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VACUUM PIPE FOR e^+e^- INTERACTIONS*

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Abstract

The design, fabrication and testing of the beryllium vacuum chamber within the Mark II detector at SLAC is described. The Be chamber encloses one interaction point of the PEP circulating ring and is a part of its beam pipe. The Be chamber is captured within the Secondary Vertex Detector (SVD), a drift chamber, which is in turn centered in the Mark II drift chamber. Both ends of the beryllium pipe are brazed to aluminum/stainless transitions for connection to stainless steel bellows. A concentric radiation-screen liner of titanium foil runs the full length of the beryllium pipe.

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Requirements

To function optimally, the vacuum chamber had to meet a number of requirements:

1. The inside diameter should be sufficiently large to clear the synchrotron radiation (due to insertion quadrupoles) that surrounds the beam itself.
2. During installation, the outer diameter of the pipe passes through the central holes of the SVD heads. (The size of these holes also determines the minimum radius of the inner band of sense wires, an important parameter for accuracy in the SVD.)
3. The chamber should support an external pressure up to 2 atm (abs) in operation and should be sealed to the SVD heads to contain the gas.
4. The chamber should be bakeable to achieve a vacuum of 10^{-8} Torr.
5. The chamber should withstand thermal and mechanical strain in operation.
6. Circumferential fissures on the inner face must be avoided to avert arcing by the image current.
7. The SVD is surrounded by a Faraday cage, topologically a torus, the inner surface of which should be a ground plane insulated from, but attached to, the beam pipe itself.
8. The chamber should present minimum radiation lengths to particles originating at the interaction point.
9. The chamber should filter out radiation backscattered from the collimating masks (located in the PEP beam pipes two meters beyond each end of the chamber).
10. In the design phase it appeared desirable to be able, outside the SVD heads, to inspect and maintain the brazed joints at the ends of the beryllium pipe. However, fabrication improvements greatly reduced the chance of leakage so that this precaution was unnecessary.

Beryllium Pipe

Because of high elastic modulus (permitting a thin wall), low density and low Z, beryllium was selected for the pipe material. A local fabricator with beryllium experience[1] was chosen to construct the entire vacuum chamber. Beryllium sheet of 1.5 mm (.060 in) thickness was supplied by the fabricator. After hot rolling to an outside diameter of 156 mm, the tube was etched to a thickness of 1.4 mm (.056 in) to remove any damaged surface crystals that could initiate cracks.

This is the third beryllium pipe produced for SLAC. Both preceding pipes had difficulties with leaks in the braze joints between the beryllium and the end rings. One of the pipes tested helium-tight, only to leak months later after

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storage in a custom box. Both pipes required rebrazing before use. This history suggested the possibility of crevice corrosion from trapped brazing flux.

Three requirements were therefore added for the SVD pipe:

1. Full radiographs of all brazed joints were required for inspection by the SLAC engineer. A cost was negotiated in advance to cover a rebraze at the engineer's discretion.
2. The design of the first braze, the longitudinal joint in the beryllium, was improved, particularly where it met the end rings.
3. The central beryllium section was lengthened to move the aluminum end rings outside the SVD heads for access after installation.

The longitudinal closure on the two earlier pipes had been an outside splice strip. This was changed to a splice bar as shown in Figures 1 & 2, to provide larger fillets and to utilize gravity to help capillarity wet the entire splice area. The splice bar was wrapped with 1100 aluminum brazing foil before being inserted between the edges of the beryllium, and a wire of 1100 was laid on each side of the bar to enlarge the outside fillets. The spring action of the tube itself provided sufficient clamping force to hold the bar during the brazing operation.

Figure 2 illustrates the appearance of the braze fillets around the splice and shows the direction in which xray negatives were taken to separate the four fillets on the film. The beryllium is nearly transparent to xrays, showing black on the negatives, while the aluminum fillets show lightly exposed; any voids appear as slightly darker spots with irregular but sharp outlines. Slightly darker areas with smoothly blended edge densities are bulges on one of the mating parts, giving a thinner aluminum section, and have no effect on the joint integrity. If a septum, holding the vacuum, but thin enough to risk penetration by crevice corrosion, is connected by a void to the (damp) atmosphere, the braze is rejectable. Hairline cracks at the surface of the fillets can usually be located after the xray shows where to look. Voids large enough to affect strength are also rejectable.

The sectioned view of Figure 3 illustrates the method of fitting the brazed beryllium tube into the aluminum end rings at the splice bar. Brazing foil was placed in the joint and a brazing wire ring was added where the fillet is shown. For this braze, which must not soften the longitudinal seam, a lower-melting aluminum alloy, 4047 (Alcoa 718), was used. This braze was first made with the beam pipe horizontal and produced an excellent braze at one end; but a number of extensive voids, some of which could be seen as hairline cracks at the surface of the fillet, compromised the other end. The tube was, however, vacuum-tight to helium.

SLAC elected to rebraze. The fabricator machined off the questionable ring and replaced it, then brazed with the pipe turned to the vertical and the ring at the bottom end, while the satisfactory upper end encountered a lower temperature. The rebraze was excellent; one small, enclosed void was fortunately

present to show that the xray film had been properly exposed. It would have been preferable to braze the end rings one at a time, in the bottom position to take advantage of gravity, and avoid the need for an exact temperature match at both ends of the furnace.

Transition Ring

Between interaction points of the PEP ring the beam pipe is stainless steel; a transition from the 1100 aluminum end ring to 304 stainless steel was required. A friction-welded ring, half 3003 aluminum alloy, and half 304 stainless, was machined as shown in Figure 3.

The small projecting flange around the aluminum fitted the relief around the 1100 end ring and provided a welding stop for the electron-beam welder. Without such a stop the welding beam would cut rather than weld. Because of the high electrical conductivity of aluminum and because the titanium sleeve, as seen by the image current, is the inner surface of the pipe at that section, the circumferential fissure created by this stop would not be at risk of arcing.

The weld between the 304 stainless half of the transition ring and the stainless tube also required a welding stop, machined as a small stepped flange in Figure 3. The resulting fissure, in poorly conductive material, could not remain and was therefore machined away after welding, without the use of contaminating lubricants. This weld, of course, was made after the titanium sleeve was installed.

Titanium Sleeve

Because the backscattered radiation arrives at the beryllium pipe with a small incident angle, providing minimum radiation length for normal incidence is easily compatible with multiple radiation lengths for the backscattered radiation. To avoid very thin foils a low density metal is desirable but low Z materials may re-radiate, so that only scandium or titanium are optimal[2]. Because the sleeve would be subject to differential thermal expansion against the beryllium tube, it would require substantial rigidity. Titanium was therefore the material chosen.

Titanium foil, 50 μ m thick, was rolled into a tube 146 mm in diameter and spotwelded with a lap joint. In addition to the narrow passages between spotwelds, vents for vacuum pumping were provided by punching eight holes of 6.4 mm diameter before forming. Each end of the tube was slit in four places for a distance of 50 mm, to ensure that the tube would not wrinkle or be strained when it was spotwelded to the stainless pipe.

To avoid internal fissures, the titanium tube was seam-welded at its edges to the surrounding pipe, but the overlapping spotwelds that form a seam-weld often lack penetration due to shunting. The tube was therefore first spotwelded close to the edges at 6 mm intervals and then seam-welded at the edge, as shown in Figure 4.

A short stainless steel extension pipe was then EB welded to the transition and the welding stop machined off. The outer end of the extension tube carried a chamfer, as shown in Figure 5, to be attached by tungsten/inert-gas (TIG) welding to the PEP ring beam pipe. The extension pipe functioned as a thermal insulator to avoid heating the transition ring with the TIG weld.

Pistons

Beam pipes are usually mounted between bellows to reduce stresses on thin walls from slight misalignments and thermal expansion. The inside diameters of bellows are matched to the pipe's so that their outside diameters are always larger than the pipe's, thus making the beam pipe a tension member under vacuum load. Because tight joints under compression may leak under tension[3], the completed beam pipe was tested under axial tension. The end caps for bakeout and vacuum test were therefore designed as pistons (Figure 5) and the pipe was enclosed in a shield made of steel pipe. A short section at each end of the shield was bored and polished to seal with an O-ring around each piston.

With the beam pipe pumped down, helium at 3 atm pressure was admitted into the annulus between the pipe and the shield. This pressure on the inside of the pistons overcame the atmospheric pressure on the outside and provided the same axial tension load as would be encountered in operation. Since the beryllium pipe would be subjected to 2 atm absolute gas pressure in the SVD Detector, the 50% overpressure gave a concurrent proof test of the pipe itself.

Faraday Cage

Two thermistors were mounted with epoxy adhesive at the middle of the beam pipe, on each side of the longitudinal splice bar, and their connecting wires were led along the fillets straddling the bar. The entire exterior surface of the beryllium was then painted with epoxy and a wrap of Mylar film, 75 μ m thick, was glued on with a 50 mm overlap. To another coat of epoxy, an aluminum foil 25 μ m thick was similarly glued. The foil, however, was only long enough to reach under the sealing rings at either end.

The sealing rings were positioned to locate inside the central holes in the SVD head plates. The rings had to be split to assemble around the beam pipe and their inside diameter was shaped to accommodate the longitudinal splice bar. They were cemented in place and their halves were joined with electrically-conducting epoxy. The rings' outer diameter held an O-ring gas seal and a copper braid that completed the electrical connection between the foil around the beam pipe and the head plates.

Thermal Stresses

In all, 142 cm of beryllium tube plus 4 cm of aluminum rings is connected in parallel with a titanium sleeve that can support only minor compressive loads. In addition to room temperature assembly, this structure must survive four environments: pumpdown, bakeout, installation, and operation with beam.

Pumpdown: The pipe is pumped down for vacuum testing, resulting in a compressive end load of 191 kg, distributed between Be and Ti proportionally to their spring constants, K:

	Be	Ti		
E	2.95×10^5	1.16×10^5	kg/mm ²	Elastic modulus
L	1470	1470	mm	Length
A	687	23.7	mm ²	Area
K	1.38×10^5	137	kg/mm	Spring constant
P ₁	-188	-2.6	kg	Pumpdown load
Δ ₁	-14	-14	μm	Pumpdown deflection

The pumpdown load and the accompanying deflection are too small to cause instability in the titanium sleeve.

Bakeout: To prevent overstressing the spotwelds holding the titanium foil, the beam pipe was baked out inside the steel sleeve and the temperature was ramped up overnight. In this manner, the temperature difference between the beryllium and the titanium was minimized. At the maximum temperature of 180°C, the loads were distributed as shown:

	Be	Ti		
α	12.8×10^{-6}	9.0×10^{-6}	°C ⁻¹	Thermal expansion
L	1473.10	1472.18	mm	Free length at 180°C
P ₂	-170	170	kg	Bakeout load
Δ ₂	-12	909	μm	Bakeout deflection

A sample of the titanium foil was spotwelded in five places to a stainless steel sheet, and tested by suspending a dead load of 24 kg at room temperature. Three spotwelds in line next to the load modeled the ring of 75 spotwelds attaching the titanium sleeve. The last two spotwelds, offset, modeled the seam weld of Figure 4. The load capability of the attachment was therefore estimated at about 600 kg. The reduction in strength of both stainless steel and titanium at the bakeout temperature is negligible.

Installation: After installation and pumpdown of the PEP ring, the beam pipe is subjected to a tensile load of 168 kg from atmospheric pressure on the bellows at either end. This load is divided between the two cylinders:

	Be	Ti		
P ₃	165.8	2.2	kg	Vacuum load
Δ ₃	12	12	μm	Vacuum deflection

Operation: In operation, the beam would deposit 0.4 mW/cm^2 [4] of thermal energy in the titanium with a beam current of 6 mW/bunch. Heat is removed by diffusion along the titanium sleeve to the stainless steel and by radiation to the beryllium tube. Equilibrium temperatures in this geometry are sensitive to the emissivities chosen for the radiative transfer. Conservative values of 0.10 were therefore assigned to both the beryllium and titanium, resulting in these temperature increases:

	<u>Re</u>	<u>Ti</u>		
ΔT_p	2.7	14.9	C°	Peak temp diff
ΔT_a	2.6	14.1	C°	Avg temp diff
ΔL_a	49	187	μm	Expansion from ΔT_a
Δ_s	2	-136	μm	Thermal strain
$\Delta_s + \Delta_a$	14	-124	μm	Operative strain
P_a	193	-23	kg	Operative load

The compressive load on the titanium sleeve during beam operation is high for such a thin tube, but the sleeve has performed well for over one year. Future beam pipes of this basic design at SLAC will be shorter, both reducing the expansion length and improving the conductive cooling of the sleeve.

Notes

- [1] The beam pipes were built by Electrofusion Corporation, Constitution Drive, Menlo Park, CA 94025. EFC has facilities for the cutting, forming, and brazing of beryllium and other metals, and electron-beam (EB) welding.
- [2] Unpublished calculation by John Jaros, SLAC.
- [3] During the SLAC experimental run that discovered the ψ meson, a leak in the positron source introduced cooling water into the linac and shut down the experiment. When the source was examined, no leak could be located with helium. Running the cooling water into a tub in the linac tunnel reduced its pressure to atmospheric, stopping the leak while the experiment was completed.
- [4] Unpublished calculation of Perry Wilson, PEP.

Fig. 1

Fig. 2

Fig.3

Fig. 4

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Fig. 5