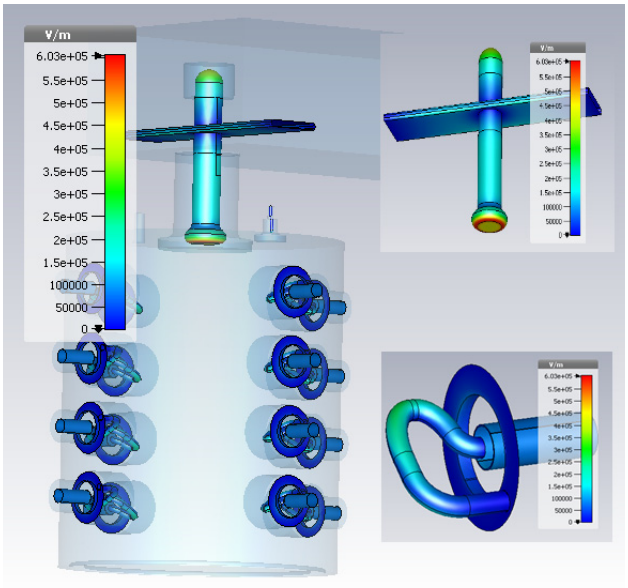


Figure 2: Electric field magnitudes at 200 kW cavity output power with cutout of input and output couplers.

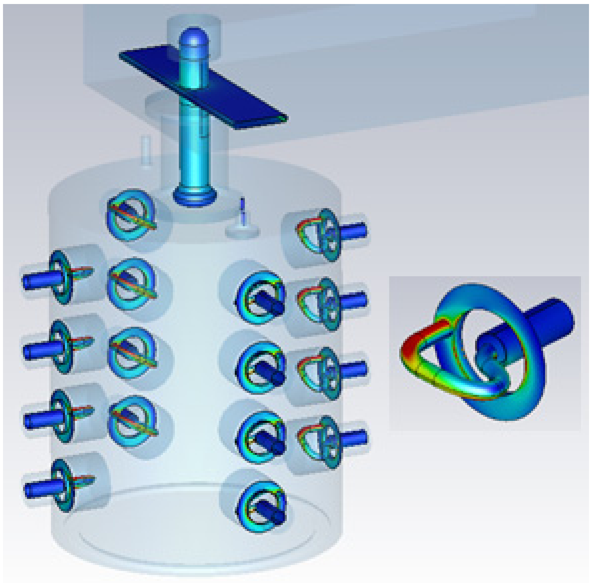


Figure 3: Surface loss density at 200 kW cavity output power.

Variations in the Qext are facilitated for the testing of the cavity combiner by the fabrication of a selection of detachable output coupler tips of varying lengths. Reducing the loaded quality factor of the cavity has significant advantages in reducing the peak field strength in the cavity, as well as reducing overall losses thereby increasing power-handling limits and/or the reliability of the cavity.

A sufficiently low quality factor also permits the utilization of a static tuner. Active tuning of the cavity is a relevant issue due to the plan for varying the power levels in the cavity by adjustment of the DC voltage levels in the amplifier to accommodate changes in beam loading. The thermal load and temperature of the cavity will vary due to changing power levels, as will the resonant frequency. To ensure a good match into the cavity and efficiency of the overall system, a lower Qext produces a larger cavity bandwidth, in addition to simplifying the complexity of the tuning assembly by replacing active tuning with a static tuner.

ELECTROMAGNETIC PERFORMANCE

The reduction of peak fields in the cavity combiner was achieved, in large measure, by optimizing the shape of critical components and reducing the loaded quality factor. The output coupler naturally intercepts the highest electric fields in the cavity and transmits the full power from the cavity. It was designed to dissipate the high local field levels and reduce field enhancement. Additionally, consideration was made for the input couplers and tuner to minimize their peak field levels well below the breakdown threshold. The peak fields and the cavity surface loss density are shown in Fig. 2 and Fig. 3 for 200 kW output power level and a Q_{ext} of 230. Corresponding local field values are listed in Tables 1 and 2.

Table 1: Peak Electric Field Magnitude at 200 kW

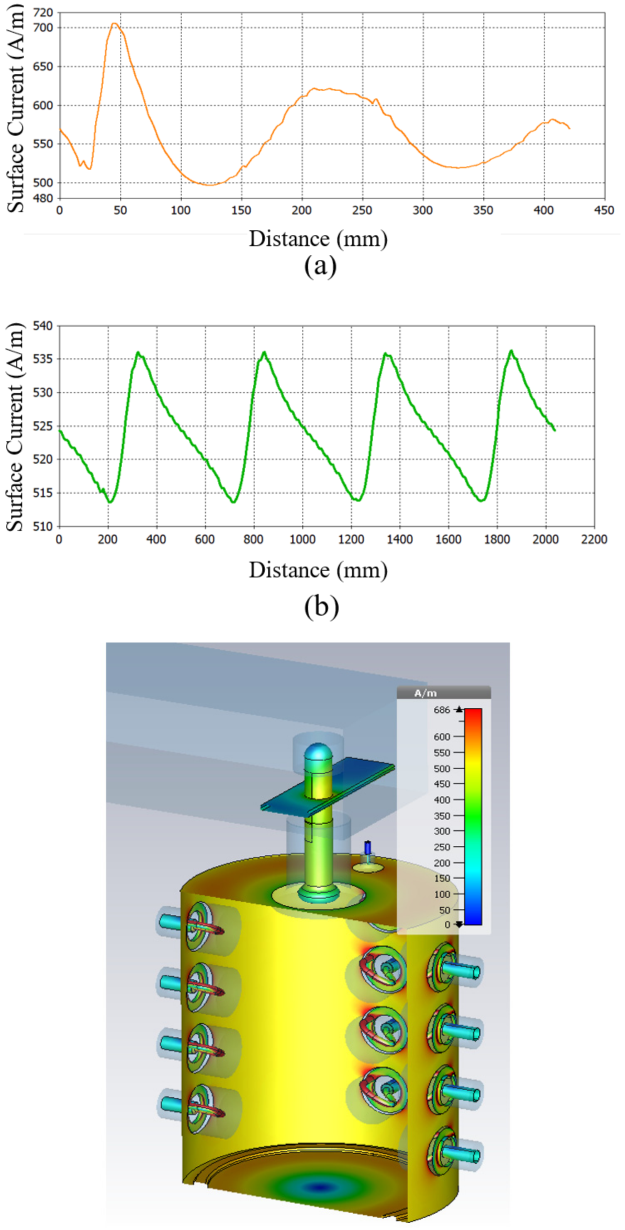
Surface	**E-field Qext=65 (MV/m)**	**E-field Qext=230 (MV/m)**
Input Coupler	0.21	0.25
Output Coupler	0.47	0.57
Cavity Body	0.21	0.42
Tuner	0.08	0.16

Table 2: Power Losses at 200 kW

Surface	**Power Loss Qext=65 (W)**	**Power Loss Qext=230 (W)**
Input Coupler	8.6	18.0
Output Coupler	61.9	59.6
Cavity Body	446	1599
Tuner	21.6	81.4

In addition to peak field regions, the possibility of breakdown episodes can occur due to the surface quality of components, as well as the flatness and contact between interfaces. Particular attention to contact surfaces along areas of high surface current density was made. These areas include the interface between the cavity panels and the top and bottom plates, the joint connecting the output coupler to the cavity, and around the input couplers.

Plots of the surface current density at 200 kW are shown in Fig. 4. The total current flow around the periphery of the input couplers averages approximately 550 A/m and peaks at 700 A/m near the contact point of the loop conductor. Around the periphery of the top and bottom plates, the current is relatively constant with an average value of 525 A/m corresponding to a total of approximately 1 kA of current passing through the interface. As a result, the contact surfaces have been carefully considered where springs and appropriate machining specifications have been used.



(a)

(b)

(c)

Figure 4: Surface current density at 200 kW output power level: (a) surface current around periphery of input coupler, (b) surface current around edge of the cavity top plate, and (c) field plot of surface current.

200 KW BACK-FFED TEST PLAN

To evaluate the absolute power-handling capability of the cavity combiner and determine the ultimate topology for the solid state amplifier system, a high-power back-feed test will be performed using a 1 MW klystron. The klystron will "back-feed" up to 200 kW into the cavity through the WR2300 waveguide of the combiner. Each of the input couplers will be used to extract power from the cavity and dissipate it in a 25-kW load. In this way, peak electric field levels, breakdown phenomenon, temperature control, high-power rf performance, and the frequency shift of the cavity at various power levels will be evaluated and used to determine the optimum topology for a stand-alone 200 kW amplifier system.

CONCLUSION

A solid state amplifier system is being designed at the APS as a replacement for existing klystron amplifiers in the storage ring. The overall topology of the system is being evaluated with a cavity combiner which has been designed for maximum power-handling capability and increased reliability. The peak fields on the surface of the conductors in the cavity have been minimized and interface joints and surface quality at high field regions have been addressed. A final solid state amplifier system which will be used to produce up to 200 kW for individual storage ring cavities will be determined based, in part, on the results and analysis performed at the completion of a 200 kW back-feed test.

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