

## PEP-II Vacuum System—Joining SS Flanges to Copper Beam Chambers\*

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### Abstract

Various methods of joining stainless steel flanges to the copper PEP-II high-energy ring vacuum chambers was investigated with regard to metallurgical soundness, reliability, complexity, and cost. The most promising method appears to be direct electron-beam welding.

### OBJECTIVE

To join 304 stainless steel knife-edge flanges to the OFE copper beam chambers with only local heating of the copper, in order to preserve the necessary strength and thermal fatigue properties of the half-hard condition (1,2). Several methods of joining stainless steel to copper were evaluated for metallurgical integrity, leak tightness, reliability and ease of joining. Figure 1 shows the flange-to-chamber joint configuration. The challenge is to join the flanges to the 10- and 20-ft-long massive copper chambers without softening the copper significantly.

### JOINING METHODS EVALUATED

The two types of joining methods involve single or multiple joints. Figure 1 shows a single joint, and Figure 2 shows one version of a multiple joint incorporating transition pieces.

### MULTIPLE-JOINT ASSEMBLY

Multiple joint assemblies of copper to stainless steel transition pieces can be made by inertial bonding (3), explosion bonding (4), or H<sub>2</sub> furnace braze bonding (5).

Test sample evaluations show that these bonding methods can produce copper to stainless steel joints that are vacuum tight with high reliability. Figures 3, 4, and 5 are examples of the joint micro structures showing no evidence of brittle phases or propensity to crack. Tensile failures invariably occur in the copper away from the joint.

These pre-bonded transitions are then joined to the beam chamber by electron-beam welding of copper to copper. We are now quite confident about electron-beam welding of copper to copper and have demonstrated that sound, narrow joints can be made with heat-affected zones extending no more than 1mm beyond the fused region (see Figure 6).

### SINGLE-JOINT DESIGN

The multiple-joint design works, but we also wanted to evaluate less complicated single-joint methods. The first technique investigated was TIG-brazing using a eutectic Ag-Cu alloy to form a fillet braze between the copper and the stainless steel flange. Tests on short sections of beam chamber

looked promising but we had difficulty getting the braze alloy to wet to the root of the joint (see Figure VI). Considerable oxidation and softening of the copper occurred away from the joint. These problems became worse when attempts were made to braze flanges to longer sections of a beam chamber. The great difference in thermal diffusivity between stainless steel and copper prevented reaching braze temperatures quickly enough to prevent extensive softening and oxidation of the beam chamber. We considered TIG brazing in an inert atmosphere enclosure and did TIG braze some short test pieces in argon. It became obvious that in order to heat the copper locally, rapidly enough to prevent extensive softening, we needed greater energy density than can be delivered with a TIG torch. An electron beam can deliver energy density 10,000 times greater and a CO<sub>2</sub> laser beam can deliver an energy density at least 1000 times greater than a TIG torch.

CO<sub>2</sub> laser welding of stainless steel to OFE copper was investigated at the University of Tennessee Space Institute (6). Pore-free, crack-free joints were made using helium cover gas. Joints made with argon showed cracking and those made with air showed excessive porosity. One serious limitation to CO<sub>2</sub> laser heating of copper is that ~ 98% of the 10.6μ radiation is reflected from the copper surface, meaning that the beam must be directed into the joint or onto the stainless steel.

The most promising approach appears to be direct welding of stainless steel to copper using an electron beam. This process is routinely used to weld 304 S.S. to OFE copper for invasive probes into H<sub>2</sub>-fueled NASA engines (7). These investigators find as we do that the joints are sound, they show no evidence of cracking, and that tensile failures occur in the copper away from the joint.

The microstructure of one of our early electron-beam welded joints is shown in Figure 8. The structure was analyzed using EDX on a scanning electron microscope and showed islands of stainless constituents within the melted zone and some grain boundary penetration of copper into the stainless steel. Although this penetration appears benign, we have found that by focusing the electron beam on the copper near the joint boundary, we can minimize this penetration.

We made four electron-beam welds joining .25" wall 3" O.D. OFE copper to 6" O.D. 304 and 316 flanges. These flanges were then tested for thermal and mechanical integrity. The abuse took the form of cycling between 500°K and 77°K ten times and pounding on the flanges in all directions with a 5-lb hammer. There were no detectable helium leaks greater than  $2 \times 10^{-10}$  cc/sec found before or after these treatments. We are currently making test welds on actual beam chamber extrusions as shown in Figure 1. These welds will be more

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thoroughly tested and then sectioned for metallographic examination and tensile testing.

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