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Cornell Electron Storage Ring phase-III interaction region vacuum chamber

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Two 115 in. long copper ultrahigh vacuum (UHV) chambers for the Cornell Electron Storage Ring (CESR) interaction region were fabricated. These chambers are a part of the phase-III upgrade project for the CESR storage ring. They incorporate several novel features including a remotely engaging differentially pumped Viton O ring sealed UHV flange, two rf shielded bellows joints, and inner stepped masking for synchrotron radiation. The fabrication of these chambers incorporates multistage electron beam welding to maintain the strict tolerance required for installation through superconducting and permanent quadrupole magnets. Before final welding, a series of electron beam welding setup tests were done to work out a welding procedure for optimizing the welding parameters and avoiding contamination in the weld zone. In this article we will describe the design, fabrication, welding, leak checking, and final UHV performance testing of these chambers.

I. INTRODUCTION

The Cornell Electron Storage Ring (CESR) is a single-ring symmetric $e^+ e^-$ collider operating on and near the $\gamma(4S)$ resonance ($E\cong5.3$ GeV). The beams collide with a small horizontal crossing angle (±2 mrad) at a single interaction point where the CLEO detector is located. CESR has achieved a peak luminosity of 1.2 X 10^{33} cm $^{-2}$ s $^{-1}$ and a peak total beam current of 750 mA.

An aggressive upgrade program (phase-III upgrade) to increase the luminosity of CESR is underway, which could increase the luminosity to 2 X 10^{33} cm^{-2} s^{-1}.[1,2] The luminosity gain can be realized with very close focusing at the interaction point (IP). The phase-III interaction region (IR) optics are optimized to move all the IR focusing elements as close to the IP as possible. It is a combination of short focal length and large physical aperture consisting of two pairs of high-gradient superconducting (SC) quadrupoles and a pair of short permanent quadrupoles magnets (PMs).[3] Four newly installed superconducting rf cavities will support a beam current of 1 A at a bunch length of 13 mm. The new insertion optics and the vacuum system components have been constructed and are to be installed into the CESR ring in the summer of 2001. The layout of the IR chambers with the magnets is shown in Fig. 1.

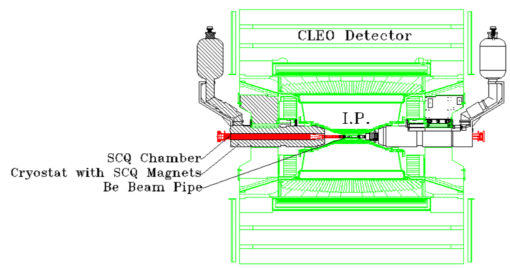

FIG.1. CESR phase-III interaction region layout.

The vacuum chamber (SCQ chamber) through the SC and PM magnets is a 115 in. long tapered pipe made of OFE CD10100 copper, which bridges the large aperture ‘‘near IR’’ pipes to the center 2 cm radius beryllium beam pipe. The center detector beam pipe (manufactured by Brush Wellman–Electrofusion Products) is a double-walled beryllium beam pipe with a gold coating on the inner wall surface.[4,5] A novel remotely engaged ultrahigh vacuum (UHV) flange (a so called magic flange) is incorporated, which greatly facilitates the installation and assembly of the IR components.[6] The seal on this flange is made with differentially pumped Viton O rings. IR pumping is accomplished by distributed large plenums with massive titanium sublimation pumps [7-9] to provide the necessary pumping speed and capacity to minimize the detector experimental backgrounds from beam gas scattering. With this pumping system the pressure in the IR will be maintained in the low 10^{-9} Torr range at full 1 A beam current, despite the high gas loads produced by the intense flux of synchrotron radiation (SR).

II. SCQ VACUUM CHAMBER DESIGN

A. Design criteria

The design criteria include UHV compatibility, SR masking, integrity with magnets and strict mechanical tolerance, proper cooling, and incorporation of beam instrumentation.

CD10100 oxygen free electronic conductivity copper is chosen for the chamber material for its high electrical and thermal conductivity and low gas desorption coefficient.

It is very critical to minimize direct and scattered SR hitting the CLEO detector. The chamber's inner surface is machined with multiple, sharp tipped masks whose profile is carefully designed so that the scattered SR from these surfaces will not be directly visible to the center detector beryllium beam pipe.

The vacuum chambers must allow maximum beam aperture and transverse adjustment of the SC quadrupoles for optics optimization. The chamber must stay clear of the magnets' warm-bore inner diameter. The defined maximum permissible extent of the vacuum chamber requires the entire 115 in. long chamber assembly's out-of-round and straightness tolerances be less than 0.020 in.

The SR power absorbed by the masks can be removed by rectangular cooling tubes which are glued onto the vacuum chamber's external channels with thermal conductive metal-doped epoxy. The coolant is PF-200. It is estimated that 1 kW of power will be dissipated in the chamber walls.

Beam position monitoring (BPM) inside the SCQ magnets is critical for beam dynamic diagnosis and tuning. Each chamber has a set of BPM pickup electrodes 67 cm from the IP.

The SCQ vacuum chamber structure is shown in Fig. 2.

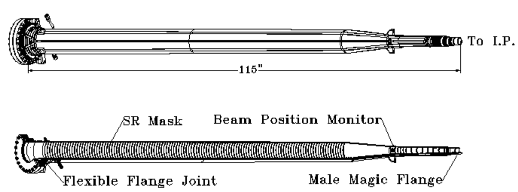

FIG. 2. SCQ vacuum chamber structure.

B. SCQ chamber components

Due to its length and complexity, the chamber was first divided into four sections for machining and then electron beam (EB) welded together, with the male magic flange (MMF) and flexible flange joint (FFJ) welded at the ends. The chamber components are shown in Fig. 3.

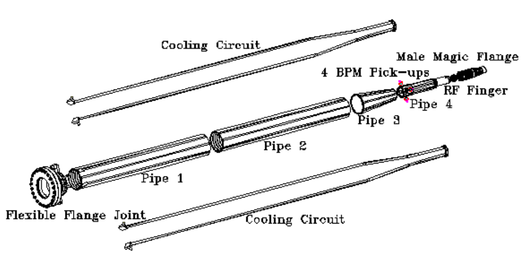

FIG. 3. SCQ vacuum chamber components.

The subassembly at the chamber's small end is the so called MMF, which can be engaged into the female magic flange of the center detector beryllium beam pipe to complete UHV flange joining by remote operation. The magic flange uses a series of shaft radial seals with differentially pumped Viton O rings (including one which provides the radio-frequency seal) in order to eliminate the bulk of the gas load which would arise from permeation through Viton O-rings. A compact gear and nut assembly provides the closing and opening forces in the very small space allowed. The chamber's outboard end is held on the cryostat by a gimbaled clamp and the chamber is movable during operation in order to allow SCQ alignment without the losing beam aperture. The front bellows provides a ±6 mrad angular and a ±2 mm longitudinal movement range. The bellows also ensures the safety of the delicate center Be beam pipe. A rf shield contact finger ring (Be–Cu alloy 25 C17200) Bridges the gap between the neighboring chambers inside the convoluted bellows to make a continuous geometry and electrical conduction path in order to allow image current to flow smoothly on the beam pipe's inner surface and to reduce the excitation of higher order modes (HOMs) in the bellow's cavity. Details of the magic flange joint are shown in Fig. 4.

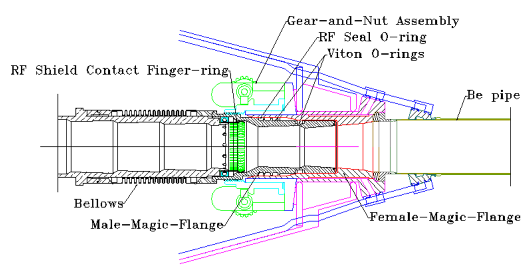

FIG. 4. Magic flange joint.

A rf-shielded bellows flexible flange joint subassembly is welded at the far end of the chamber from the IR. A detailed drawing of it is shown in Fig. 5. The bellows absorbs thermal expansion and contraction of the beam pipes during beam operation. It also provides the necessary working space for installing beam pipes as well as some tolerance for misalignment of the beam pipes. A rf shield contact finger strip (again Be–Cu alloy 25 C17200) is installed between the gap of the neighboring chambers.

Each BPM consists of four button style pickups welded into the vacuum chamber, as shown in Fig. 6. The buttons are slightly recessed from the chamber wall, and placed 45° relative to the horizontal plane to avoid direct synchrotron

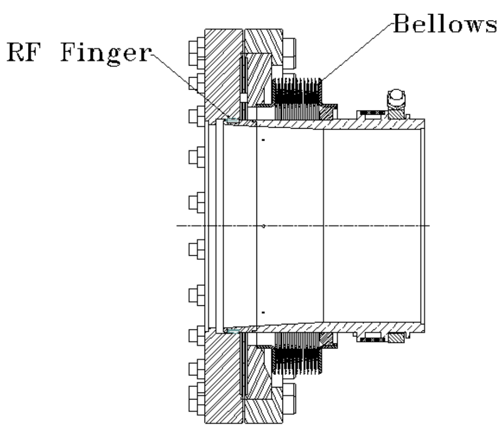

FIG. 5. Flexible flange joint.

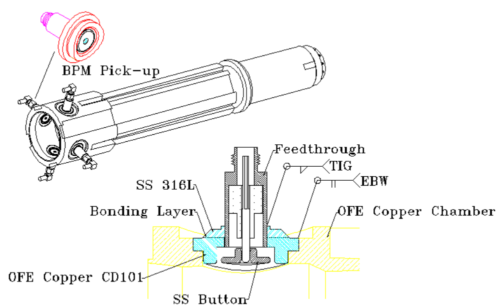

FIG. 6. Beam position monitor.

radiation. The feedthrough housing is made of stainless (SS)-Cu explosion-bonded material to reliably weld the stainless steel feedthrough sleeve into the copper chamber. The bonded material was thermal shock tested by baking to 200 °C followed by immersing into liquid nitrogen and then leak checked.

III. MANUFACTURE

The four copper beam pipes, MMF, FFJ, and BPM sub-assemblies are welded using an EB welder. EB welding can minimize the heat affected zone, minimizing distortion and shrinkage, and the high vacuum welding environment prevents copper from oxidizing during welding.

There are several cooling channels cut into the outer surface of the chamber and material must be machined off several welds after welding to make the external cooling channels continuous through these joints. The original wall thickness at the welds is only 0.26–0.32 in. and 0.13–0.14 in. must be cut off, shown in Fig. 7. This requires deep weld penetration so that the remaining part (only 0.13–0.18 in.) of the weld can be UHV tight.

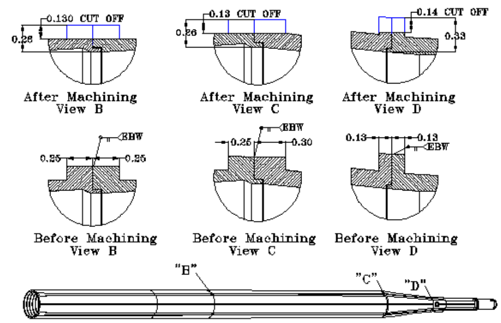

FIG. 7. Weld joints structure.

The welding of the 115 in. long beam pipe assembly requires that the EB weld vacuum chamber be long enough to accommodate the entire pipe. The EB welding was performed in the VX-138 EB welder (weld chamber interior dimensions: 138 in. X 108 in. X 107 in.) at Sciaky Inc. on a contract basis.

A. EB welding setup tests

In order to keep the welds UHV tight after machining and to meet the required straightness tolerance, much attention has been paid to the EB welding/machining /straightening procedure to ensure success. The basic EB welding (EBW) parameters such as accelerating voltage, beam current, welding (beam spot travel) speed and focusing current all affect the final beam spot size and weld penetration depth. Each joint has a different outer diameter (o.d.) dimension and wall thickness and requires its own set of welding parameters. The parameters were developed on various short copper tubes of the same o.d. and wall thickness as the real joint parts.

The goal of EBW tests was to work out a welding procedure for

(1) optimizing the best weld penetration to ensure an UHV tight weld after channel cuts while avoiding any over-penetration spatter on the inner surface of the chamber;
(2) keeping an even penetration and weld zone to avoid any out-of-round distortion and asymmetric shrinking at the weld, since a slight distortion at the weld region may cause a straightness error for such a long vacuum chamber;
(3) keeping weld beads as flat as possible, since the clearance between the vacuum chamber and the magnets' inner diameter (i.d.) is only 0.055 in.;
(4) checking how much the previously machined

cooling channels (0.585 width X 0.130 depth) near the welding joint affect the weld heat sink and therefore vary the weld penetration depth along the azimuth.

The setup welds were cross cut, polished, etched and examined to determine the optimum welding parameters for each joint (shown in Fig. 8). Some of the setup welds were also leak checked before and after 0.130 in. was machined off at the welds.

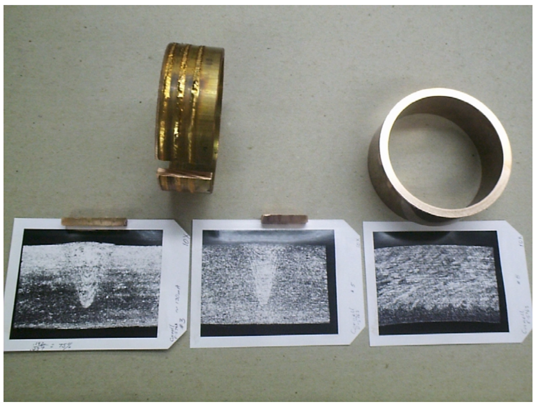

FIG. 8. E-beam welding setup tests.

B. Cleaning procedure

The primary purpose of cleaning is to assure a low outgassing rate from the material under vacuum and assure TIG/brazing/EB welding quality. After fabrication all parts were degreased by washing in detergent followed by polishing with several different acids to remove oxide, according to the type and size of the material.

(1) Citranox chemical cleaning of long copper pipes 1 and 2;
preheated citric acid (1 1/4 to 2 1/2 oz per gallon) To 75 °C;
soaked pipes in acid for 2 h;
rinsed with distilled water;
rinsed with isopropyl;
blown dry with pure N_2 ;
wrapped the pipe open ends with clean aluminum foil;
bagged and sealed the pipe with pure N_2 until the assembling EB welding.
(2) Etching of copper pipes 3 and 4;
immersed degreased pipes in solution (35% de-ionized H_2O, 45% HNO_2 , 20% H_3PO_4) for 2 min;
rinsed with distilled water;
rinsed with isopropyl;
blown dry with pure N_2 ;
wrapped the pipe open ends with clean aluminum foil;
bagged and sealed the pipe with pure N_2 until the assembling EB welding.
(3) Ultrasonic cleaning of the remaining small components;
ultrasonic cleaning in isopropyl bath for 10 min;
blown dry with pure N_2 ;
bagged and sealed the parts with pure N_2 until the assembling EB welding.

During the fabrication of subassemblies of BPM, MMF and FFJ, leak checking was performed after each brazing or TIG welding to ensure the part was UHV tight before going to the next step in fabrication. During leak checking, vacuum grease (Fomblin, Varian Inc.) was applied on the sealing rubber sheet to ensure high leak rate sensitivity. However, the EB welding setup tests showed that a trace of Fomblin vacuum grease residue on the copper edge may cause many pores in the weld zone. These could be potential leaks, especially after the weld is machined off some material. Therefore some Fomblin cleaning/removing tests were done with 10 pairs of copper coupons (0.25 in. X 1.0 in. X 1.0 in.). These coupons were first coated with Fomblin and then cleaned with different solvents (such as acetone, methanol, freon and Fomblin perfluorosolv PFS-1) or different cleaning procedures (such as soaking, wiping, ultrasonic cleaning) prior to EB welding. After EB welding, they were cut at weld joints and the cross sections were examined under a microscope with 25 X magnification. The results showed that the best solvent to remove Fomblin film from the copper surface was acetone or methanol. Acetone effectively dissolves heavy organics but tends to leave residues and is chemically unstable on surfaces in vacuum. Methanol has the advantage of good stability in vacuum plus the capability to remove any small amounts of acetone that may remain from the previous acetone wipe. Therefore, the best procedure is acetone wiping followed by two 10 min ultrasonic cleanings in a methanol bath. Fresh methanol was used for each methanol bath cleaning.

C. EB welding

During welding the pipes to be welded were mounted on a head and tail stock under the EB welder gun and the entire pipe was rotated. For each weld joint a set of tooling was made to hold the two joined pipes with zero gap and to adapt the pipes to the EB welder head and tail stock. The tooling varied in size and geometry for each joint. Great effort was made to ensure the tooling and pipes tightly fit each other, with only a 0.001–0.002 in. tolerance. This was crucial to minimize welding distortion of the long assembly.

D. Straightening and machining

The chamber was mechanically straightened to within 0.010 in. concentricity after welding of the two long pipes. The straightening was accomplished by using a hydraulic press on the chamber every 90° in azimuth and was done several turns in stages while checking the out-of-round each turn. Because the remaining welds after straightening have very small distortion of the overall straightness, no more straightening had to be done after the final welding.

Machining of cooling channels at EBW joints B, C, and D was performed on a NC controlled vertical boring mill. No lubricant was applied during machining.

IV. QUALITY CONTROL

A. Leak check

After each welding or machining operation, the assembly was pumped down and leak checked with a Varian 960D dry leak detector. All welds were leak tight the first time they were pumped.

A final leak check was performed by connecting the two chambers to an oil free turbopump station which was equipped with a residual gas analyzer (RGA) and a calibrated helium leak. In order to drive out the moisture adsorbed on the chamber wall and increase the leak check sensitivity, the chambers were baked to 140–150 °C for 45 h. No leak was found at a helium leak rate of 2×10^{-9} Torr l s^{-1}.

B. UHV vacuum performance

After bakeout, the chamber specific outgassing rate was measured to be about 5×10^{-13} Torr l s^{-1} cm^{-2} , obtained with the rising pressure method. The RGA spectra indicated that the residual gases present in the chambers were H_2 (50%), H_2O (30%), CO (6%) and CH_4 (12%) with negligible heavier mass species. It showed that the chambers were remarkably clean, with negligible hydrocarbon contamination. It also confirmed that the chambers were UHV tight, since there were negligible O_2 and N_2 traces in the RGA spectra.

B. Mechanical inspection

The chamber straightness was inspected and the overall out-of-round distortion was found to be within 0.020 in., which matches the requirement that the chambers stay clear of the magnets' i.d.

V. CONCLUSION

The interaction region vacuum chambers for CESR phase-III upgrade have been constructed and tested, and match the specified project requirements. We took advantage of EB welding to weld the vacuum chamber with good dimensional accuracy and excellent vacuum properties.

ACKNOWLEDGMENTS

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