DESIGN AND IMPLEMENTATION OF CESRTA SUPERCONDUCTING WIGGLER BEAMPIPES WITH THIN RETARDING FIELD ANALYZERS*

Y. Li#, M. Billing, S. Greenwald, T. O'Connell, M. Palmer, J. Sikora, Eric Smith, K. Smolenski, CLASSE, Cornell University, Ithaca, NY 14853
J. Corlett, R. Kraft, D. Munson, D. Plate, A. Rawlins, Berkeley National Lab, Berkeley, CA 94720
M. Pivi, SLAC, Menlo Park, CA 94025
K. Kanazawa, Y. Suetsugu, KEK Accelerator Laboratory, Tsukuba, Japan

Abstract

Wiggler magnets are one of the key components in the ILC Damping Ring. It is critical to the ILCDR GDE to understand electron cloud (EC) growth and patterns, and to develop EC suppression techniques in the wiggler beampipes. The CESR-c superconducting wigglers (SCWs), closely matching the parameters of the ILCDR wigglers, serve as unique testing vehicles. As part of the CesrTA project, we replaced the copper beampipes of two SCWs with EC diagnostic beampipes, where one of the beampipes is uncoated and the second is coated with a thin TiN film. Each of the EC diagnostic beampipes is equipped with three retarding field analyzers (RFAs) at strategic longitudinal locations in the wiggler field. Each of the RFAs has 12-fold segmentation to measure the horizontal EC density distribution. To maintain sufficient vertical beam aperture and to fit within the SCW warm bore, a thin style of RFA (with a thickness of 2.5 mm) has been developed and deployed. These SCWs with RFA-equipped beampipe have been installed and successfully operated in the re-configured CesrTA vacuum system. This paper describes the design and the construction of the RFA-equipped SCW beampipes and operational experience.

INTRODUCTION

Electron cloud (EC) buildup in beampipes prevents achievement of desired ultralow beam emittance in the International Linear Collider (ILC) Damping Ring (DR). As one of the key components in ILC DR, understanding of EC growth and patterns, and evaluation of various EC suppression techniques in wiggler beampipes is critical to the ILC DR Globe Design Effort (GDE). We describe in the paper a unique design and implementation of thin retarding field analyzers (RFAs) in CESR-c wigglers, as a part of CesrTA program [1].

RFA WIGGLER CHAMBER DESIGN

CESR-c wigglers [2] are 8-pole superferric magnets with main period of 40-cm and trimming end poles. Closely matching the ILC DR wiggler requirements, these SCWs are idea testing vehicles.

Simulations predicted distinct longitudinal and transverse EC density distributions in wiggler beampipes. The design goal is to place RFAs at strategic longitudinal locations in the wiggler magnetic field to measure transverse EC density distributions. As shown in Fig 1, RFAs are implemented at three locations, RFA#1 at boundary between two center poles, RFA #2 at center of pole and RFA #3 at 'edge' of pole.

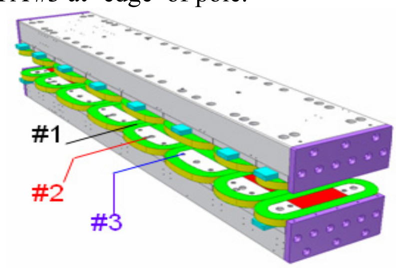

Figure 1. Longitudinal locations of three RFAs with respect to the wiggler magnet poles.

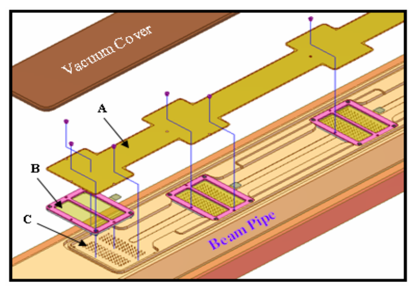

Figure 2. Structure of thin RFA consists of (A) electron collector, (B) retarding grid and (C) electron transmission holes on top of beam pipe.

The structure of the RFAs is illustrated in an exploded view in Fig. 2. Electrons in the beam pipe drift through transmission holes to the detector. All holes (240 per RFA!) have a diameter of 0.75mm, about 1/3 of wall thickness, to avoid radio-frequency interference to the RFA signals. The retarding grids are made of photo-chemical etched 0.15mm thick stainless mesh, with an optical transparency of 38%. By nesting in alumina frames, the grids are spaced 1-mm from the grounded beam pipe top and from the RFA collector, respectively, sufficient to withhold required 500 V maximum grid bias potentials. The transmission holes are patterned into 12 groups, matching the detector pads on the flexible thin detector (see below) for measuring EC transverse distributions at three RFA locations.

It was very challenging to replace the existing beampipe in the CESR-c wiggler with the RFA beampipe without dissembling of the wiggler magnet and the associated cryostat structure. To create vertical space for the RFA components, the copper extrusion beampipe

* Work supported by the National Science Foundation, the US Department of Energy, and the Japan/US Cooperation Program
# YL67@cornell.edu

inner height had to be reduced from 50.0mm to 43.5mm, in order to for the RFA beam pipe to clear the wiggler magnet warm bore. This was accomplished by splitting the existing copper extrusion into two halves to reduce the side height. After all the RFA feature machining, the two halves were re-joined via electron-beam welding.

As shown in Fig.3, the total available vertical space for the RFA components is only 2.5mm, of which ~2.2mm was occupied by the grid structures. We elected to use flexible printed circuit as the RFA electron collector. The flexible circuit is made of 0.15mm Kapton® ribbon with copper thin films clad on both sides. The overall circuit thickness is ~0.2 mm. The front side of the circuit (facing the grids) is etched to form three RFA patches (each with 12 collector pads), electric connection lines for all 3×12 collector pads, and the termination soldering pads, as depicted in Fig.4. The back side of the collector circuit serves as the signal shield ground. The electric design considerations for the flexible circuit will be described in detail in [3] in this proceeding.

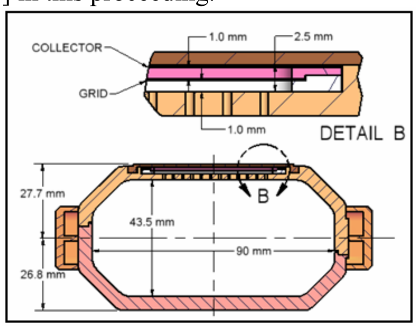

Figure 3. Cross-section of the RFA wiggler beampipe at one of the RFA locations.

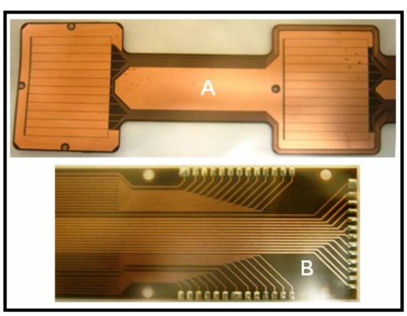

Figure 4. Sections of RFA flexible circuit showing (A) collector pads for RFA #1 and #2; (B) Electric lead soldering pads for three RFAs.

BEAM CHAMBER CONSTRUCTION

Many steps of heavy welding are required in the RFA wiggler chamber construction. We have designed the chamber in such way to have all the welding that may overheat the portions of the beampipe near the RFA flexible circuit done prior to the installation of the Kapton® based circuit, which is rated to maximum temperature of 220°C. To avoid heating damage to the flexible circuit, a 'duck-under' channel was created beneath a stainless steel disk that later will be welded to the wiggler insulation vacuum vessel, as shown in Fig 5, in the design. During the beampipe construction, all vacuum welds, except the final RFA vacuum cover, can be done, and leak checked without presence of the flexible circuit. With the duck-under channel, one can feed through the flexible circuit from the RFA portion of the beampipe (inside wiggler insulation vacuum) to the RFA electric connection port.

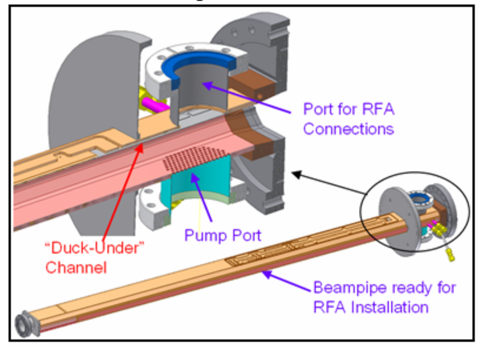

Figure 5. Beampipe at a state ready for RFA component installation. A detailed cut-out view shows a duck-under channel for feeding through the flexible circuit.

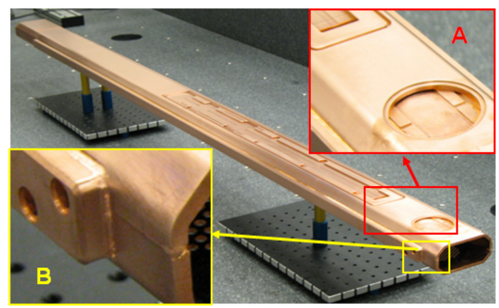

Figure 6. Beampipe after EB-welding (insert B). The 'duck-under' channel is visible in insert A.

The beampipe fabrication started by splitting the fully annealed OFE copper extrusion into two halves. The copper extrusions are the type used for PEP II LER Quad beampipe, as well as for the original CESR-c SCW beampipe. All RFA-related features on the top half were machined at LBNL's machine shop with CNC machinery, including RFA grid pockets, 720 electron transmission holes, duck-under channel, and all the weld-prep features. After cleaning, a cover plate was E-beam welded under the top halve to form the duck-under channel. Then the two finished halves were joined together using a CNC E-beam welder, with ~1 mm E-beam penetration at seams. After passing leak checking, two side cooling channels were also E-beam welded to the chamber. Figure 6 shows the chamber after e-beam welding. Measurements using NC coordinate machine found that amount of distortion of the EB-welded beampipe is well within design tolerances. Subsequently, all other vacuum components (including end flanges and transitions, RFA connection port and vacuum pumping port) were manually welded to the beampipes with tungsten inert gas (TIG) welding in argon environment to avoid oxidation of the copper beampipes. A temporary flange was welded to the end of the beampipe away from the RFA locations to facilitate initial leak checking, bakeout and coating. At this stage, all the UHV joints of the beampipes, with exception of the top RFA vacuum cover plate, were finished (as shown in Fig.5) and were ready for the final RFA components assembly.

To ensure required UHV quality, both beampipes were baked to 150°C under vacuum. After the bakeout, one of the two RFA beampipes produced at LBNL was coated with TiN thin film in the beampipe interior by a SLAC team. As a part of EC diagnostic and suppression studies at CesrTA, the effectiveness of EC suppression by TiN coating can be evaluated in wiggler magnetic field upon final RFA installation, by comparing with the RFA wiggler chamber with bare copper surfaces.

RFA INSTALLATION

The two partially finished wiggler beampipes at LBNL were shipped to Cornell for final RFA component assembling and integration to the SC wiggler assemblies.

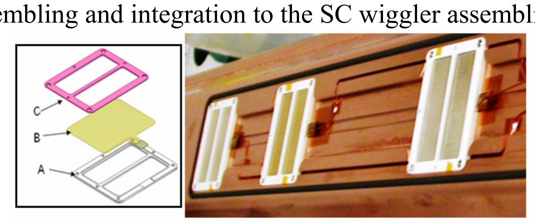

Figure 7. Three RFA grids installed on top of the RFA transmission holes. An exploded view of the grid shows ceramic base (A) and cap (C), and grid mesh (B).

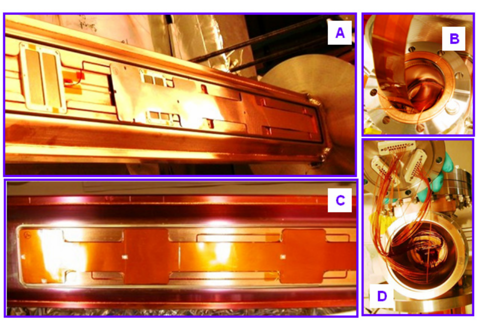

Figure 8. (A)Flexible circuit through duck-under channel, with (B) soldering pad end at RFA connection port. (C)After attaching all connection leads, the circuit was precisely located on top of the grids frames by five ceramic head pins. (D)All 45 leads connected to three 15-pin D-type feedthroughs on a 4-5/8" flange.

The stainless steel meshes used for retarding grids of the RFAs are completely nested in a precisely machined ceramic base frame and a ceramic cap (Fig.7) to avoid leakage current at bias voltages up to 500V. The meshes were coated with ~0.3µm thick gold film on the side facing the electron emission holes to reduce secondary electron emission. The nested grids were then fastened onto the beampipe with specially machined #2-56 screws with very thin heads (<0.2 mm in height). To simplify the RFA characterization, all three grids were individually connected.

Kapton® ribbon based flexible circuit (fabricated by Cirexx International) was used as the electron collectors due to very limited space. As it is a part of CESR vacuum, steps were taken to prepare the flexible collector circuit before it is used on the RFA beampipe. Vacuum outgassing tests confirmed UHV compatibility of the RFA circuits. After many failed attempts in using gold-tin soldering alloy (an UHV-compatible alloy) for the RFA electric connections, we resorted to more commonly used SnPb Flux cored solder. After pre-tinning soldering pads on the flexible circuits, the flexible circuits were ultrasonically cleaned with solvent and de-ionized water to remove residual flux and then vacuum baked to 180°C. Outgassing and residual gas compositions of the circuits were found to be acceptable for UHV application. Both sides of the circuits were masked with UHV-compatible Kapton® tapes with silicone adhesives, with only the RFA collector pads exposed. Sequence of the installation of the flexible circuit is shown in Fig 8. After thorough electric checks, the RFA installation was finished by E-beam welding of OFE copper RFA vacuum cover. The finished RFA beampipes were baked to 150°C before final insertion to the wiggler magnet assemblies.

With careful planning, the original beampipe was safely retrieved from the CESR-c SCW while keeping magnet and cryogenic systems intact. After machining off temporary flanged end, the RFA beampipe was inserted in the wiggler warm-bore, and precisely positioned with respect to the wiggler magnet by survey. Extreme care was taken in the final welding stages (including final beampipe flange and seals to the wiggler insulation vacuum vessel) to prevent overheating of the RFA components.

CONCLUSION REMARKS

With collaboration of Cornell, LBNL, SLAC and KEK laboratories, two RFA wiggler beampipes were successfully constructed and integrated to the CESR-c SC wigglers. Both RFA wigglers were performed well upon installation at CESR in October 2008.

Construction of two more RFA wiggler beampipes is underway to investigate other EC suppression techniques, with continuing collaboration among the four institutes. One of the beampipes will have triangular-shaped grooves on the bottom beampipe, while the other beampipe a clearing electrode.

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