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TEMPERATURE STABILITY IN CRYOGENIC BRIGHTNESS-OPTIMIZED RADIOFREQUENCY GUN (CYBORG)*

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Abstract

X-ray free electron lasers (XFEL) and other x-ray producing light sources are large, costly to maintain, and inaccessible due to minimal supply and high demand. In addition, concepts for future electron colliders benefit from cost reduction size is reduced through normal conducting RF cavities are operated at very high gradients. It is advantageous then to consider miniaturizing electron linacs through a variety of means. We intend to increase beam brightness from the photoinjector via high gradient operation (>120 MV/m) and cryogenic temperature operation at the cathode (<77K). To this end, we have fabricated a new 0.5 cell CrYogenic Brightness-Optimized Radiofrequency Gun (CYBGORG). CYBORG serves three functions: a stepping stone to a higher gradient cryogenic photoinjector for an ultra-compact XFEL (UCXFEL); a prototype for infrastructure development useful for concepts such as the Cool Copper Collider (C^3); and a test bed for cathode studies in a heretofore unexplored regime of cryogenic and very high gradient regime relevant for the National Science Foundation Center for Bright Beams. We present here commissioning status of CYBORG and the associated beamline focusing in particular on C-band RF power development and thermal balancing of the gun in the cryogenic environment.

INTRODUCTION

At UCLA, we have commissioned a new laboratory for Multi-Objective Testing of High Gradient RF Accelerators (MOTHRA). The facility is currently functionally being used for cryogenic and Cband RF development and other basic science research. The main feature of the facility will be the soon to be commissioned CYBORG (Cryogenic Brightness Optimized RF Gun) beamline. The compact cryogenic cband beamline will serve three main functions: an infrastructure development platform for future normal conducting cryogenic accelerators like C^3 [1]; a stepping stone to an ultra high gradient ultra-compact xfel photoinjector [2, 3]; and as a test bed for low temperature cathode studies for the Center for Bright Beams (CBB) [4].

The primary motivational case we will consider here is as a test environment for advancing the goals of the CBB in the pursuit of higher brightness photocathodes. The objectives are to develop primarily a way to measure cathodes in extreme environment of cryogenic temperature and very high gradient fields [5].

The practical implementation of this concept is hindered by a number of complications. For these proceedings we will focus on the progress towards full commissioning of the CYBORG beamline through the context of temperature dependent considerations including balancing of the thermal load including the impact of the conduction cooling and pulsed RF heating. The necessity of this discussion cannot be understated as this is the will be one of the first conduction cooled cryogenic normal conducting RF cavity based accelerators.

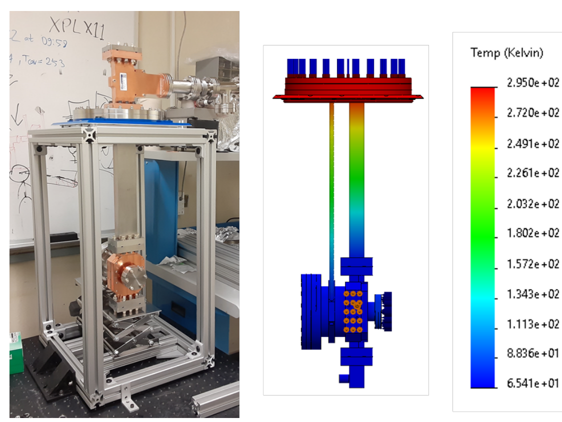

Figure 1: Assembled CYBORG drop down section to left and thermal simulations of heat leaks and conduction cooling through the gun on the right. Note the support struts were found to be be necessary during initial commissioning thus significantly reducing the heat leaks expected.

PHOTOGUN HEATING

We begin by considering the main sources of heating of the gun: heat leaks from room temperature penetrations out of the cryostat and the pulsed RF heating from the driving power. The gun is a reentrant Cband half-cell cavity design based on the Tantawi style distributed coupling. More in depth information on cavity shape, simulations, and design parameters can be found in previous publications [6, 7].

Fig. 1 shows a photo of the assembled in-vacuum CYBORG drop down section which has since been placed in the large volume vacuum chamber which serves as the cryostat. The gun is thermally isolated from room temperature via a stainless steel waveguide which is visible in the photo to the left. To the right in the figure we have a thermal simu-

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lation showing the expected temperature gradient using the specifications of the CH110LT cryocooler that we use for cooling. We note that in the thermal simulations there exist additional heat leaks totaling about 5-10 W from additional support struts parallel to the steel waveguide.

Mechanical analysis was performed to assess the additional torque produced by removing these supports. It was determined that their presence is not immediately necessary so we have consequently not included them in the existing gun drop-down section. In doing so we should be able to cool the gun low than the originally simulated 65 K, setting the new realizable goal around 55 K. The removal of the support struts adds a small angled misalignment to the gun due to the increased torque from the longitudinal asymmetry of the gun leading to an off axis center of mass. The total deflection amount is however smaller than the expected motion due to thermal contraction of the steel waveguide so it is likely not a major issue.

RF Power Generation

The klystron powering CYBORG is a Cband Thales tube which we mounted into an Sband XK5 klystron tank via custom couplers. It has been commissioned to single megawatt output power levels using a custom made modulator and pulse forming network (PFN). Previous discussion in earlier publications established the possible need for cathode backplane modifications to tune the cavity due to the presence of excess braze material during fabrication [8].

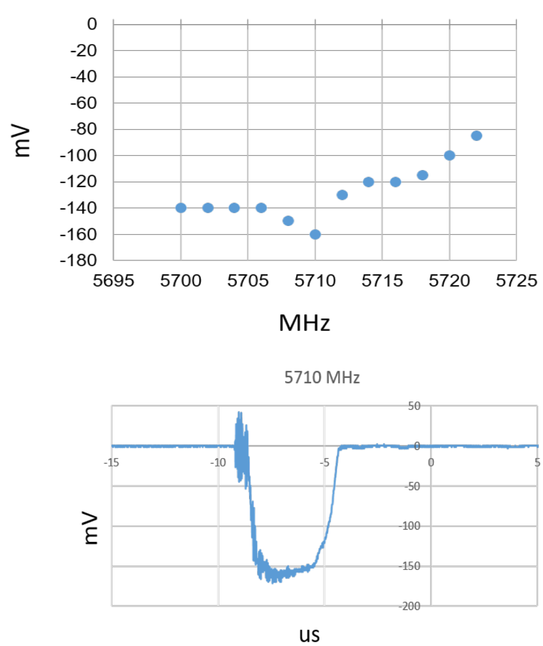

Figure 2: C-band klystron output from Thales tube with XK5 pulse tank and custom PFN. 5710 MHz is the central frequency

Before manufacturing a new cathode to tune the cavity correctly we performed a bandwidth measurement. From these results we showed that at least for the near term single MW testing the existing back plane would be sufficient. The results of the bandwidth measurements and one example klystron pulse at the central frequency of 5710 MHz can be seen in Fig. 2. The moderately wide bandwidth should allow CYBORG to operate in the full range of interest between 295 and 60K albeit at somewhat reduced power at the lower temperatures.

CRYOGENIC COOLING

The second half of the equation for temperature stability is the question of cooling. Conduction cooling via a cryocooler is our chosen method of cooling for a number of reasons including cost effectiveness at the smaller scale of a single test gun. In addition, we must consider insulation for radiation and convection.

CYBORG is cooled via high thermal conductance braids manufactured by Techapps. We have further designed several cryocooler coupling pieces for maximum versatility as this project is new and details of the design can change through our exploratory commissioning work. In addition, several designs for alternative for cryocooler connections were designed and evaluated. These studies are covered more extensively in an associated proceedings contribution. Black body radiation is shielded from the gun by multi layer insulation (MLI). Fourteen layers of alternating aluminized mylar sheets and thermal insulators are wrapped around the cryocooler, gun, and copper coupler pieces. They are maintained as isotherms with the cold samples they shield.

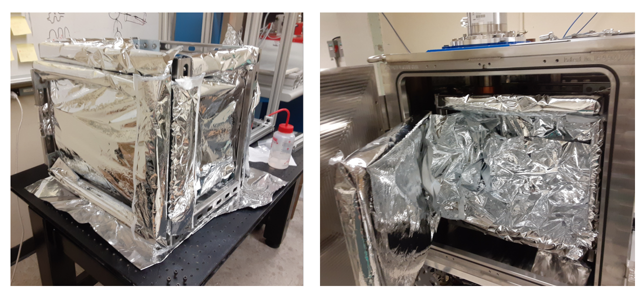

Figure 3: Image of MLI shielding layer tested for extra shielding in case gun thermal break waveguide section heat leack is too great.

In an attempt to future proof our setup, we considered the necessity of a second cryocooler to also cool an additional (slightly warmer) outer shielding. The idea of this shielding would that it could be placed in the cryostat but not used unless the gun needed extra cooling due to increase RF rep rates in future measurements. Photos of the outer shielding design that was created are shown in Fig. 3.

Initial implementation of the colder outer shielding where shown to be superfluous in the case of the simple test load measurements and while cooling pillboxes (as expected). More about the scientific merit of these pillbox experiments is detailed in a companion proceedings contribution. Pragmatically speaking however, the shield was not spaced far enough from the inner shield in the final gun configuration

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to prevent detrimental heat leaks preventing reaching target low temperatures. As a result, the outer shielding layer will likely not be used in the near term CYBORG experiments.

An additional relevant consideration for our design is the evaluation of transient RF heating which could damage the test cathodes or ruin the stability of the cathodes temperature at low T. The question of temperature gradients across the cavity must be addressed and continual examination is ongoing.

CATHODE COUPLING

As a final consideration, we must address the need for replaceable cathodes in CYBORG and the relationship to thermal balancing. The INFN style cathode minipucks are a common template for replaceable high brightness cathodes and are used in multiple photoinjectors [9]. We want to test them on the our beamline so we must consider their integration in a cryogenic gun rather than the room temperature cavities they are more often used with. We have used the FERMI gun style backplane to allow for maximum versaitility in coupling designs [10, 11]. Press fits and RF springs become unpredictable at cryogenic temperatures as unlike materials contract at different rates. Instead we propose and interference fit wherein a precision machined copper backplane contracts around the molybdenum INFN minipuck hopefully creating a useable RF seal.

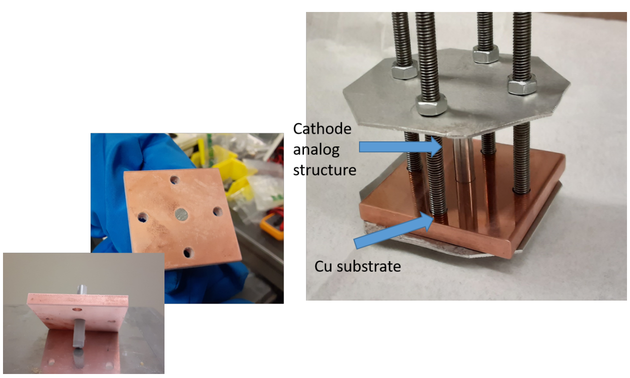

Figure 4: Photos of cathode puck integration seal testing for CYBORG. Initial proof of principle testing was performed with liquid nitrogen and is currently being fitted for cryocooler testing to lower temperatures.

In order to test the validity of this concept we have created an an initial analog piece shown in Fig. 4. It is a simple jig consisting of a copper plate with a hole in which an analog molybdenum rod can be inserted at room temperature and cooled to cryogenic temperatures in order to create the seal. Mechanically the seal has been proven to be effective under significant stress. These tests were only at 77K so colder cryocooler trials are being actively studied in our cryogenic materials testing setup [12]. The main question for the mechanical sealing is whether a seal can be made only with only elastic deformation for the sake of re usability. Later tests will involve measuring pillbox cavity quality factors with the molybdenum rod inserted in order to evaluate the quality of the RF seal.

FUTURE DIRECTIONS

The RF and cryogenic subsystems are nearing full completion. CYBORG is fully housed in its long term cryostat and static load cooling with the gun can begin soon. Dark current measurements as a function of the full range of operational temperature from 295K to below 77K will be made in the coming months as soon as additional radiation shielding is added to the lab bunker space. Cathode integration tests will continue with the addition of RF seal testing in cryogenic pillboxes.

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