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WELDING AND COPPER PLATING INVESTIGATIONS ON THE FAIR PROTON LINAC

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Abstract

A FAIR injector linac for the future FAIR facility is under construction. In order to meet the requirements for copper plating of the CH-cavities, a variety of tests with dummy cavities has been performed and compared to simulation. Further dummy cavities have been produced in order to improve the welding techniques. In addition, the results on 3d-printed stems with drift tubes will be presented.

OVERVIEW

The present GSI injector UNILAC (universal linear accelerator) [1] will serve as one injector for the future Facility for Antiproton and Ion Research (FAIR) [2]. However, a large part of the FAIR experiments will be conducted with secondary antiprotons which will be produced by bombarding a target with an intense proton beam. Because the UNILAC is optimized for heavy ions, i.e., particles with an $A/q >> 1$, a dedicated proton injector is presently under construction. It consists of a ladder RFQ [3] followed by six CH structures (Crossbar H-mode).

Figure 1 shows the structure of the proton linac [4]. The main acceleration from 3 MeV up to 33 MeV will be realized with three coupled CH-cavities (CCH) connected by a coupling tank housing a focusing magnetic quadrupole triplet lens, followed by a diagnostic section at 33 MeV and finalized up to 68 MeV by three single CH-modules. The cavity design of all six CH-type cavities has been developed by IAP University of Frankfurt [5]. They operate at a resonance frequency of 325.224 MHz. It is designed to provide a proton beam with an energy of 68 MeV and a current up to 70 mA at a rf pulse prepetition rate of 2.7 Hz.

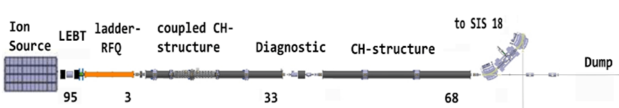

Figure 1: Layout of the proton linac.

Figure 2 shows the first coupled CH-DTL cavity. The low energy part consists of ten gaps, followed by the coupling cell and by the eleven-gap high energy part. The whole cavity has an inner length of about 1.4 m and the cylindrical tanks have an inner diameter of about 307 mm (first section) and 316 mm (second section). The coupling cell has a length of about $2\beta\lambda$. Twelve fixed (five in tank one and seven in tank two) and three movable tuners (located at each cavity and at the coupling cell) are foreseen.

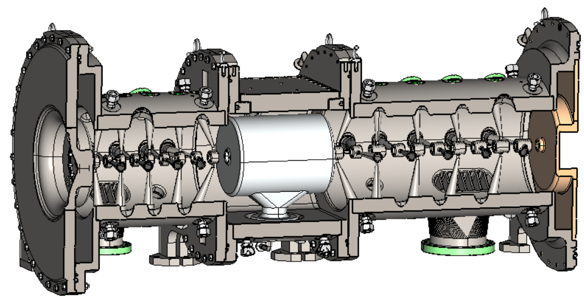

Figure 2: 3d-model of the first coupled CH-cavity.

WELDING AND COPPER PLATING STUDIES

Due to these complex monolithic structures with tiny distances of the stems and aperture of the tank design, there is no possibility of conventional welding from the inside. Other welding techniques (outside welding) are not well established at GSI. In addition, copper plating for these novel structures is particularly challenging. Therefore, four types of test dummies are planned for CCH1, which can be considered as the most complex structure. Table 1 shows our learning process for the new welding technique from the outside, as well as the copper plating process.

Table 1: Learning Process Outside Welding and Copper Plating Per Dummy In Percent

Learning Process	Copper Plating	Welding
Dummy 1	50 %	0%
Dummy 2 & 2.1	90%	10%
Dummy 3	95%	70%
Dummy 4	98%	100%

DUMMY 1

Dummy 1 (see Fig. 3) is a simple rolled steel sheet with straight stems tacked inside. This dummy has already been copper plated at GSI.

Figure 3: Dummy 1 consists of a simple rolled steel sheet with straight stems tacked inside.

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The first iteration (Fig. 4 top) without any surface treatment shows worse copper plating results on the top of the stems and the tank wall due to missing direct air distribution. After stripping off the copper, the second iteration (Fig. 4 bottom) of copper plating with better air distribution and optimized anodes showed better results on the stems, but even worse results on the tank wall due to an electrolytic degreasing bath, which has been in use already.

Figure 4: First copper plating iteration on Dummy 1 (top) and second iteration of copper plating (bottom).

Finally, after three iterations of copper plating, a good result with optimized anode geometry, a new degreasing bath, and better air distribution could have been achieved (Fig. 5).

Figure 5: Third iteration of copper plating on Dummy 1 with the best result.

DUMMY 2 & 2.1

Dummy 2 is a more complex model of the first CCH1 section manufactured at GSI workshop in May 2019 (Fig. 6). This model consists of a rolled steel sheet with flanges. The angular stems are welded out of three parts and tacked inside the cavity.

After successful copper plating at GSI (Fig. 7), photomicrograph show that the copper layer is very uniform and continuous in the area of the tank wall and the stems. Adhesion to the base material is well-developed, and no cracks or other defects were detected in the copper layer. Except in the area of the drift tubes, the copper layer thickness varies significantly. The front surfaces are then partly no longer exactly parallel to each other, which would affect the electrical acceleration field negatively.

In parallel, electrostatic simulations performed in cooperation with the University of Frankfurt with the goal to optimize the geometry of the galvanic anodes. Details are given in Ref. [6].

In order to be able to verify the results of the electrostatic simulations, a new dummy 2 is presently under construction. In addition, the longest cavity section of CCH2 with about 1.3 m (Dummy 2.1) should be copper plated in the new electrolytic bath, which is currently under construction. Dummy 2 and 2.1 will be copper plated when the galvanic workshop is commissioned in early 2023 after a refurbishment.

Figure 6: Dummy 2 with a more complex structure of CCH1.

Figure 7: Copper plated Dummy 2 of CCH1.

DUMMY 3 (3D-PRINTED STEMS)

Dummy 3 is the first Dummy testing the welding process. Shown here simplified by a plate with a stem, which is welded from the outside (Fig. 8). Tests with e-beam welding are performed at Pink GmbH Vakuumtechnik in Wertheim, Germany.

A stem end part was welded to a small plate made of stainless steel 1.4404 (V4A - 316L) from the outside via e-beam welding. The stem is 3d-printed 1.4404 material. Since 3d-printed elements are not tested material for such purpose, an approval of the additive manufacturing is required.

The welding root has a thickness of maximum 0.4 mm, the vacuum leak test did not show any defects, as well as no flaws could be detected via an X-ray test. The mechanical-technical parameters provide acceptable results, so that this material / this manufacturing process can be used.

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The copper plating could be characterized as intact, continuous and uniform (also the area of the e-beam weld). Only the area of the weld overlap from the beginning and end of the welding root shows increased peaks, which need to be reworked.

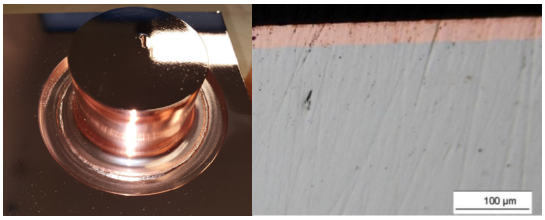

Figure 8: Dummy 3 – Plate with 3d-printed Stem - copper plated Dummy 3 (left)), photomicrograph of the copper layer (right).

DUMMY 4 – PRETEST

A pretest tank with three angular stems of the first section from CCH1 to qualify the manufacturer (Pink GmbH Vakuumtechnik in Wertheim, Germany) for the CH cavities is required (Fig. 9). The stems are 1.4404 3d-printed material, the tank is forged stainless steel 1.4404 (finishing via turning, grinding, milling, and polishing). If the dimensional accuracy is given, this dummy will be copper plated at GSI in order to finally adjust the copper layer at the welding root.

Figure 9: Dummy 4 – Pretest tank of CCH1 with three angular stems out of 3d-printed steel.

FOS – CCH1

A stainless steel tank of the first CCH will be built, fully prepared to be suitable for vacuum and water cooling. First low level rf and tuning tests will be done with clamped aluminum stems to check the simulations and make any necessary adjustments to the design of the drift tubes.

In a second step, the stems and drift tubes will be made of 3d-printed stainless steel (perhaps with some modifications if simulation and measurement do not match) and welded into the tank, followed by the copper plating and high power tests. If everything fits, this is the first cavity for operation with beam.

CONCLUSION

This paper showed the development of the welding and copper plating process for a very complex accelerator structure. As conventional welding from the inside is not possible, e-beam welding is to be used to weld the stems with the drift tubes inside the cylindrical cavity from the outside. The tank is to be made of forged stainless steel 1.4404 (V4A - 316L). The stems and drift tubes will be 3d-printed in one part of 1.4404 stainless steel. For a final check of the rf parameters, a first of series tank of CCH1 with clamped aluminum stems is currently under construction. Later, the aluminum stems will be replaced by 3d-printed 1.4404 stems e-beam welded from the outside for operational use.

OUTLOOK

After several test dummies, the welding and manufacturing process have been verified, so that the fabrication of CCH1 as FoS has already started. In order to be even more reliable, it is initially equipped with clamped aluminum stems. According to the current status, the FoS of CCH1 is to be delivered to GSI at the end of 2022 for the first low level rf and tuning tests. Awaiting the results of the compliance of dimensions of the pretest in the near future, as well as pressure and X-ray tests of the welding seam to complete the studies and fix the manufacturing process.

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