I.2: Wax electroforming of Prototype Acceleration Grid (PAG) plate for IPR

Design and Manufacturing Technology Division of RRCAT initiated a project to develop ion extractor grids for Neutral Beam Injection (NBI) system for generating high-energy neutral hydrogen beams for the Institute for Plasma Research (IPR), Gandhinagar. A critical component of the NBI system is the ion extractor assembly, which consists of three OFE copper grids: (i) Acceleration Grid, (ii) Deceleration Grid, and (iii) Earth Grid. The acceleration grid experiences a heat load of approximately 1.75 MW/m², necessitating efficient heat removal through a dense network of wavy semi-circular cooling channels (radius ≈ 1.1 mm) embedded between the rows of beam apertures.

Fabrication of the ion extractor grid is technologically demanding and involves several specialized processes, including: (i) joining of dissimilar metals—SS304L rods to an OFE copper plate—for fabrication of the water manifold; (ii) electroforming of OFE copper to a thickness of about 3 mm to form embedded cooling channels; and (iii) precision CNC machining of the grid plate. Only a few manufacturers worldwide possess electroforming capabilities, and their services are available at very high cost. Indian industry is still in the process of developing the electroforming technology.

To address this challenge, DMTD developed the cold additive manufacturing capability for copper electroforming up to 3 mm thickness on CNC-milled OFE copper plates to fabricate embedded cooling channels. Machined grooves were initially filled with wax and coated with silver to provide electrical conductivity for subsequent electrodeposition. Copper deposition was carried out in an acidified bath at a current density of ~2 A/dm² using periodic reversal mode, followed by thermal removal of wax.

Fig. I.2.1: Machined wavy grooves on the grid plate

Fig. I.2.1 shows the Prototype Acceleration Grid (PAG) plate after machining and chemical cleaning. The machined grooves were first filled with wax, followed by silver coating on the wax to impart electrical conductivity, enabling subsequent copper electrodeposition, as illustrated in Fig. I.2.2 and I.2.3. Fig. I.2.4 shows electrodeposited PAG plate with about 3 mm thick uniform copper plating on the entire plate surface including silver coated wax.

The final PAG plate contains 214 apertures of 8 mm diameter, with a 0.4 mm clearance from the adjacent cooling channels arranged in a dense network of 2 mm wavy semi-circular channels (Fig. I.2.5). Channel continuity was verified using LCD, volumetric, and radiographic inspection methods. Helium leak testing at the Ultra High Vacuum Technology Section of RRCAT confirmed leak-tightness below 1×10^{-9} mbar·lit/s after 8 bar pressure testing and vacuum baking at 180 °C for four hours.

Fig. I.2.2: Wax filled wavy grooves on the grid plate

Fig. I.2.3: Wax filled wavy grooves coated with silver

Fig. I.2.4: Copper deposited on the silver coated wax

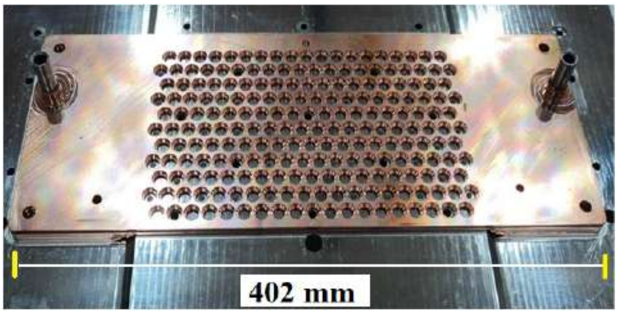

Fig. I.2.5: PAG plate with embedded cooling channels

This development demonstrates strong potential for the indigenous fabrication of critical components with fine embedded cooling features required for advanced accelerator and fusion applications.

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