FABRICATION PROCESSES FOR THE PEP-II RF CAVITIES*

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Abstract

This paper presents the major steps used in the fabrication of the 26 RF Cavities required for the PEP-II B-factory. Several unique applications of conventional processes have been developed and successfully implemented: electron beam welding (EBW), with minimal porosity, of .75 inch (19 mm) copper cross-sections; extensive 5-axis milling of water channels; electroplating of .37 inch (10 mm) thick OFE copper; tuning of the cavity by profiling beam noses prior to final joining with the cavity body; and machining of the cavity interior, are described here.

1 INTRODUCTION

"Rarely [have we] faced so complex a manufacturing task as the cavities" [1]. To present all of the interactions, dependencies, and processes among the different disciplines and organizations involved in the 1700 labor hour effort to produce a single RF Cavity is difficult. This paper is therefore divided into major subsets of the process.

2 CAVITY BODY FABRICATION

2.1 Fabricating Copper Bowls

The fabrication process begins with a class 2 [2] OFHC copper plate of 1.5 inch (38 mm) thickness and 39 inch (1 m) diameter. The thickness is reduced to 1.25 inch (32 mm) by diamond fly-cutting an equal amount of stock from each side. This removes any subsurface contaminants that may have been imbedded during the rolling process at the mill. Relief of skin stresses is an additional benefit of this procedure.

The desired shape is obtained by forcing the stock plate through a 21.75 inch (552 mm) diameter ring with a mandrel. This operation is performed at room temperature. The mandrel's shape is a slightly undersized version of the cavity's inner contour.

2.2 Equatorial Electron Beam Weld Preparation

A numerically controlled lathe is used to machine the inner contour of the bowls, leaving .08 inch (2 mm) stock material for removal after subsequent processing. We allowed .02 inch (.5 mm) on the face of the bowls to compensate for shrinkage during the welding together of the two halves. The outer contour is machined to final size at this point. Datum features, used until late in the fabrication process, are cut into the bowl halves at this time

2.3 Electron Beam Welding the Equatorial Joint

For the prototype cavity we developed EBW parameters that would bury the root porosity in a 0.5" (12.5 mm) thick sacrificial backing-bar located on the exit side of the weld joint. The backing-bar was removed during a subsequent machining operation. For the production cavities we adapted the "over penetration" technique used for the equatorial ports, thus eliminating the backing bar. We effectively mitigated problems with porosity in the weld taper-off by centering a port penetration over the taper off area. Distortion due to welding proves to be negligible; therefore, we are not forced to reestablish datum surfaces following this welding operation.

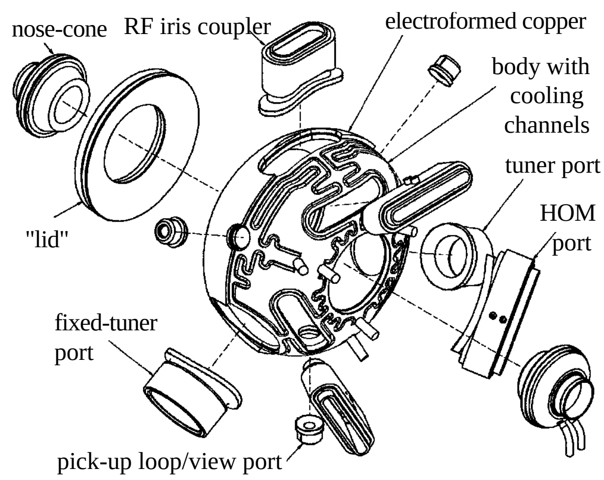

Figure 1: An exploded view of a PEP-II RF cavity, body cooling channels on one half (exposed), equatorial and HOM port inserts, nose-cones and "lid" section.

2.4 5-Axis Milling of Water Channels

The cavity body contains six discrete cooling circuits totaling approximately 780 inches (20 m) in combined length, figure 1. The intricate geometry was electronically transferred from the designer's computer to the manufacturer's programming system. The water channels were cut into an epoxy model, then inspected to verify the accuracy of the machine tool program before proceeding on the copper cavity body. A reference hole is

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incorporated to establish a clocking orientation for the water channel and port penetration.

2.5 Electroplating of OFE Copper

A machinable wax is placed into the water channels. This serves as a space holder during the electroplating operation that generates the covering for the channels. Silver powder is burnished into the wax to provide a conducting surface. The activation procedure removes excess silver and any other residues from the copper body to ensure proper adhesion between the plating and the cavity body.

The cavity is rotated at 5 RPM while fully submerged in an acid sulfate chemistry. An intermediate machining of the outer contour is required prior to achieving the final plating thickness of .4 inch (10 mm).

2.6 Water Channel I/O Location and Port Penetrations

Referencing the clocking hole allows us to locate the inlet and outlet points of each cooling channel after they have been covered by the electroplating. We place a pipe threaded hole at each end of the cooling channels to ensure a positive joint during the dewaxing procedure. These holes are reworked in a future operation to accept welded fittings.

We cut the port penetrations into the body leaving them .08 inch (2 mm) undersize to avoid damaging the final penetrations during dewaxing. The precise location of the port penetrations ensures the proper relationship between cooling water and port bodies. This is crucial due to the high body temperature predicted by computer models during the design phase [3].

2.7 De-Waxing of Water Channels

The cavity body is heated to approximately 100 °C with a hot air gun to soften the wax. The viscous wax is forced from the water channels with 90 psi (620 kPa) of air pressure. Once an air passage is established teflon hoses are attached and perchloroethylene is pumped through the cooling channels for 30 minutes to remove the remaining wax. A final rinse with clean solvent is done to ensure the wax is cleared from the water channels. A 15 minute hydrostatic test at 300 psi (2 MPa) is performed to ensure the integrity of the bond between the electroplated copper and the parent material.

2.8 Finishing of Port Penetrations

The nine port penetrations are finished to a tolerance of .002 inch (.05 mm) to help ensure successful EBW of ports to the cavity body. The electroplated copper is relieved from the weld joint area so that the EB weld is only in the parent metal, thus avoiding potential water to vacuum leak paths.

The cavity body is degreased, deoxidized, and etched in a chromic acid bright dip, removing approximately .0002 inch (.005 mm) to provide a clean part for EBW. The cavity is then wrapped in lint free paper and aluminum foil for shipping to the welding vendor.

3 PORT AND LID FABRICATION

The 11 ports welded to the cavity consist of five styles -- Iris, Tuner, Observation, HOM, and Beam nose -- performing different functions, yet all using similar fabrication techniques.

3.1 Fabrication of Ports

The ports are fabricated as piece parts; the copper components are assembled by hydrogen furnace brazing with a 35Au65Cu alloy. The features that mate with the cavity body are then machined to final specification. The beam nose ports retain .4 inch (10 mm) stock material in length during this fabrication stage, allowing for the tuning process.

The HOM port fabrication process incorporates the stainless steel vacuum flange blank during brazing. The vacuum and RF sealing surfaces of the flange are machined after this brazing to avoid the distortion due to welding processes typically used for this type of component. The features that mate with the cavity are then finalized.

3.2 Lid Fabrication

The cavity lid is fabricated from a 16 inch (406 mm) diameter by 2 inch (50 mm) thick plate of OFHC copper. The lids are processed similarly to the cavity bodies, namely, water channel formation by plating, and EBW joining of a port. The lid/beam nose sub assembly is machined after welding to generate precise locating features that mate with the cavity body. The beam nose is machined to its final length prior to being joined to the cavity body.

4 ELECTRON BEAM WELD ASSEMBLY OF CAVITY AND PORTS [4]

The cavity body and nine ports are joined with EBW technology. We developed several different techniques to ensure we met the vacuum, structural, and electrical criteria for the PEP-II RF Cavity. At this stage the mounting pads are also EB welded to the cavity body.

4.1 Two Stage Welding of HOM Ports

Three HOM ports are welded into the cavity body from the inside using a 75% penetration structural weld followed by a cosmetic wash-weld. The wash-weld uses a very diffuse beam that gently “stirs” the weld pool, resulting in a smooth, uniform surface. No porosity is visible in the weld taper-off area after finish machining.

4.2 Over Penetration Welding of Equatorial Ports

We theorized that the root porosity could be “blown through” the weld joint from the outside when attaching the six equatorial ports. This process requires the beam to over penetrate the joint, necessitating a beam stop. We anticipated small porosities in the weld taper-off area when we machine the surface final RF; therefore, the taper-off area is positioned so EB wash welding is possible for repairs.

5 FINAL MACHINING OF THE CAVITY

5.1 Datum Transfer

We transfer the original datum to surfaces on the mounting pads using a horizontal spindle CNC milling machine. This transfer is required since the original datum must now be removed. This operation enables us to mount the cavity in a fixture that will be used for all subsequent operations, thus ensuring the proper relationship among the final features. Mounting holes and fiducial locations are precisely located for attaching and aligning the cavity in its raft assembly.

5.2 Final Machining of RF Surface

The openings for the lid sub assembly and its opposing beam nose are machined on a CNC vertical turning lathe. This joint is for EBW; therefore, tolerances of .002 inch (.05 mm) are held.

The final machining of the RF surface is also performed at this step. Using the lid opening for access, the tungsten carbide tool shaves away the .08 inch (2 mm) stock that was left in the initial processing of the bowls. The final RF surface is a 40 µinch (1 µm) Ra finish and is within .005 inch (.012 mm) of the nominal profile.

This operation reveals any pits we will see in the weld taper-off area of the equatorial port welds. These voids are sealed with EBW, leaving smooth repaired spots which are preferable to the pits.

5.3 Electron Beam Welding of Lid to Cavity Body

The lid subassembly is EB welded to the cavity body in a two stage process. The initial weld, a 75% penetration structural and vacuum weld is made from the outside of the cavity. This is followed by a cosmetic wash weld on the inside surface. The smooth undulations of the internal weld bead do not significantly affect the operation of the cavity. The internal welds do however result in the deposition of a copper foil on the RF surface which must be removed during the cleaning procedure.

5.4 TIG Brazing of Water fittings

Stainless steel water fittings are attached to the electroplated copper of the cavity using a conventional TIG torch and 72Ag28Cu braze alloy. Weld prep grooves are needed to thermally isolate the weld area, as the heat otherwise dissipates throughout the cavity too rapidly.

6 TUNING AND FINAL FABRICATION PROCESSES

6.1 Tuning

A beam nose, precut to leave .1 inch (2.5 mm), is temporarily installed into the cavity. The frequency is measured and a determination made as to how much material to remove from the beam nose in order to attain the target frequency. After this material is removed the beam nose is cleaned and reinstalled for verification prior to final EB welding.

6.2 Electron Beam Welding of Nose

The beam nose is EB welded to the cavity body in a fashion similar to the lid/cavity EBW. As with the lid weld, the minor undulations of the internal weld bead do not significantly affect the operation of the cavity. Final frequency and vacuum integrity verifications are made.

6.3 Cleaning

The finished cavity is cleaned according to an approved process. An alkaline cleaner is used to remove extraneous dirt followed by a deoxidizer to remove the surface oxidation. The copper residue from the EB welding is removed using 600 grit aluminum oxide paper followed by a white abrasive pad. We repeat this process until a visual inspection of the cavity shows that the foil is removed. A chromic acid bright dip bath is used to remove approximately .0002 inch (.005 mm) of copper and any embedded abrasive material. This leaves the RF surface with a 24 µinch (.6 µm) Ra or better finish.

The cavity is rinsed in deionized water and then blown dry with bottled nitrogen, then all openings are covered with foil for transporting to the assembly area. A nitrogen purge is maintained while the flanges are blanked off and a nitrogen atmosphere of 2 psig (14 kPa) is left in the cavity to prevent reoxidation of the inner surfaces. The cavity is then mounted in its installation raft and cooling lines attached prior to shipment [5].

7 ACKNOWLEDGMENTS

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