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HIGH-POWER PROTOTYPE CANON COUPLER FOR APS-U BOOSTER CAVITIES*

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Abstract

The Advanced Photon Source Upgrade (APS-U) plans to achieve a beam capture efficiency above 90% at 17 nC bunch charge into the Booster. Due to large beam loading at injection, the 352-MHz Booster cavities will be significantly detuned necessitating effective-power handling much greater than the 100 kW power rating of the present coupler. Canon Electron Tubes & Devices Co., Ltd. (CETD) has designed and built a compact prototype coupler for the APS-U Booster using a high-power ceramic disk window design in addition to accommodating significant space restrictions and additional diagnostics and cooling requirements. The coupler design was modified from an existing 500 MHz, 800 kW coupler that has been in routine operation at KEK-B [1]. The APS-U coupler has been installed and tested in the high-power 352-MHz test stand at the APS. The details of the design and testing of the prototype coupler will be reported in this paper.

INTRODUCTION

The Advanced Photon Source is currently in the process of upgrading its facility to a 4th generation multi-bend achromat light source. The beam energy will be 6 GeV while the beam current will be increased to 200 mA with 324 and 24 bunch modes. Due to swap-out requirments of a complete bunch, the booster must extract a high charge bunch up to 17 nC into the Storage Ring. In order to maximize injection efficiency, the beam is injected on-momentum, while in order to reduce the horizontal emittance, the beam is extracted off-momentum by as much as -1%.

As a result of the high charge, beam loading in the booster cavities deteriorates the injection efficiency. It is mitigated both by detuning the cavity at injection and by overcoupling the cavity. Overcoupling serves both to reduce the loaded cavity quality factor to help subdue the effects of beam loading and also increases the cavity bandwidth thereby reducing the input power requirements as the cavity is detuned.

The coupler shown in Fig. 1 was fabricated by Canon for the APS-U. It is inductively coupled and is rotatable to adjust its match. It has been designed to accommodate a significant standing wave due to cavity detuning relative to the rf source as well as due to overcoupling. These mismatches create local, equivalent power maxima reaching equivalent power levels up to 500 kW.

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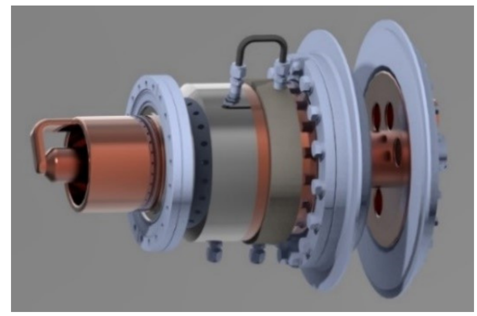

Figure 1: APS-U booster coupler geometry.

DESIGN

The design of the coupler was guided by best practices including the use of low-loss, high thermally conductivity dielectrics, reduction of multipacting with Ti coatings, minimization of electric field magnitude, and avoidance of direct line-of-sight between dielectrics and the beam.

A cross-section of the APS-U coupler which was fabricated and tested is shown in Fig. 2. The selected coupler is based on a 500-MHz, 800 kW design from KEK-B with a proven record for reliability. The coupler utilizes a disk ceramic window similar to windows used in klystrons manufactured by CETD at power levels of 1.2 MW [2]. The alumina ceramic was chosen based on prior experience and due to its low loss tangent.

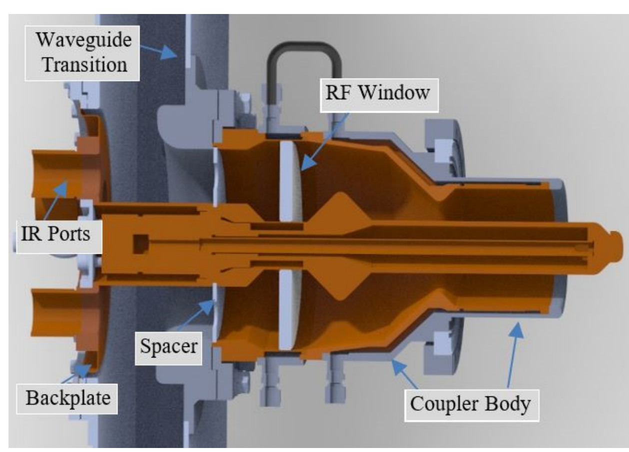

Figure 2: Cross-section of mechanical design of coupler and waveguide transition.

Significant revisions were made to the coupler for the APS-U to avoid intereferences with a beam transport line in the booster tunnel that was compounded by the lower operating frequency of 352-MHz. The length of the coupler

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was substantially reduced by shortening the inner conductor and modifying the matching elements at the same time ensuring a sufficient cavity coupling depth. Additionally, a ¼-ht transition waveguide was used as well as mechanical interfaces were truncated. It is also worth noting the outer and inner conductor capactive matching features were designed to eliminate line-of-sight between the rf window and the beam to prevent any charge buildup and window degradation.

A dielectric spacer was incorporated as a support for the inner conductor and as a stress relief for the rf window. Rexolite was considered as a suitable alternative material to teflon due to its resistance to deterioration in radiation environments. However, given consideration of its low thermal conductivity and a loss tangent of 5×10^{-4}, the resultant temperture rise and material stresses were excessive. As a result, alumina was also chosen for the ceramic spacer. In addition, two ports were included in the backplate of the coupler for forced air cooling of the ceramic spacer and window.

The backplate is a detachable componenet of the coupler. As a result, a leaf spring was incorporated into its periphery to ensure conformability with the waveguide transition. More importantly, the leaf spring also helped to ensure circumferential contact with the inner conductor of the coupler body and the backplate. This contact occurred at the groove which captured the spacer and where the highest magnitude of electric field also existed.

Diganostic ports are utilized on the backplate for an arc detector and a pair of IR sensors for temperature interlocks. Necessarily, the backplate is rotatable to accommodate alignment of the IR ports with holes in the ceramic spacer. The IR sensors monitor the temperature of the rf window through 20 mm diameter viewing apertures in the spacer. An IR sensor with a 22:1 ratio of distance to spot size, where 90% of the radiation energy is collected, creates a 16 mm spot size at the location of the hole in the spacer for a relatively unobstructed view of the rf window.

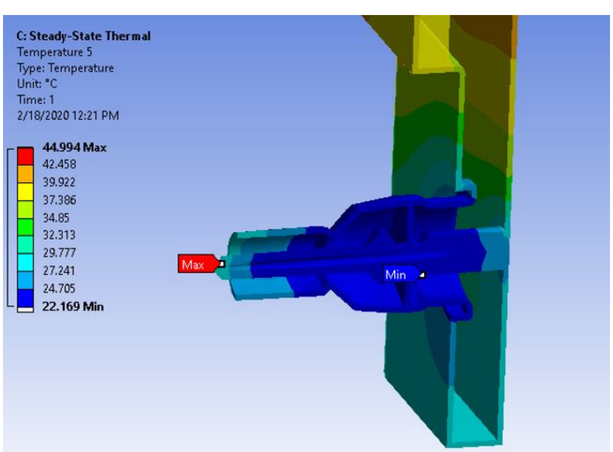

Figure 3: Temperature profile after thermal analysis with 500 kW input power and water and air cooling.

Thermal simulations were performed of the coupler with a 5-cell booster cavity. With 500 kW input power into a critically matched coupler, the temperature profile is shown in Fig. 3 where the maximum temperature rise is located on the coupling loop inserted into the cavity. With enhanced cooling of water on the inner and outer conductors and air cooling through ports on the backplate, the temperature rise of the rf window and the spacer was limited to a few degrees.

MANUFACTURING & ASSEMBLY

All vacuum components of the coupler including the rf window and copper conductors were Ti coated with approximately 3-5 nm on the window and 0.1 µm on the copper to suppress multipacting. After brazing, it was found that the coating on the outer conductor of the coupler body developed a distinctly bluish hue as shown in Fig. 4. Elemental testing indicated that the dicoloration was due to the creation of a titanium oxide layer during brazing and was not considered signficant to the performance of the coupler.

The coupler construction followed strict standards for vacuum compatibility with the APS-U lattice. A residual gas analyzer test was performed after baking to verify vacuum compatibilty and measured no detectable chlorine, flourine, or sulfur and no partial pressure above 5×10^{-11} Torr above 44 amu.

The coupler was fabricated into separate, detachable components consisting of a coupler body, ceramic spacer, and backplate that were each assembled onto the waveguide transition. A portable articulating arm coordinate measurement machine (CMM) was used in order to ensure concentricity and co-planarity between each of the coupler components, the waveguide transition, and the cavity. Once assembled and properly aligned, the coupler was rotatable to match to the cavity. Afterwards, the backplate IR viewports were aligned with the apertures in the ceramic spacer.

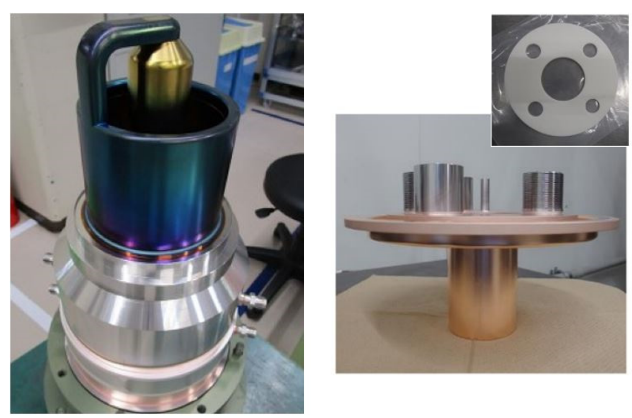

Figure 4: Fabricated components of coupler: (left) Coupler body; (right) Backplate and spacer.

TESTING

The ANL test stand consists of a klystron capable of producing 1.2 MW; however, the test cavity limits power to 200 kW. To test the coupler up to 500 kW, the coupler was overcoupled to create a mismatch and thereby a standing wave with electric field maxima locally producing equivalent powers of 500 kW along the length of the coupler.

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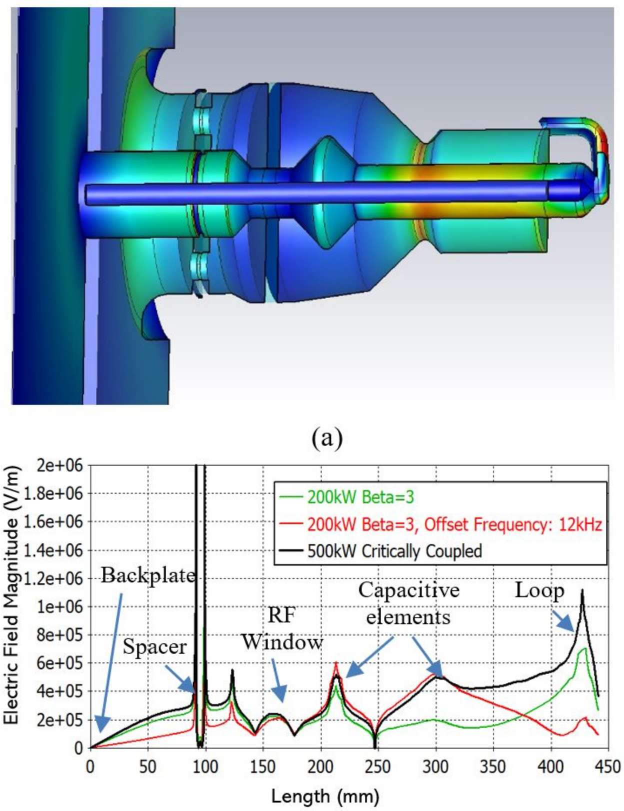
The coupler was tested using a two step process with the coupler overcoupled to β = 3. The intention was to mimic the local field levels that existed with a critically coupled cavity system at 500 kW using 200 kW input power available at the test stand, as shown in Fig. 5. In the first case, with β = 3, field patterns were similar along the mismatched coupler spanning from the backplate to beyond the rf window. In the second case, detuning the cavity by 12 kHz from the source frequency created field magnitudes that were similar from the rf window to the 2nd capacitive element.



(a)

(b)

Figure 5: Electric field on coupler: (a) Cross-section showing magnitude along coupler metallic surfaces, (b) Line plot of magnitude along surface of inner conductor from the backplate to the coupler loop. The nominal case of 500 kW forward power, shown in black, is compared with cases where the coupler was overcoupled and additionally the cavity was detuned relative to the source frequency.

Testing of the coupler was thereby accomplished by mismatching the coupler to β = 3 and conditioning up to 200 kW on-resonance and again 12 kHz off-resonance. The conditioning process consisted of pulsing rf to 200 kW at varying pulse lengths and duty factors until CW operation was achieved. The resultant maximum temperature rise of the rf window was less than 10 ºC and vacuum levels remained stable with only two events that occurred at high-power due to arc detector trips.

The APS-U booster coupler has recently been installed in the booster tunnel where the interaction of the coupler with beam will be evaluated. A phase shift was incorporated into the transmission line leading to the coupler to compensate for its greater electrical length of approximately 45º. The coupler was installed on a single cavity where the remaining three cavities will remain critically matched with their original couplers. Due to the mismatch of β = 3 introduced by the APS-U coupler and given consideration that a single rf amplifier supplies power to the four cavities, an overall power increase of approximately 10% is expected.

CONCLUSION

A prototype Canon coupler was designed for reliable operation up to 500 kW in the booster tunnel for the APS-U. It was designed to replace an existing coupler in order to support high charge requirements and improve injection efficiency for the APS-U. The coupler has been fabricated and successfully tested in the APS test stand up to 500 kW equivalent power. It has been installed in the booster tunnel and will be evaluated with beam during the upcoming run period at the APS.

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