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DEVELOPMENT OF A 704.4 MHz CH CAVITY USING ADDITIVE MANUFACTURING

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Abstract

A novel 704.4 MHz CH structure is under development. Due to its relatively small spatial dimensions (22 cm in diameter and 33.7 cm in length), the additive manufacturing (AM) technology is an attractive choice for the construction. For a proof of concept, a simplified model with one stem, one drift tube, and a small part of another stem was printed with copper. This structure was also foreseen for CW operation, so the design of the water-cooling channels inside the drift tubes and stems have been optimized and checked by the Ansys simulation. The progress with the realization of the 704.4 MHz CH structure will be presented.

INTRODUCTION

With the potential application to shorten the middle energy parts ($\beta = 0.2 \sim 0.5$) of large-scale linear accelerators considerably, a new CH (crossbar H-mode) structure has been proposed to extend the highest working frequency for all built CH cavities, 360 MHz, to 704.4 MHz [1, 2].

The main design parameters and the MWS [3] simulation results of a 704.4 MHz CH cavity are summarized in Table 1. The simulated effective shunt impedance is $Z_{\mathrm{eff,MWS}}$ = 53.46 MΩ/m and the RF power consumption P_{c} = 1.5 kW which has been calculated using 85% of $Z_{\mathrm{eff,MWS}}$ with a safety margin. For this 704.4 MHz CH cavity, the distribution of the RF power consumption is as follows: 60.6% on the stems, 32.2% on the drift tubes, and 7.2% on the tank wall, respectively.

Table 1: Design Results of a 704.4 MHz CH Cavity [1]

Parameter	Value
Frequency f [MHz]	704.4
Gap number	7
Tank length [mm]	337
Tank inner radius [mm]	80
Tank outer radius [mm]	110
Tube inner aperture radius [mm]	10
Shunt impedance simulated by MWS $Z_{\mathrm{eff,\,MWS}}$ [MΩ/m]	53.46
RF power consumption P_{c} [kW]	1.5 (using 85% of $Z_{\mathrm{eff,\,MWS}}$)

For the water-cooling design of the 704.4 MHz CH cavity, 2.5 kW of heat load (including ~ 70% of additional RF power in terms of $Z_{\mathrm{eff,MWS}} \times 85\%$) was applied to the CH cavity in the thermal simulation, where 1.5 kW for the stems, 0.8 kW for the drift tubes, and 0.2 kW for the other parts, respectively [1].

In a follow-up study [4], a more detailed mechanical design focusing on how to achieve practical RF coupling and tuning as well as simpler assembly was done (see Figure 1). The main changes implemented in the new cavity design are as follows:

- The outer profile of the cavity has been changed from a cylindrical shape to an octagonal one.
- The electrodes (1 electrode = 1 stem + 1 drift tube + 1 stem) become mountable. As shown in Figure 2, the base diameter of this kind of electrode at one end is smaller than that at another end so that the whole electrode can be inserted through the whole cavity wall and can then be fixed on the cavity wall.
- Two inductive plungers as well as capacitive RF-coupler and pick-ups have been added.

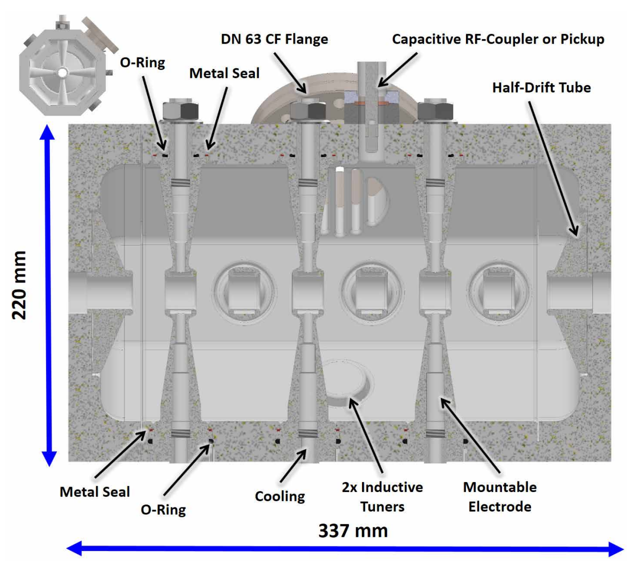

Figure 1: CAD-model of the 704.4 MHz CH cavity with 6 water-cooled and mountable electrodes [4].

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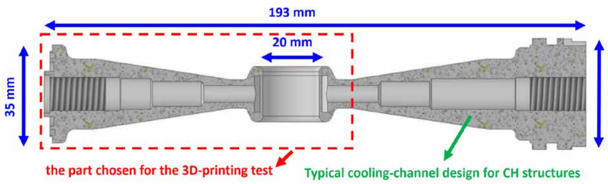

Figure 2: A mountable CH electrode.

To realize this very compact cavity, it was foreseen to use the Additive Manufacturing (AM) technology already at the beginning when the concept of the 704.4 MHz CH structure was proposed [1]. As the first step for a proof of concept, a simplified model with one stem, one drift tube, and a small part of another stem (see the part inside the red frame in Figure 2) has been printed with copper using a 3D printer "TruPrint 1000 Green Edition" [5, 6].

3D PRINTING OF A PROTOTYPE

The AM technology is a kind of state-of-the-art technology for construction and the Selective Laser Melting (SLM) method is a main technical approach for additive manufacturing with metal materials [7]. It uses laser as the energy source to scan the metal-powder bed layer by layer according to the 3D CAD slice-model. The scanned metal powder will be rapidly melted by the heat of the laser beam and then rapidly solidified. In this way, one can obtain metal parts in the designed shape.

One advantage of the SLM method over the traditional methods is that it can overcome many difficulties in manufacturing metal parts with complex shapes. This is especially suitable for the construction of the 704.4 MHz CH cavity that has small electrodes with complicated cooling channels inside.

In Figure 3, the absorption rate of different metals is plotted as a function of the wavelength of the adopted laser. Generally speaking, the shorter the laser wavelength, the higher the absorption rate, especially for copper. Therefore, we have decided to take the 515 nm wavelength instead of the common-used 1064 nm for the 3D printing of our prototype.

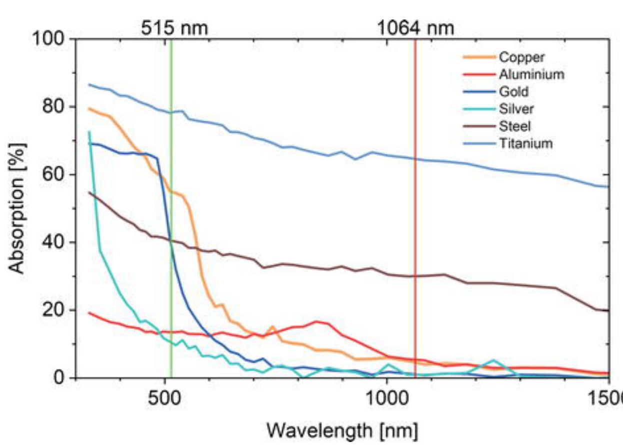

Figure 3: Absorption rate of different metals as a function of the laser wavelength (taken from [7]).

Figure 4 shows the CH-electrode model printed with copper [8]. A 3D scanner "GOM Atos Core 135" was used to check the surface quality provided by the 3D printing. The deviations are mainly in the range of ± 75 µm. It is worthy to mention that most of the discrepancies were found in the area close to the connection of the stem and the drift tube. To improve the surface quality, post-processes by means of plasma electrolytic polishing were carried out in cooperation with the Beckmann Institute [9]. The results showed that surface roughness could be reduced from Rz80 to Rz6 with plasma electrolytic polishing [8].

Figure 4: CH electrode model printed with copper (left) and checked with Computed Tomography (right) [8].

In order to check whether there are non-copper materials contained in the printed product, an X-ray fluorescence analysis was carried out at the GSI technology laboratory. In the measurement, a copper content of 99.99% was identified [8].

Last but not least, to check if pores, blowholes, cracks, and other defects are inside the printed prototype, the non-destructive testing method, Computed Tomography (CT), has been adopted. In the right graph of Figure 4, one can see the well-printed cooling channels inside the printed prototype clearly [8].

IMPROVEMENT OF THE COOLING-CHANNEL DESIGN

The preliminary thermal simulation of the 704.4 MHz CH cavity was done using MWS [1]. As this structure had been also foreseen for CW operation, a more careful simulation using the professional software Ansys Discovery [10] was performed.

In the MWS simulation, it was found that the RF power losses were mainly distributed on the 4 CH electrodes in the middle of the tank. In the Ansys Discovery simulation, it is assumed that the total RF power losses for all stems and drift tubes (i.e. 1.5 kW + 0.8 kW) are distributed on

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these 4 electrodes (which means an even larger safety margin) i.e. each electrode has an average RF power losses of 0.58 kW.

Figure 5 shows that the temperature of the hottest spot on a CH electrode with typical cooling channels (see Figure 2) is 71.7 °C at a cooling-water pressure of 6 bars and at a cooling-water flow rate of 14.4 × 10^{-6} m^3/s (the temperature of the input cooling water is 25 °C). The temperature increase is higher than that in the MWS simulation. For a more reliable CW operation, therefore, it was decided to further improve the cooling-channel design.

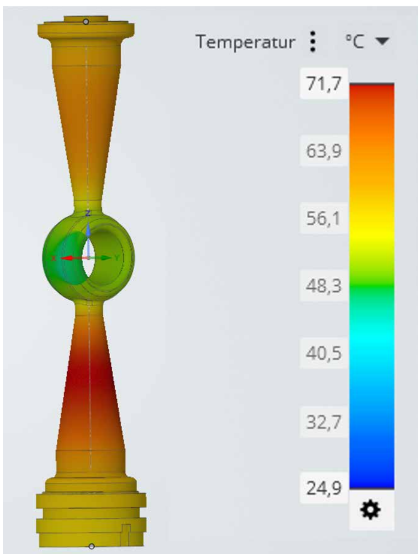

Figure 5: Ansys simulation of a CH electrode with typical cooling channels (see Figure 2).

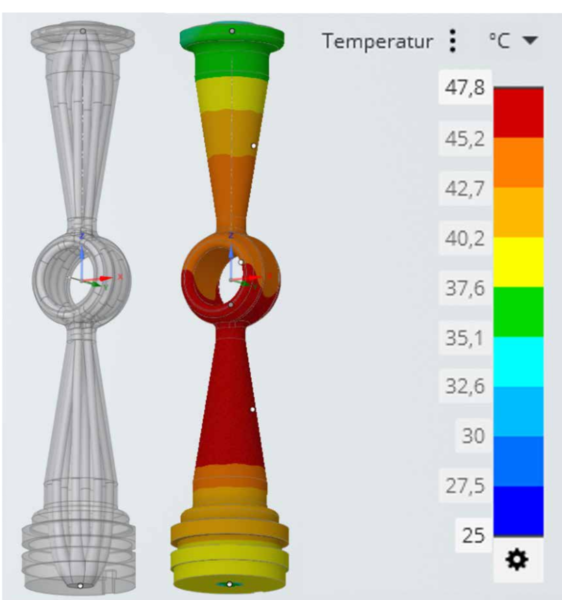

Figure 6: Ansys simulation of a CH electrode with improved cooling channels.

In Figure 6, an improved cooling-channel design is shown. It uses 8 slimmer channels (Ø = 3 mm) instead of one thick channel for cooling the stems and these 8 channels will be merged as 4 channels in the drift-tube part. It can be seen that the maximum temperature drops by 24 °C thanks the new design.

CONCLUSION

The highlights of the new R&D towards the realization of the 704.4 MHz CH structure have been presented. The planned next steps are as follows:

- To manufacture the whole CH cavity using the AM technology.
- To perform low-level RF measurements on the 3D-printed cavity.
- To find a suitable RF power source for high power tests.
- The beam test can be done in the future e.g. by putting the 704.4 MHz CH cavity at the end of the MYRRHA injector [11] that is under construction.

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