Vacuum System Design for the PEP–II B Factory High-Energy Ring

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Abstract

The design of the vacuum system for the PEP–II B Factory High-Energy Ring is reviewed. The thermal design and vacuum requirements are particularly challenging in PEP–II due to high stored beam currents up to 3.0 amps in 1658 bunches. The vacuum chambers for the HER arcs are fabricated by electron beam welding extruded copper sections up to 6 m long. Design of these chambers and the vacuum pumping configuration is described with results from vacuum and thermal analyses.

INTRODUCTION

PEP–II consists of a 9.0 GeV High-Energy Ring (HER) for electrons and a 3.1 GeV Low-Energy Ring (LER) for positrons in the 2,200 m PEP tunnel. The design luminosity for PEP–II is 3×10^{33} cm^{-2} sec^{-1}, 30 times higher than PEP–I. This is achieved via high stored beam currents up to 3.0 A in 1658 bunches per ring. The vacuum system design is therefore challenging due to the resulting high thermal and gas loads. The PEP–II rings are hexagonal with 240 m arc regions joined by 120 m straight regions. Vacuum valves isolate each region. The HER straight region vacuum chambers will be fabricated from 95 mm stainless steel tubing with 304 stainless steel knife-edge flanges. All flanges in the HER have an internal RF seal to carry wall currents and limit higher order mode losses. The HER arc chambers consist of a 1.5 m quadrupole chamber and 6 m dipole chamber fabricated from extruded copper. Half-hard C10100 OF copper was chosen for good heat conductivity, low photodesorption coefficient, and good radiation containment [1]. Chambers are designed for low impedance (< 1 Ω for the ring) to avoid beam instability and to minimize higher order mode heating.

VACUUM SYSTEM ANALYSIS

System Design

Peak SR linear power desposition on HER arc chambers is 102 W/cm at a beam energy of 9.0 GeV and a beam current of 3.0 A, with 10% of the power back-scattered around the chamber walls. Finite-element modeling shows peak wall temperature at the SR impingement zone to be 100°C with an average wall temperature of 60°C. This temperature differential produces a 13,700 PSI compressive stress as the heated zone tries to expand, but is constrained by the bulk of the cooler chamber [2]. Data for half-hard C10100 shows the material will not yield or suffer fatigue related cracking for at least 10^4 cycles. Our fabrication processes are designed to maintain the half-hard temper.

The design vacuum pressure of 1×10^{-8} Torr in the arc regions and 3 x 10^{-9} Torr in the straights will be attained with an all-ion-pumped system. The photon dose in the arcs is 1.5×10^{19} photons/s/m, 15 times greater than PEP-I, resulting in a dynamic gas load of 1×10^{-6} T-l/s/m [3]. Dipole magnets take up most of the arc beam line circumference, so Distributed Ion Pumps (DIP) provide most of the required pump speed (>130 l/s/m). Lumped 60 l/s differential ion pumps on the quad chambers provide noble gas pumping during accelerator operation and maintain vacuum pressure when the beam and DIPs are off.

Photodesorption Testing

An accurate understanding of the photodesorption coefficient (η) is required to ensure acceptable vacuum pressures with high PEP-II photon doses. A test program was carried out at Brookhaven National Laboratory's NSLS facility by C. Foerster, et al [4]. Copper samples were exposed to photon beams in the VUV beam line (0.5 keV, 110 mrad) and X-ray beam line (5.0 keV, 23 mrad). The rates of photodesorption were measured for photon doses up to 10^{23} photons per meter which confirmed our predicted η value of 2 x 10^{-6} molecules per photon (N2 equivalent) after 100 amp-hours of operation. Using the planned cleaning and fabrication processes, the expected desorption rate and gas load for the HER arcs should be within the capacity of our pumping system.

Distributed Ion Pump Testing

Distributed Ion Pump (DIP) speed tests were performed at the Lawrence Livermore National Laboratory (LLNL) to

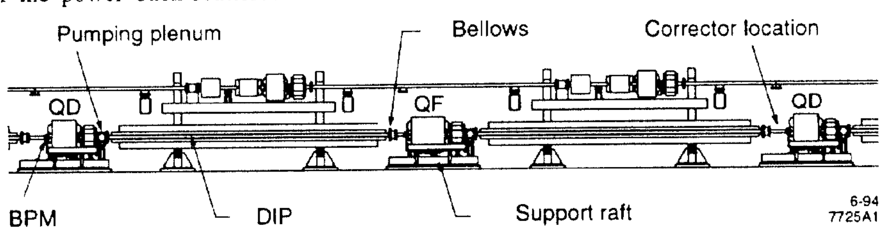

Figure 1. HER arc cell showing dipole and quadrupole chambers.

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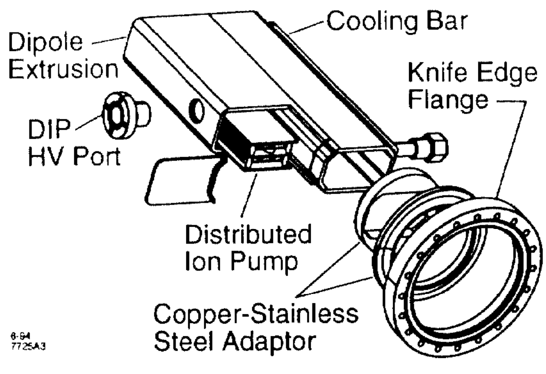

Figure2 Isometric view of HER dipole vacuum chamber

confirm pumping capacity. DIP modules with varying cell size and plate spacing were tested over a range of dipole field strengths and operating pressures. These tests demonstrated an acceptable DIP speed for the HER arcs of more than 130 L/s/m. A combination nonevaporable getter/DIP design is being evaluated at LLNL that could yield an even higher pumping speed. The DIP uses a parallel plate anode rather than the more traditional tubular cell anode used in PEP–I. Polarity of the LLNL pump is reversed from traditional designs; the anode is at ground and cathode at negative high voltage due to a concern for ejection of titanium ions into the beam chamber, which would degrade beam lifetime. Pure titanium will be used for the cathodes and stainless steel for the anodes.

VACUUM CHAMBER DESIGN AND FABRICATION

Dipole Chamber

The dipole chamber consists of three copper extrusions, a DIP with high-voltage feedthrough, and two end flanges. Since copper cannot be extruded in one multiport section like aluminum, separate extrusions must be joined by Electron Beam (EB) welding. The cooling bar is first EB welded to the dipole extrusion. The dipole chamber is then bent by stretch-forming to a 165 m radius to conform to the beam orbit. This is done by stretching the extrusion axially to the yield point and forming it over a preshaped mandrel. This process minimizes residual stress and relieves stress from previous EB cooling bar welding The process is fast, produces a smooth accurate bend, and is efficient for production.

Next, chamber ends are machined for flange attachment and the chamber is chemically cleaned. A pattern of 3 mm high pumping slots is cut into the 6 mm thick DIP separator screen using a computer controlled, high-pressure water jet. Slots are sized to minimize beam-to-DIP coupling and higher order mode losses, yet give acceptable conductance for gas molecules into the DIP. The slotted screen is inserted into the dipole extrusion to divide the beam and pump passages, and EB welded in place. The DIP is installed, and the DIP passage end plate and vacuum flanges are EB welded. Stainless steel flanges are attached to the copper extrusion via a stainless-copper adapter [5]. The chamber is glow-discharge cleaned, then vacuum baked at 200°C for about 72 hours.

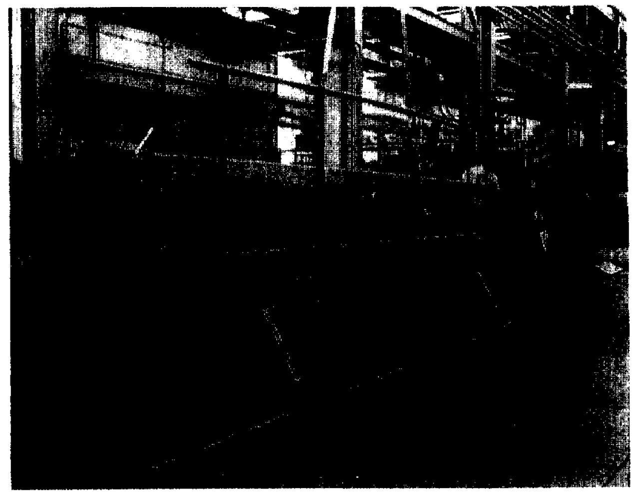

Figure 3 Photograph of HER dipole extrusion during stretch-forming at SLAC.

Quadrupole Chamber

The quadrupole vacuum chamber integrates beam position monitor (BPM), bellows, high-conductance pump cell, mask, supports, and vacuum flanges. A water-cooled mask in the pump cell absorbs SR power that would otherwise strike flanges and the uncooled chamber ends. The SR power density on the mask is calculated to be 225 W/cm, but since the mask is thermally isolated, and free to expand, peak stresses are acceptable. ®Glidcop, an alumina dispersion strengthened copper, is used for the mask body.

Arc BPM feedthroughs are EB welded to the quad extrusion. Straight section BPMs will be mounted in a similar manner to SST tubing. The feedthrough assembly integrates a ceramic insulator, a 2 cm diameter stainless steel button, and an SMA connector in an electrically smooth 50 Ω unit. The outer body is made of 70/30 electronic grade Cupronickel, compatible with brazing the ceramic, and readily weldable to the copper extrusion. A flexible bellows provides compliance for thermal growth and fabrication tolerances. An inner shield made of rhodium plated, beryllium-copper fingers conducts wall currents and minimizes higher order mode heating. EGGS calculations show that 10% of incident SR power is scattered inside the vacuum chamber, with part striking the bellows shield [1]. The spring fingers are fixed on one side to conduct heat to cooled surfaces, but sliding on the other side with sufficient contact force to conduct surface currents.

Electron–Beam Welding

Electron-beam welding is a reliable, computer-controlled process that minimizes warping and yields accurate tolerances. Welding is done in vacuum, which minimizes weld porosity and oxidation of copper surfaces. Tungston-inert gas welding can apply 10^3 W of power in an unfocused area with significant annealing of adjacent copper. In comparison, EB welding can apply 10^7 W in a narrowly focused zone at weld speeds over 2 m/s so heat-affected zones are very small.

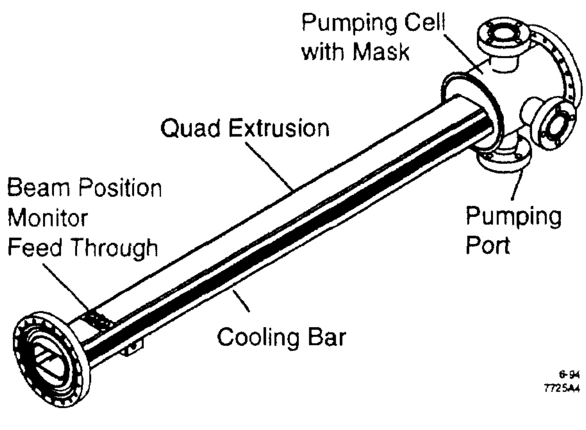

Figure 4 Isometric view of quadrupole vacuum chamber.

We performed extensive testing to develop techniques for EB welding of copper with minimal annealing in the bulk of the material. Short sections were test-welded and sectioned to evaluate hardness, tensile strength, and metallographic quality. The EB process has worked extremely well. For example, our cooling bar weld is 9 mm deep and 2.3 mm wide, with a heat-affected zone only 0.8 mm wide. Adjacent material is unaffected and retains its half-hard temper. Further, we have leak-tested a total of 40 m of test weld with not one vacuum leak.

SLAC is procuring an EB machine to perform the required welds. The system will be cryogenically pumped with dry backing pumps, and will be housed in a class-100K clean room. A laser guided seam tracker and multiaxis computer control will allow weld joint accuracy to about 0.05 mm.

Chemical Cleaning

SLAC has an extensive chemical cleaning facility for copper, which has been used successfully for many years. We evaluated less environmentally challenging methods, but chose a modified version of the SLAC procedure, which gives a full acid etch followed by passivation. We evaluated each step in the process using XPS evaluation of copper samples to minimize surface contamination—particularly carbon, which readily forms CO and CO2 during accelerator operation. Based on this study, we have made small changes to the cleaning process. Only a modest upgrade of the facility was required to accept 6 m lengths.

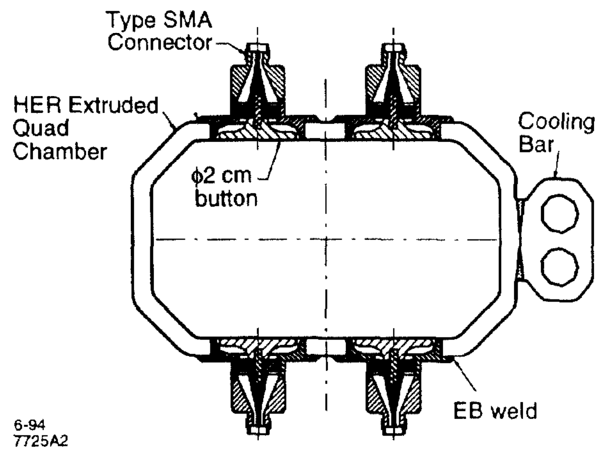

Figure 5 Cross section of quadrupole chamber showing BPM feedthroughs.

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