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FABRICATION OF ION SOURCE COMPONENTS BY ELECTROFORMING*

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Abstract: Several components of the Oak Ridge National Laboratory (ORNL)/Magnetic Fusion Test Facility (MFTF-B) ion source have been fabricated utilizing an electroforming process. A procedure has been developed for enclosing coolant passages in copper components by electro depositing a thick (≥0.75-mm) layer of copper (electroforming) over the top of grooves machined into the copper component base. Details of the procedure to fabricate acceleration grids and other ion source components are presented.

Introduction

Neutral beam heating systems for fusion experiments such as MFTF-B, TFTR, and D-III will require positive ion sources operating at 2–5-MW power levels for long-pulse (~30-s) durations. The various components of these ion sources, such as acceleration grids and plasma generator electrodes, consequently require considerable cooling. This is accomplished by fabricating the components with internal passages through which water or other coolants can be circulated.

The method that has been used at ORNL for aperture-type accelerator grid fabrication has involved the brazing of small-diameter (1.5-mm) straight copper tubes into grooves machined into a copper plate. The ends of the tubes terminate in manifolds. In order to optimize transparency, the coolant channels must weave back and forth between holes in a serpentine pattern. This makes the use of the small tubing difficult.

An alternative method of constructing an acceleration grid is to make a composite with two sheets of material. Grooves are machined into one or both pieces and brazed together. This method has been utilized[1] in making small area (~50-cm^2) copper grids. For large area (≥400-cm^2) grids, the task of obtaining complete leak tightness between apertures and coolant channels while not blocking any channels with brazing alloy is difficult.

Another method of enclosing coolant channels in a copper plate is by electrodepositing a thick (≥0.75-mm) layer of copper (electroforming) over grooves machined into the plate. This method has been used in fabricating rocket nozzles, except nickel was electrodeposited onto copper. The method was first pursued several years ago at ORNL with limited success. Interest was rekindled about 2 years ago when the Institut für Plasmaphysik (IPP) supplied ORNL with two electroformed plates from which 10 × 25 cm accelerator grids could be fabricated. IPP was interested in this method for their ion source development. A 10 × 25 cm plasma grid was fabricated from one of the plates and successfully operated in our ion source. In light of this success it was decided to develop a copper electroforming process for use in our continuing ion source development. The process developed has been used in the fabrication of several components for the ORNL/MFTF-B 13 × 43 cm ion source (Fig. 1). The components included the accelerator grids and various flat and cylindrical liners.

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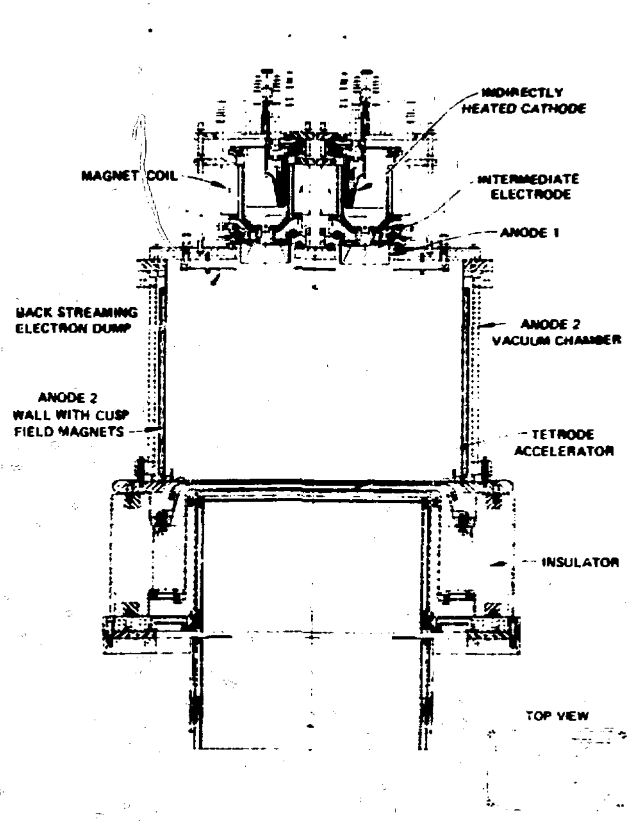

Fig. 1. ORNL/MFTF-B 13 × 43 cm ion source.

Electroplating Bath

An electroplating bath that was simple, easy to maintain, and adequate for the job was desired. Since the geometry of most of the components to be plated was relatively simple (flat), an acid copper solution of medium concentration with no additives was chosen. The solution consisted of 175 g/L of solution copper sulfate, 60 g/L of solution sulfuric acid, and distilled water.

A number of baths were set up with this solution: one for plating flat plates, another for cylinders, and another for deplating (to be explained later). All tanks and connecting plumbing were made of polyvinyl chloride (PVC). The solution in each tank was continuously circulated and filtered through a 10-micron filter. The pumps and filters were located outside of the tanks. The solution in each bath was returned near the bottom of the tank at several places and directed upward between the work piece (component

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being plated) and the anodes. The anodes used were commercial copper anodes containing 0.05% phosphorus. Each anode was covered with a polypropylene bag to contain particles and hung from a copper bar. In the largest tank (0.61 m x 0.91 m x 0.91 m deep), the work pieces (flat plates) were hung from a copper bar that was agitated in a straight path during plating at a ~0.5-Hz repetition rate and a stroke of ~5 cm (Fig. 2). Cylindrical work pieces were plated in a 0.61-m cube-shaped tank. The work piece was positioned at the center of the tank and agitated by rotating ±90°. An anode was hung near each of the four corners of the tank.

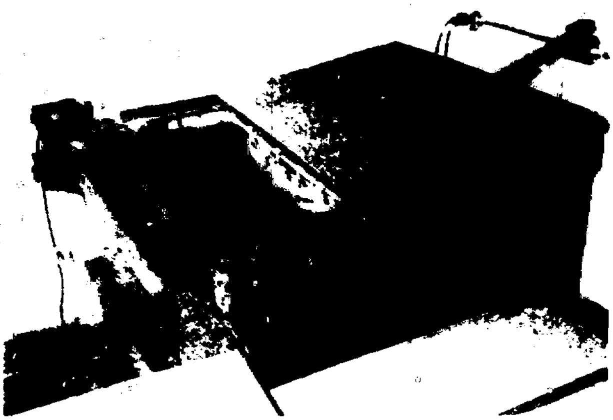

Fig. 2. Target plating tank.

The bath solutions were analyzed periodically and corrected as necessary. Anodes were replaced in order to maintain approximately 1.2 to 2:1 ratio between the anode and the work piece areas.

Fabrication Procedure

The procedure for the fabrication of copper components with internal coolant channels by electroforming involved several steps.

Initial Machining

The components were initially machined from oxygen-free high conductivity (OFHC) copper, including grooves where coolant passages were to be located and reference holes or marks (Figs. 3 and 4). OFHC-type copper was used because it deplates better than non-oxygen-free types. OFHC copper was also desirable because the part was furnace brazed later. Plates were machined oversized by ~4 cm on the width and length so that the somewhat porous copper plated near

Fig. 3. Grid plate with serpentine grooves.

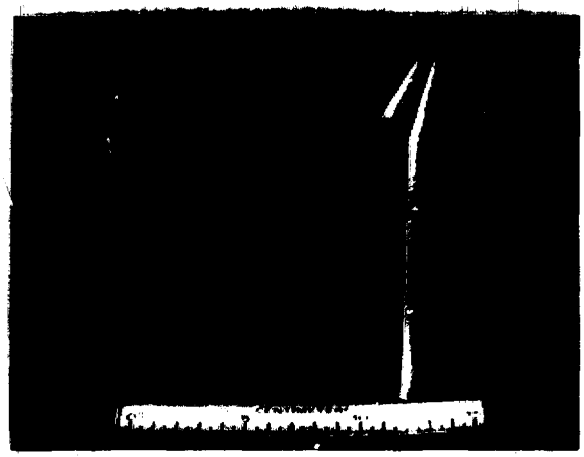

Fig. 4. Intermediate electrode liner details.

the edges would be machined off when finished. Cylinders were either lengthened or had aluminum extensions attached for the same reason.

Filling Grooves with Wax

The grooves in the component were filled with a wax compound. The wax used was a red jeweler's wax (Fisher Scientific, Cat. No. 15-530).* It is in stick form and melts at a temperature of ~115°C.

The component was degreased and then heated on hot plate and/or with a heat gun. A hot plate alone worked well for flat plates, whereas a heat gun was required for cylindrical parts so that the heat could be kept localized as waxing proceeded around the periphery. The wax was melted into each groove and filled to slightly above the surface of the copper since the wax shrinks somewhat when it solidifies. After the part cooled to room temperature, the wax was wet sanded even with the surface of the copper using #100 grit sandpaper. An orbital sander worked well for the flat plates. The sanded surface was then washed off with water and blown dry. This surface was kept clean and not touched with bare hands.

Silvering Wax

The surface of the wax had to be made conductive so that copper would electrodeposit onto it. This was done by coating the wax with fine silver powder (Handy-Harmon Silflake 135).* The powder was brushed onto the wax with a fine bristle brush. The silver was then rubbed into the wax using a smooth, stiff piece of paper such as an index card. The loose powder was dusted off. The surface was then carefully heated with a heat gun to bring the surface of the wax just to its melting point. The surface appeared glossier as sanding marks smoothed out. The silver powder also became more embedded into the wax. This process was repeated two or three more times until the wax wouldn't take any more silver.

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*Reference to any specific commercial product, process, or service by trademark, trade name, manufacturer or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. government or any agency thereof.

Masking

Surfaces such as the backside of plates, the ends of cylinders, and reference holes that were not to be electroplated had to be covered with insulating material. PVC sheets, vinyl tape, and masking paint were used for this. The masking extended around the edges or ends of the parts ~0.5 cm to reduce excessive plating at these high field areas.

Deplating

Each component was cleaned prior to placing it in the plating bath. This was done by electroetching or deplating the surface to be plated in a separate bath. This bath was identical in composition to the plating baths. The component was polarized positive with respect to another copper or stainless plate with an area equal to or greater than the area of the component. The current density was set to 2.2 A/dm^2, and the part was deplated for ~10 min. A thin darkish film formed on the part, which was washed off in a water spray (Fig. 5). The part was inspected carefully for cleanliness and inadequate silvering. If any dirty spots remained, they were brushed lightly with a stainless steel brush and the deplating repeated. If the red color of the wax could be seen anywhere, resilvering would be necessary.

Fig. 5. Washing plate in water spray after deplating.

Electroplating

If no flaws were found, the part was put into the plating bath while still wet. The part was then polarized negative with respect to the anodes and plated at a current density of 2.2 A/dm^2. During the first few minutes of plating, the part was lifted out of the bath momentarily and inspected to make sure the silvered areas were plating satisfactorily and bridging to the base copper. If any areas were not plating well, it was necessary to go back and correct the problem. Sanding and silvering could sometimes be repeated on a small area.

Most components were plated for 2 to 2.5 days, which resulted in a plating thickness of 1.2 to 1.5 mm. The plating rate was ~0.025 mm/h. Figure 6 shows a grid plate after electroplating.

Machining after Plating

The component was machined after electroplating, leaving 0.75 mm of plated copper. Access holes to the channel ends were drilled also (Fig. 7).

Fig. 6. Grid plate after electroplating.

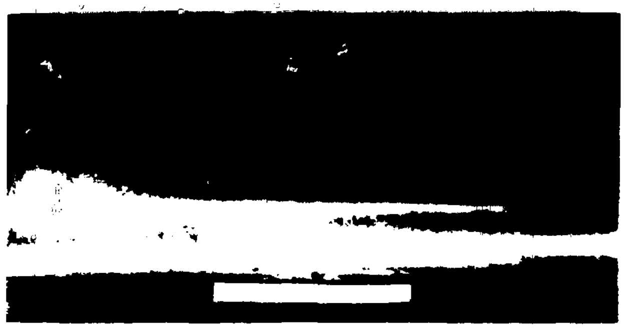

Fig. 7. Grid plate machined and channel access holes drilled.

Wax Removal

The component was then heated slowly on a hot plate and/or with a heat gun to melt the wax. Care was taken to heat access hole areas first so that the expanding wax could flow out freely. If restrained, the heated wax can produce tremendous hydraulic pressures that can burst the copper channels. Compressed air was used to blow out the wax from each channel. When all the wax possible was cleared out in this manner, the remainder of the wax was removed by circulating ethyl alcohol through each channel. A pump connected to the part with appropriate temporary manifolds was found useful for this.

Test of Plating

Before continuing with the fabrication of a component, the integrity of the plating was tested. To do this the part was heated in an inert gas atmosphere or vacuum furnace to the eventual brazing temperature (760°C). Any contamination that might have been on the original plate of was collected during plating would volatilize and swell the copper (blister). The part was then vacuum tested for any leaks through the plating.

Final Assembling

If the plating integrity checked out satisfactorily, the component was ready for the final assembling operations of additional machining and/or brazing. Accelerator grid plates were drilled and machined to size and tested for leaks again. The plates were then brazed into their respective manifold frames (Fig. 8). After leak and x-ray tests the assemblies were machined to their final size (Fig. 9).

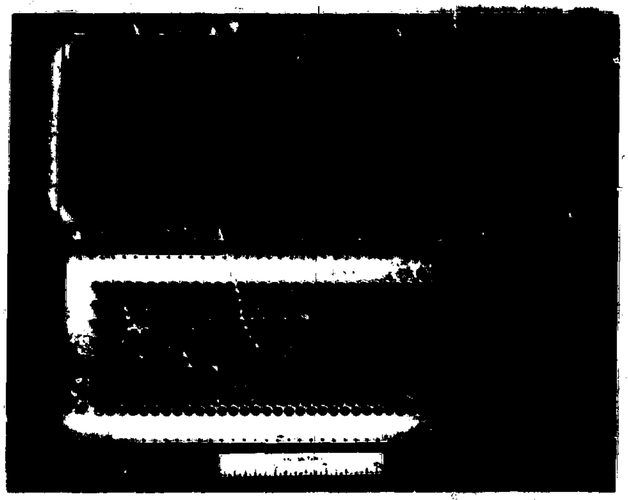

Fig. 8. Accelerator grid plate and manifold frame ready for brazing.

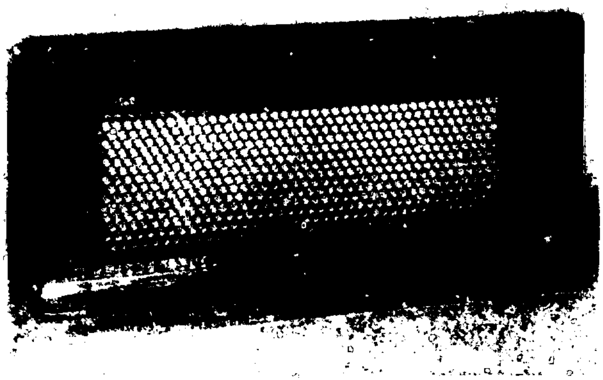

Fig. 9. Finished plasma grid.

Repairing

It was found that various defects such as blisters, leaks through the plating or between apertures and coolant channels, and machining mistakes could be repaired by electroplating. A number of grid plates and other components that had undergone expensive machining were salvaged in this manner.

A shallow dimple was carefully machined into the part at the location of the defect using a hand-held rotary file or grinder. The part was then masked everywhere outside the dimpled areas and electroplated in one of the baths following the same deplating and plating steps previously described. The plated areas were smoothed down afterward. Defects as deep as ~2 mm were repaired in this manner.

Another means of electroplating a small area on a component is shown in Fig. 10. A stream of plating solution from a 3-mm-diam copper tube was directed onto the desired spot using a small pump. The solution was collected by a PVC drainboard and returned to a reservoir-filter assembly. The copper tube served as the anode and was the supply of copper. Electroplating could be limited to areas as small as 1.5 mm in diameter.

Fig. 10. Spot plating equipment.

Discussion

The described method of electroforming copper ion source components has proven to be quite successful. The four accelerator grids, the intermediate electrode liners, the second anode liner, and several other components in the ORNL/MFTF-B 13 × 43 cm ion source were fabricated by this method. Detailed results of testing this ion source are reported elsewhere at this conference,[4] but a hydrogen ion beam of 40 A at 75 keV for 30-s pulse durations was obtained. This method of fabrication seems quite versatile and could be useful for other cooled copper components, such as ion beam defining plates and dumps, rf antennas, shields, and waveguides.

References

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