THE RF AND MECHANICAL DESIGN OF A COMPACT, 2.5 kW, 1.3 GHz RESONANT LOOP COUPLER FOR THE APEX BUNCHER CAVITY*

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Abstract

The Advanced Photo-injector Experiment (APEX) at the Lawrence Berkeley National Laboratory (LBNL) is an injector system designed to demonstrate the capability of a normal conducting 186 MHz RF electron gun operating in CW mode to deliver the brightness required by X-ray FEL applications operating at MHz repetition rate, such as LCLS-II. A 240 kV, 1.3 GHz CW buncher cavity design was developed as part of the APEX experiment. The two-cell cavity profile has been optimized to minimize the RF power requirements and to remove multipacting resonances over the full range of operation. In order to excite the cavity stably at pi-mode and remove the dipole-like coupler kick, the two cells are independently driven by four, 2.5 kW, coaxial resonant loop couplers with integrated ceramic RF windows and a matching section in the body of the coupler. The coupler's inner conductor has a single diameter change at a specified distance from the ceramic insulator in order to cancel the wave reflected from the ceramic window, thus comprising the coupler matching section. The details of the RF analysis, mechanical design, fabrication and testing of the coupler are presented here.

INTRODUCTION

APEX is a demonstration injector system at LBNL that uses a normal conducting 186 MHz CW RF electron gun [1, 2]. The system was designed to deliver a high brightness, MHz rep rate beam for X-ray FEL type applications (see Fig. 1).

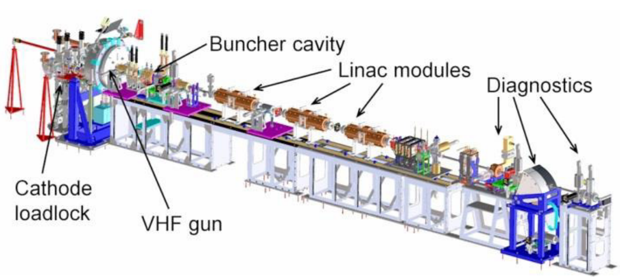

Figure 1: Overview of the APEX Phase II system.

The APEX beamline includes a two-cell brazed copper buncher cavity operating at 240 kV, 1.3 GHz CW [3]. The two-cell cavity profile has been optimized to lower the RF power requirement to 7 kW as compared to 14 kW for a single cell design. The weak intra-cell coupling results in a frequency separation between zero and pi-mode of only ~1 MHz. The two cells are excited independently by coax loop couplers to avoid mode mixing. A resonant type magnetic coax loop coupler capable of delivering 2.5 kW of RF power has been designed, fabricated and tested. Each buncher cavity cell uses dual RF feeds with two additional perpendicular dummy ports to minimize the dipole and quadrupole kicks (see Fig. 2). Each of the four couplers is powered by a separately controlled amplifier to allow independent phasing. The upper and lower dummy ports are also used for RF pickups and vacuum pumping.

Figure 2: Two-cell, 1.3 GHz buncher cavity CAD model.

A commercially available high vacuum coaxial RF window capable of delivering the required power at this frequency range is not readily available. LBNL has developed a new design for a low impedance resonant type coax RF window integrated with a loop coupler that meets the power requirements and geometry constraints of the cavity [4].

DESIGN FEATURES

The buncher coupler developed by LBNL is a coaxial structure with a bandpass response centered at 1.3 GHz and with several tens of MHz bandwidth. As shown in Fig. 3, the coupler's inner conductor has a single step in diameter that results in an impedance change from 50 to 20 ohms. The step is located at a specified distance from the ceramic insulator in order to cancel the wave reflected from the ceramic window, thus comprising the matching section of the coupler. The RF window is used to separate the vacuum in the buncher cavity from the upstream (air) side. The exact distance between the step and the ceramic window was determined by means of low power RF measurements using a dummy coupler with a sliding ceramic insulator. RF losses on the vacuum coax line and ceramic window were calculated to be less than 1 W, so the coupler can be cooled only through conduction to the water-cooled cavity body.

*This work is supported by the Office of Science, United States Department of Energy under DOE contract DE-AC02-05CH11231.
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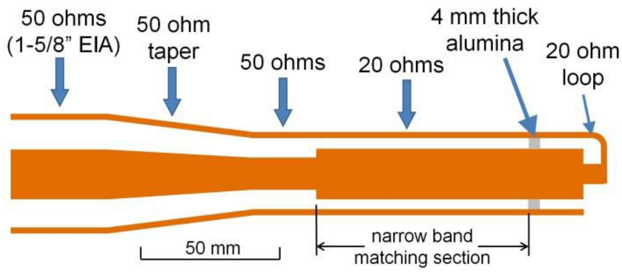

Figure 3: Internal geometry of the RF loop coupler.

A mechanical design was developed that incorporates the required internal geometry, facilitates the brazing of the ceramic window, and provides a tip and loop size and configuration that is compatible with the cavity dimensions (see Fig. 4). The coupler input flange is based on a standard 1-5/8" EIA geometry; the tapered section of the coupler allows the coupler tip to adapt to a rotatable 2-3/4" Conflat flange for making a vacuum and RF seal with the cavity body. A secondary flange is used on the input end to support the inner conductor and to prevent axial forces from acting on the ceramic.

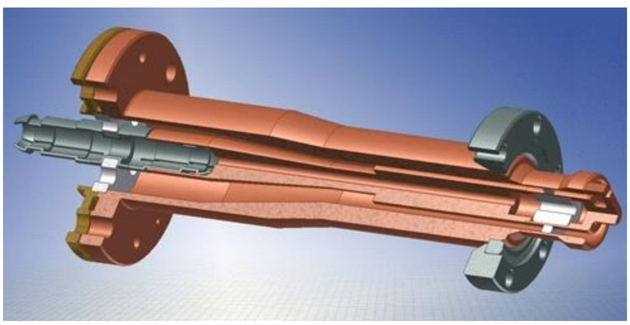

Figure 4: CAD model cutaway of the RF loop coupler.

FABRICATION SCHEME

The biggest challenge in the fabrication of the coupler was to devise a reliable method of brazing the ceramic window to both the inner and outer copper conductors to form a vacuum tight seal capable of maintaining the 10^{-10} Torr vacuum level in the cavity. A design was developed that minimized the effect of the much higher thermal expansion of copper as compared to the alumina RF window (see Fig. 5). A ceramic slug was used in the hollow inner conductor to minimize the thermal expansion of the inner conductor during brazing; if the inner conductor was solid copper, the ceramic window could break, or the braze joint could fail when the copper contracts during cooldown. The outer conductor was locally thin to facilitate external fixturing and ensure a good braze to the window OD. A braze development program was carried out to test various iterations of this design. The final braze configuration and fixturing were developed by California Brazing, located in Newark, CA, USA. The loop connection to the outer conductor is completed by TIG brazing the outer axial segment after the window braze. A photo of the loop end of a completed coupler is shown in Fig. 6.

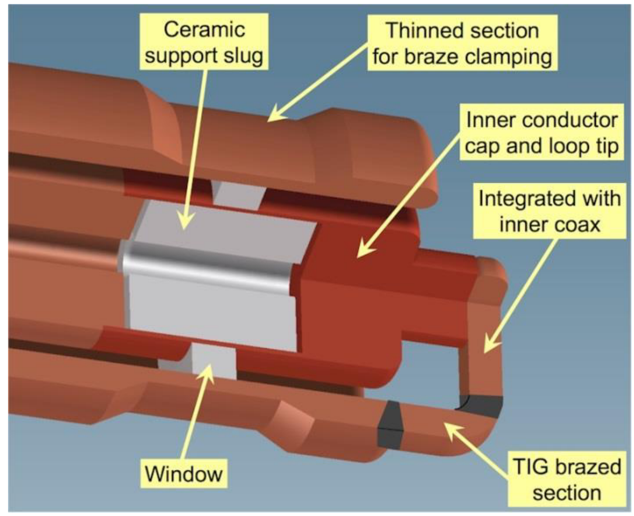

Figure 5: Details of the coupler window and loop areas.

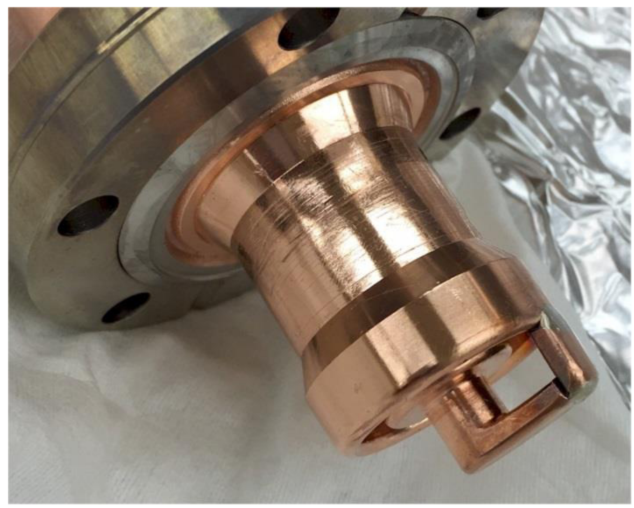

Figure 6: Photo of the loop end of a completed coupler.

MULTIPACTING ANALYSIS

A multipacting study was carried out for the buncher coupler design [5]. From the analysis standpoint, the coupler consists of the uniform coax line and the non-uniform coupler loop. Multipacting in the uniform coax line was evaluated analytically, and no multipacting is expected in this region. Analysis of the non-uniform loop requires 3D simulation. The S3P code is used for RF simulation of the buncher cavity, and TRACK3P is used for multipacting tracking on the vacuum side of the RF window (see Fig.7). Fig. 8 shows that electron resonances distribute continuously when the cavity voltage is between 240 kV and 80 kV, and resonance energy at 240 kV is between 0 eV and 140 eV. The TRACK3P analyses predict two-point multipacting between the coupler loop area and the cavity walls. The maximum electron impact energy is only 140 eV, but the coupler is coated with ~200 nm of titanium nitride to mitigate any multipacting risk. The cavity itself has only a few higher order multipacting modes, which are avoided during operation.

ISBN 978-3-95450-182-3

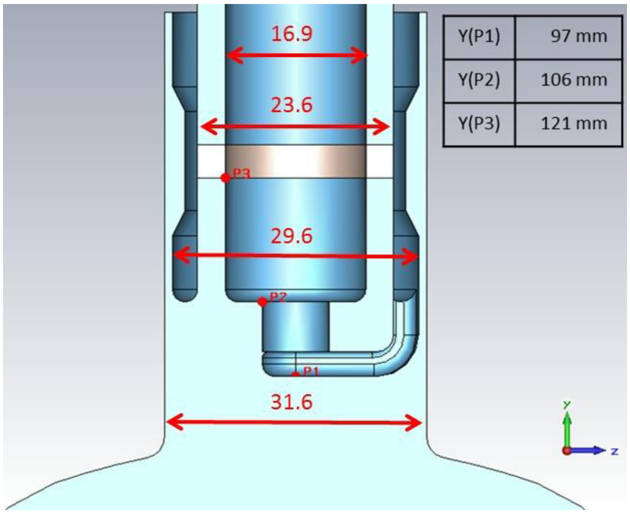

Figure 7: Multipacting model of the RF coupler.

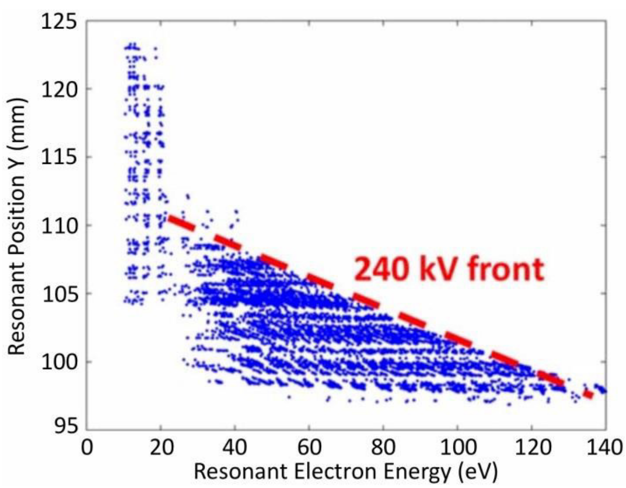

Figure 8: Electron resonance position v. resonant energy.

INSTALLATION AND OPERATION

A total of eight RF couplers were fabricated, with no ceramic window braze failures. A photo of a completed coupler after TiN coating is shown in Fig. 9. During installation, the correct coupling is set by clocking the coupler bodies based on low power RF measurements. Four TOMCO 2.5 kW, 1.3 GHz solid-state amplifiers deliver RF power to the couplers through semi-rigid 1-5/8" coax lines. A photo of the couplers installed in the APEX buncher cavity is provided in Fig. 10. The buncher system has been run reliably at full power on a regular basis with no issues.

SUMMARY

A novel design for a coaxial resonant loop coupler with an integrated ceramic window and a matching section in the body of the coupler has been developed for the Advanced Photo-injector Experiment at LBNL. The four couplers deliver 2.5 kW each to a two-cell, 240 kV, 1.3 GHz CW buncher cavity. A set of couplers has been successfully fabricated and tested to full power on the APEX system.

Figure 9: Photo of a coupler assembly after TiN coating.

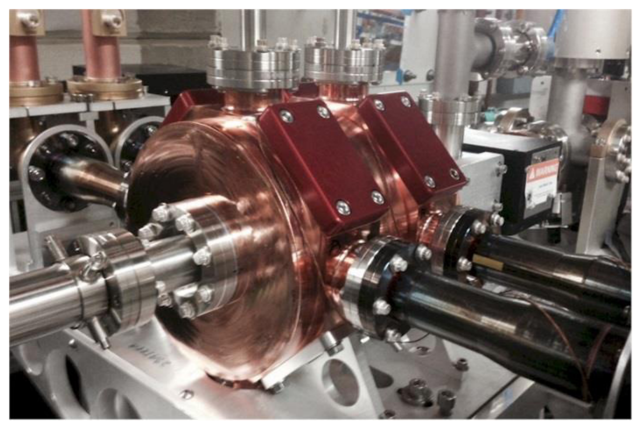

Figure 10: Installed buncher cavity and couplers in APEX.

ACKNOWLEDGMENT

The authors would like to acknowledge the technical expertise of the engineers at California Brazing in Newark, CA, USA for developing and perfecting the ceramic window brazing technique.

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