ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR18

MECHANICAL DESIGN OF A QWR CAVITY FOR THE NEW ISIS MEBT

J. Cawley†, I. Rodriguez, J. Speed, ISIS, Rutherford Appleton Laboratory, STFC, Didcot, UK

Abstract

The Quarter Wave Resonator (QWR) is a longitudinal bunching cavity for the MEBT section of the Pre-injector Upgrade project at ISIS. Four cavities are required with at least one functional spare. The production of a full scale prototype is discussed here. Three main manufacturing challenges were encountered as follows: the tight manufacturing tolerances of the stainless steel tank, most noticeably the 80 μm tolerance along the length of the 370 mm bore; the 50 μm +/- 10 μm copper plating layer on the inside of the complex geometry cavity; and the brazing of the copper lid to a long (280 mm) stem with the use of a jig, to achieve a tight precision in the length inside the cavity. Trials for all these have been conducted before being accurately assembled with a CMM, with lessons learnt and the final solutions presented.

VESSEL MANUFACTURE

The QWR tank is a vacuum vessel that operates at 1e-7 mbar, with a power coupler port, two frequency tuner ports, four pick-up ports, the mounting of the stem, two beam ports with nose cones and a vacuum port (Fig. 1).

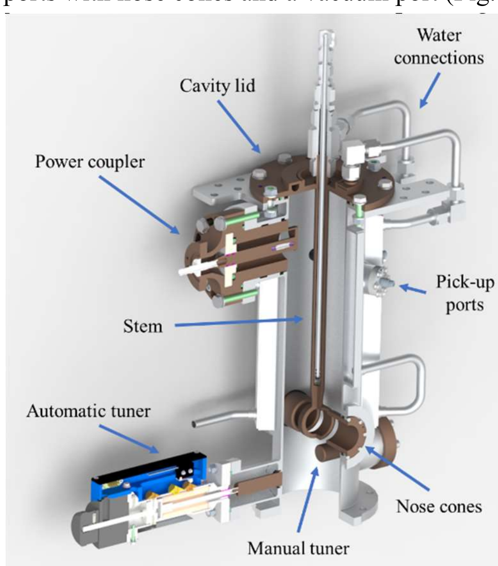

Figure 1: Labelled QWR assembly.

The vacuum vessel could have been made from solid copper rather than a stainless steel tank with a copper plating layer. Using stainless steel allows a thinner wall (3 mm) compared to copper (10 mm) due to the vacuum deflection, maximising the beam pipe bore diameter and the space between flange to flange (allowable cavity length). Furthermore, there are manufacturing benefits such as stainless steel being easier to machine to tight tolerances [1].

The initial approach for the manufacture of the tank was to weld the ports and flanges to the main bore of the vessel. The final tolerance of 80 μm along the length of the 370 mm bore would be achieved with a final skimming process over the welds. At the time, four companies were involved with the manufacture. The conclusion was that an alternative approach was required in order to achieve the tight mechanical tolerances, driven by the RF design [1]. The main challenge observed from the manufacturers was the heat distortion added from welding, resulting in difficulties to achieve and to ensure the tolerances and the leak tightness of the welds after they were skimmed over to achieve the final dimensions.

One of the manufacturers [2] proposed to machine the majority of the tank from a single billet of material (Fig. 2), only requiring welding on the cooling channel caps, automatic tuner and the power coupler flanges. This approach removed all internal welds on the bore and greatly reduced the heat distortion in the vessel by moving the remaining welds away from the surface of the bore.

Figure 2: QWR machined from a solid billet.

Further changes included the modification of the manual tuner port to reduce the need of an extra weld and its associated weld distortion (Fig. 3). Similar design changes were made for the four CF16 pick-up ports used for operation, which greatly simplified the manufacture with a CNC once the weld is removed (Fig. 3).

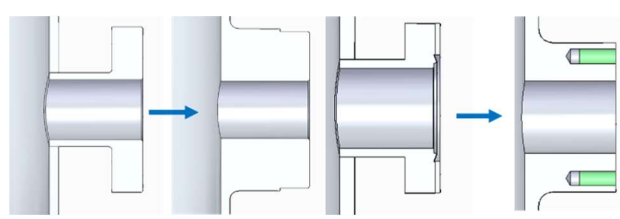

Figure 3: Manual tuner and pick-up port redesign.

All tanks were inspected using a CMM (Fig. 4) to check whether the specified tolerances had been achieved. The new manufacturing approach was considered a success, and five new tanks were ordered for the production run.

† jon.cawley@stfc.ac.uk

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR18

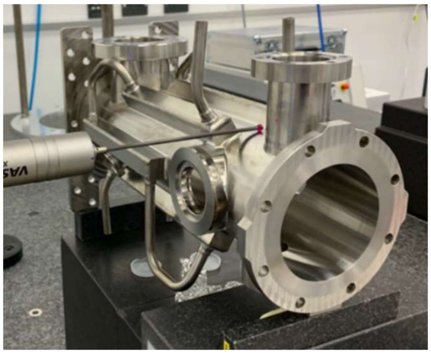

Figure 4: QWR tank being inspected by CMM.

COPPER PLATING

The plating specification is 50 +/- 10 µm along the main bore and looser in the side ports. The main bore plating thickness directly affects the final mechanical dimensions (i.e. inductive component of the cavity) which correlates to the resonating frequency of the cavity, which is fundamental to the operation. A sensitivity analysis [1] was completed to define the thickness and tolerance of plating required. The skin depth in copper at 202.5 MHz is ~5 µm, resulting in a minimum thickness of 6 x skin depth ~ 30 µm being required.

All of the tanks were inspected pre & post copper plating using the CMM. Several points were taken inside the tank, relative to external, un-plated datums with a particular focus on the main bore along the length (Fig. 5).

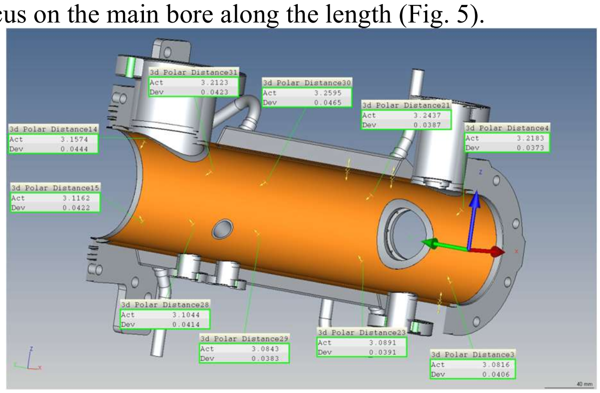

Figure 5: Copper plating thickness from CMM.

During one of the copper plating trials [3], it was observed that the plating thickness was greater at one end compared to the other. It was concluded that the conductivity and diameter of the anode was the limiting factor. The current density was lower at the end of the anode which correlated with a reduced thickness. In addition, extra pre-plating points were added into the CMM program to ensure the gradient of the plating was being captured fully. The following trial used a Platinized Titanium anode with a diameter of 25 mm rather than 12 mm. The outcome showed a more consistent uniformity along the bore.

Other issues that were observed during copper plating trials included bubbles being trapped under the surface of the plating. This was concerning because it not only affected the surface finish but there was a risk that the contents of the bubble could burst when under vacuum and RF power. Therefore, all bubbles on the tanks resulted in not accepting the plating. During the initial trials, tanks were baked out at 400 °C for two hours to check adhesion of the plating. There was no indication of plating adhesion issues, therefore it was decided not to require the bake out QWR tanks prior to operation, as that could show problems that would have never happened during normal operation.

The copper plating process was completed in two stages; the ports were plated first followed by the main bore. The tank is not immersed in a plating solution, rather a deposition process when current is applied to the anode which is inserted internally. Therefore, there is no need to mask the outer surfaces, only blanking of the port flanges is required. One of the common issues was poor plating coverage close to the edge of the ports but this was not a problem because finger strip grooves were installed close to the bore. The top flange has two grooves, the inner for RF sealing with finger strips (copper plated) and the outer for vacuum sealing which was masked (not copper plated).

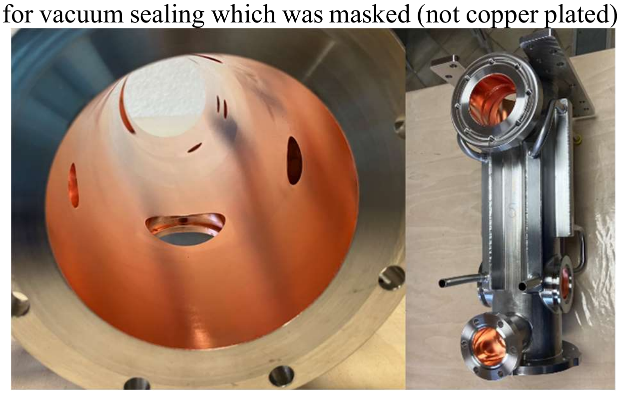

Figure 6: Copper plating of the QWR tank.

The trials concluded that the copper plating tolerances could be achieved to meet the specification. Once the five production tanks were manufactured and inspected, they were sent to be copper plated (Fig. 6).

The machined bore specification is 89.9 +/- 0.08 mm, copper plating layer 50 +/- 10 µm and final tank diameter is 89.8 +/- 0.08 mm. Upon inspection the dimensions of the production tanks are shown in Table 1.

Table 1: Final Tank and Plating Dimensions

Tank	Machined diameter	Plating thickness	Final diameter
1	89.898 mm	33 µm	89.844 mm
2	89.914 mm	50 µm	89.821 mm
3	89.878 mm	49 µm	89.783 mm
4	89.913 mm	49 µm	89.816 mm
5	89.887 mm	48 µm	89.791 mm

All dimension values are within tolerance apart from the plating thickness for Tank 1. This was expected because after plating there were pitting points that protruded from the surface. It was decided to remove the plating, grind the surface and replate. There was a larger range of thicknesses compared to the other four tanks, but it is suspected that the thickness value is closer to 50 µm because the tank was not reinspected post grinding. However, Tank 1 is still within tolerance for the final bore diameter.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR18

STEM AND LID BRAZING

The lid consists of a copper disc with a cooling channel machined into the top with a central hole for the stem. The stem is a cylindrical rod with a machined torus-like shape at the end [4]. To optimise the brazed joint, a test piece, shown in Fig. 7 was completed with varied parameters such as; clearance (0.05, 0.1, 0.15, 0.2 mm), number of rings of solder, chamfer vs counterbore and including or not including a chamfer on the underside. From the braze trials [5], it was concluded to use a clearance of 0.1 mm, a 1 mm chamfer on top, two rings of solder and a 0.5 mm chamfer on the underside.

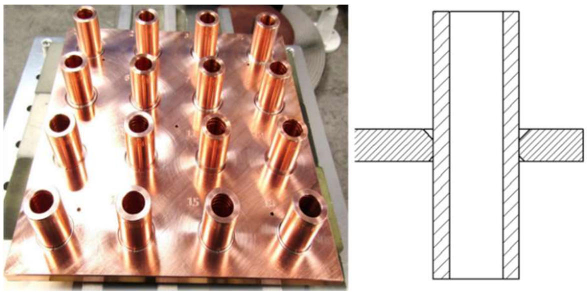

Figure 7: Brazing trials with varying parameters.

The cavity length (distance between lid and stem/beam axis) needs to be within +/- 0.2 mm and the position into and out of the plane of the torus within +/- 0.1 mm [1]. It was decided to control the brazing process between the stem and lid using a jig (Fig. 8). The brazing process was completed in a vacuum oven at low temperatures (275 ºC). Holes were added into the jig to allow the stem and tank to heat up uniformly by radiation. An alignment pin is placed through the stem torus to hold it in the correct position [6].

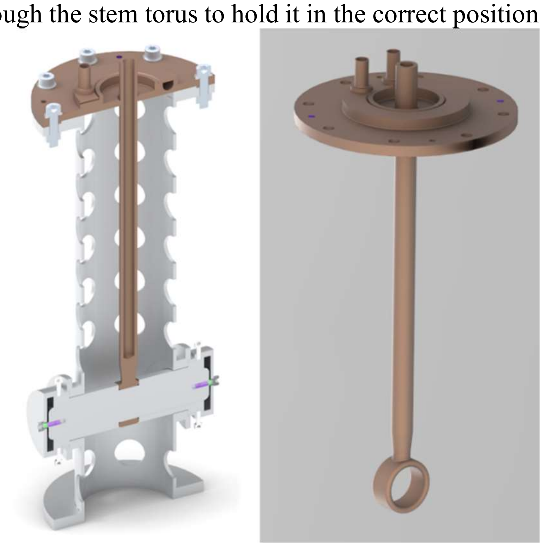

Figure 8: Stem and lid brazing with jig.

There were some challenges with the disassembly of the jig. The tight fit of the alignment pin and the torus after brazing resulted in the removal of the pin and alignment collars not being as simple as anticipated. For the production tanks, the brazing alignment process has been updated to improve disassembly whilst maintaining required alignment tolerances.

PRECISION ASSEMBLY

The final stage of the prototype assembly was to install all components into the copper plated QWR tank to within required tolerances. One of the critical dimensions was the spacing between the stem and the nose cones (the cavity gaps). The gaps were adjusted to 9.075 +/- 0.020 mm shown in Fig. 9 and Fig. 10. This was achieved by carefully bending the soft stem by hand using a CMM to check.

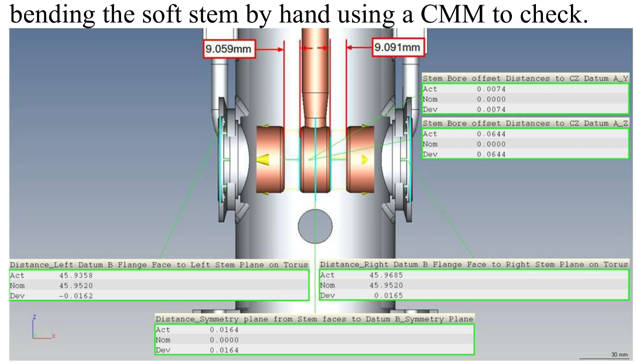

Figure 9: Inspected stem torus and nose cone alignment.

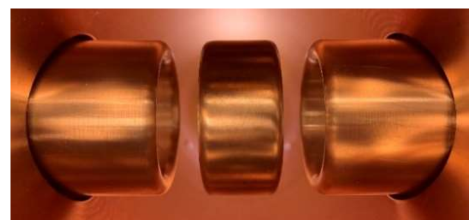

Figure 10: Stem torus and nose cone alignment.

Other connections (power coupler, tuners, water cooling fittings, pick-up loops) were assembled and adjusted to make the cavity ready for measurements.

CONCLUSION

The main challenges of the mechanical design of the QWR for the new ISIS MEBT have been presented, including the tank manufacture, copper plating, brazing of the stem and lid and precision assembly. A fully completed QWR prototype has been assembled. The whole process looked good and reproducible to be applied to the main run.

The four production cavities with a functional spare have been inspected after the copper plating and the final thicknesses achieved were excellent, resulting in the final bore dimensions being within tolerances. The brazing of the lids and stems are currently being completed before the precision assembling of the final cavities and the subsequent characterization and tuning with a VNA. Finally, they will be power tested in the new ISIS MEBT [7] once all fully assembled. The VNA tuning and testing at full RF power will be presented in a future paper.

ACKNOWLEDGEMENTS

I would like to thank Bernd Szcepaniak from Galvano-T for copper plating the QWR cavities. I would also like to thank Dave Wilsher and Sam Allum from the Metrology group at Rutherford Appleton Laboratory for their support. Finally, Tomasz from Egkenn Vacuum Technology did a great job achieving the machined tolerances of the tanks.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR18

REFERENCES

[1] I. Rodriguez, "Design of a QWR cavity for the new ISIS MEBT", in *Proc, 14th Int. Particle Accelerator Conf. (IPAC' 23)*, Venice, Italy, May 2023, pp. 2227-2229. doi: 10.18429/JACoW-IPAC2023-TUPM017

[2] Egkenn Vacuum Technology Sp. Z o.o., Biłgoraj, Poland, https://www.egkenn.eu/

[3] Galvano-T electroforming-plating GmbH, Windeck, Germany, https://www.galvano-t.de/en/home/

[4] I. Rodriguez, "QWR for the ISIS MEBT – Technical Design Report", Rutherford Appleton Laboratory, UK, Feb. 2019.

[5] Special Techniques Group, Culham Centre for Fusion Energy, Oxfordshire, UK, https://ccfe.ukaea.uk/divisions/fusion-technology/special-techniques/

[6] A. Lees, "QWR for the ISIS MEBT – Mechanical Design Report", Rutherford Appleton Laboratory, UK, May 2019.

[7] S. Lawrie *et al.*, "A pre-injector upgrade for ISIS, including a medium energy beam transport line and an RF-driven H− ion source", *Rev. Sci. Instrum.*, vol. 90, no. 10, Oct. 2019. doi:10.1063/1.5127263