ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJ004

R&D FOR THE REALIZATION OF A VERY HIGH FREQUENCY CROSSBAR H-MODE DRIFT TUBE LINAC

M. Heilmann*[1], C. Zhang[1], and H. Podlech[2,3]
[1]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany
[2]IAP, Goethe University, Frankfurt, Germany
[3]Helmholtz Research Academy Hesse for FAIR (HFHF), Frankfurt, Germany

Abstract

A 704.4 MHz Crossbar H-mode (CH) drift tube LINAC has been proposed for performing a radio frequency jump at $\beta \approx 0.2$. Up to now, the highest frequency of the constructed CH cavities is 360 MHz. In principle the operation frequency for an H_{210}-mode cavity can be up to 800 MHz. At 704.4 MHz, the cavity dimensions become small, which bring challenges for many practical problems e.g. construction, vacuum pumping and RF coupling. This paper presents the performed R&D studies for the realization of such a very high frequency cavity.

INTRODUCTION

The crossbar H-mode (CH) drift tube LINAC (DTL) has been developed as a kind of efficient RF-structure for accelerating low- and medium-β beams [1, 2]. In principle, the operation frequency for a CH-structure can be up to 800 MHz [1], but up to now, the highest frequency of all realized CH-cavities is 360 MHz [2]. In a recent study [3], a kind of novel 704.4 MHz CH-DTL has been proposed to enable a radio frequency jump from 176.1 MHz to 704.4 MHz at $\beta \approx 0.2$ for a large-scale LINAC (Fig. 1). This fourfold increase in radio frequency can shorten the entire LINAC [4,5] as well as can reduce the related construction and operation costs considerably. 704.4 MHz is almost twice the highest frequency of already constructed CH-cavities. The preliminary RF-structure design results have shown that such a very compact cavity can work in CW-mode both at room temperatures and at liquid helium temperatures [3]. As a further step towards the realization of a 704.4 MHz CH-DTL cavity (firstly normal conducting), more practical aspects e.g. mechanical design, vacuum pumping and RF coupling are being investigated carefully.

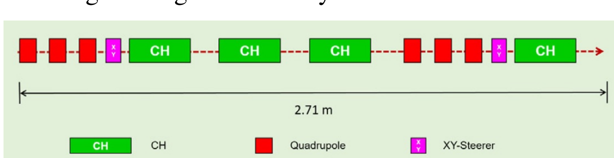

Figure 1: Schematic overview of the frequnecy jump section based on four 704.4 MHz CH-DTLs (taken from [3]).

VERY HIGH FREQUENCY CH-DTL

The normal conducting CH-DTL for 704.4 MHz will have an octagonal tank cross-section to mount for the first time

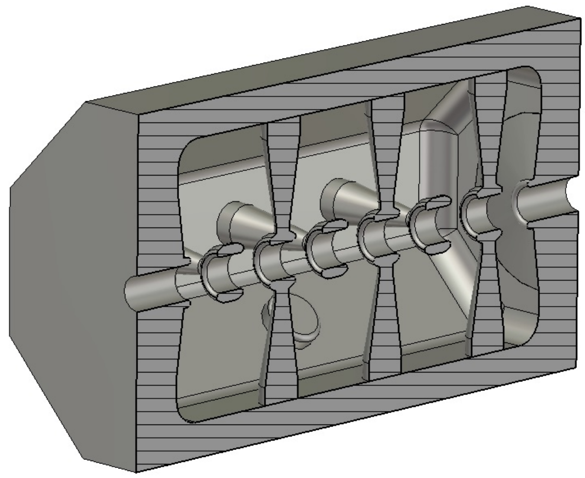

Figure 2: CST-MWS [6] model of the recent design of the 704.4 MHz CH-DTL (side view).

Table 1: Design Parameters of the NC CW CH-DTL

Parameter	Unit	Value
RF-frequency	MHz	704.4
β		0.186
Gaps	#	7
Gap length	mm	19.8
Drift tubes	#	6
Drift tube length	mm	19.8
Drift tube aperture	mm	20.0
Tank diameter (inner)	mm	160.0
Tank length	mm	337.0
Total RF-power	kW	1.5
Acceleration gradient	MV/m	0.5
Shunt impedance (sim.)	MΩ/m	53.46
Kilpatrick Factor		0.24

CH-drift tubes with its stems into a tank (Fig. 2, Table 1). For superconducting [7–9] and room temperature CH-DTLs [10, 11], the standard way is to weld the drift tubes into the tank. The drift tubes are not welded into this very high frequency CH-structure to reduce the risks and challenges at copper plating of the cavity (Fig. 3). The copper plating of a normal conducting CH-structure becomes more critical for a smaller diameter in combination with an increased cavity length, so another option for this small cavity can be to manufacture the tank from copper.

* m.heilmann@gsi.de

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJ004

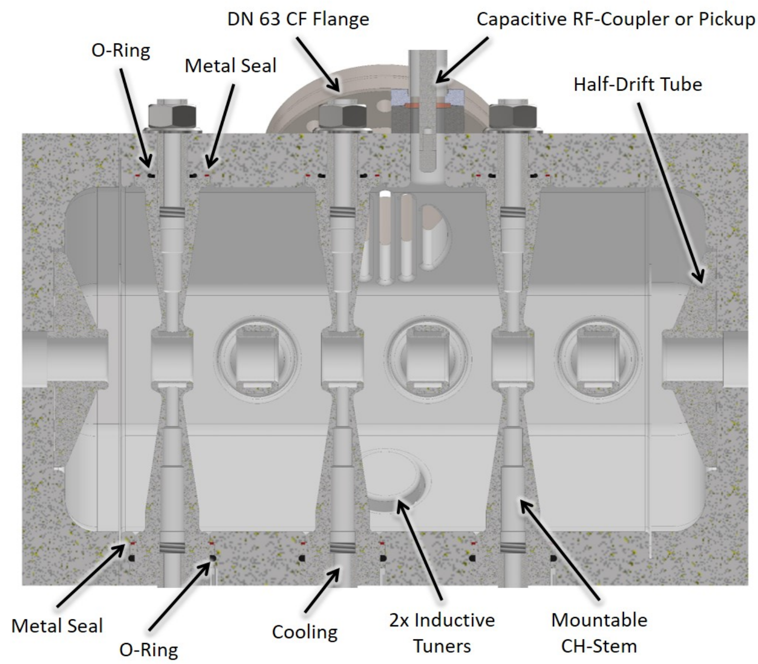

Figure 3: CAD-model of the very high frequency CH-DTL with six water cooled and mountable drift tubes (side view). The cavity has an octagonal cross section for simplified assembly and an inner diameter of 160 mm. Two plungers are installed and the RF-incoupling and the pickup's are capacitive.

The desired homogeneous copper layer thickness distribution in an accelerator is not longer given at a CH-drift tube in relation to the tank wall. The individual drift tube has a greater increase in layer thickness due to the copper plating and this reduces the distance between adjacent drift tubes. The minimal displacement of the gap center is part of further error studies at beam dynamic investigations, but the resulting frequency deviation is especially in a very high frequency accelerator not negligible.

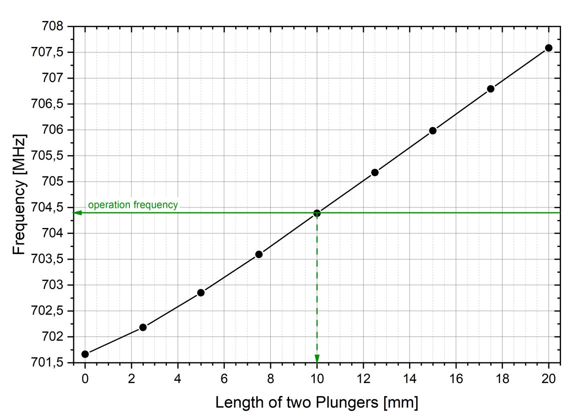

Figure 4: Simulated frequency of the very high frequency CH-DTL depending on the position of the two plungers (∅33 mm).

A mountable CH-stem has a flat surface from the stem to the tank wall, that will reduces the magnetic field at the bottom of the stem. The typical three-stage vacuum con-

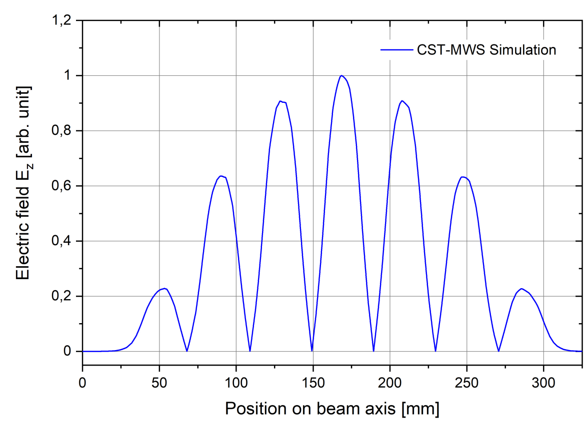

Figure 5: Simulated electrical field distribution on beam axis at the operation resonance frequency of 704.4 MHz.

cept (metal seal, pre-vacuum gloove and O-ring seal) is also available for every drift tube with its good electrical and RF-contact about the metal seal.

The power RF in this normal conducting CH-DTL has a capacitively incoupling because an inductive incoupling requires more installation space and the rotating of the loop induce an unwanted frequency change during minimization of the S_{11}-parameter. The location between the stems of the capacitive incoupling as well as the pickups have been established as a standard in a SC CH-DTL.

The very high frequency is sensitive and therefore an extended tuner concept is used. In addition to the static and dynamic frequency tuners, the end plates of the tank

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJ004

can be shortened during production for greater frequency adjustment. The designed frequency deviation of the two tuners of about ± 3 MHz is too large for later operation, but necessary to compensate the expected deviation between the simulated and measured frequencies (Fig. 4). The diameter of the frequency tuners can be reduced for fine tuning and a different diameter is also possible without any noticeable affecting of the field distribution on the beam axis (Fig. 5). The tank breakthroughs of the RF-incoupling and pickup's as well as the vacuum slots are also integrated for more accurate simulation.

A simplified connection between tank and stem of the CH-drift tube can be realized in the next step by 3D printing. The advantage of 3D printing on a DTL is the connection of complicated, vacuum-tight and water-cooled geometries. The goal is a complete 3D-printed CH-cavity with drift tubes, stems and all flanged connectors. First 3D-printed IH-drift tubes (1.4404 stainless steel) [12] and trials of UHV pipelines (316L stainless steel) [13] were successful, but in both cases the flanges must be lathed to avoid leaks. The printing of high-purity copper is technically possible, but the choice of material for 3D-printing is crucial for the further course of the investigations and mechanical rework of the surface. The used copper must have high electrical conductivity combined with a low outgassing rate and high surface quality. The end plates of the tank will be built separately in order to continue to be able to guarantee the iterative frequency adjustment.

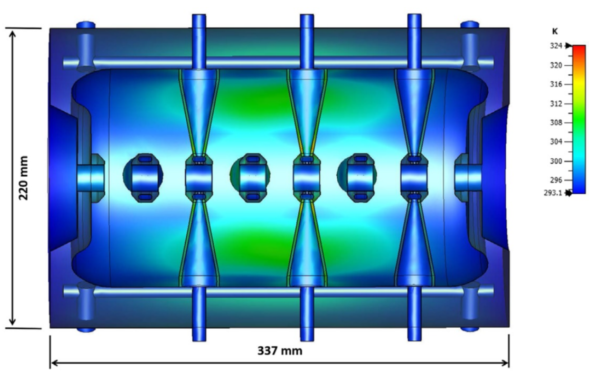

Figure 6: Simulated temperature distribution of the 704.4 MHz CH-DTL with 2.5 kW of input RF power, highest thermally stressed point at the stem (T=324 K) and constant 293.1 K water cooling (taken from [3]).

The temperature investigations with CST-simulations for CW-operation at 2.5 kW RF-power results in a maximum temperature difference of 31°C [3] between the cooling water and the highest thermally loaded point on the stem (Fig. 6). The drift tubes and stems are fully cooled and multiple cooling channels are located in the tank and the two end plates.

OUTLOOK

The very high frequency CH-DTL has been investigated and simulated, the next step is the detailed elaboration of a 3D-printed and normally built variant. A separate vacuum test for the first mountable CH-stems is planned, followed by the construction of a complete prototype CH-structure. First tests on the frequency behavior of the cavity can be carried out with the uncoppered prototype and after the copper plating, detailed investigations of the temperature behavior depending on the incoupled high RF-power are foreseen.

Additionally, consideration is being given to an SC version of the very high frequency CH-structure.

REFERENCES

[1] U. Ratzinger, "Effiziente Hochfrequenz-Linearbeschleuniger für leichte und schwere Ionen", Habilitationsschrift, Goethe University, Frankfurt, Germany, 1998.

[2] H. Podlech, U. Ratzinger, H. Klein, C. Commenda, H. Liebermann, and A. Sauer, "Superconducting CH structure", Phys. Rev. ST Accel. Beams, vol. 10, p. 080101, Aug. 2007. doi:10.1103/PhysRevSTAB.10.080101

[3] C. Zhang, D. Koser, N. Petry, H. Podlech, and E. Tanke, "Frequency Jump Using 704.4 MHz Radio-Frequency Quadrupole and Cross-Bar H-Type Drift Tube Linear Accelerators", *Phys. Rev. Accel. Beams*, vol. 24, p. 040101, Apr. 2021. doi:10.1103/PhysRevAccelBeams.24.040101

[4] M. Vretenar, V.A. Dimov, M. Garlasch´e, A. Grudiev, B. Koubek, A.M. Lombardi, S. Mathot, D. Mazur, E. Montesinos, and M. Timmins, "High-frequency compact RFQs for medical and industrial applications", in *Proc. 28th Linear Accelerator Conf. (LINAC'16)*, East Lansing, MI, USA, Sep. 2016, pp. 704-709. doi:10.18429/JACoW-LINAC2016-TH1A06

[5] B.P. Xiao, S. Belomestnykh, I. Ben-Zvi, J.C. Brutus, A. Fedotov, G. McIntyre, K. Smith, J. Tuozzolo, V. Veshcherevich, Q. Wu, W. Xu, and A. Zaltsman, "Design of Normal Conducting 704 MHz AND 2.1 GHz Cavities for LEReC LINAC", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 3634-3637. doi:10.18429/JACoW-IPAC2015-WEPWI061

[6] Dassault Systemes Deutschland GmbH, CST Studio Suite, CST MicroWave Studio, https://www.3ds.com/products-services/simulia/products/cst-studio-suite/

[7] M. Busch, M. Amberg, K. Aulenbacher, W. Barth, F. Dziuba, S. Mickat, H. Podlech, and U. Ratzinger, "Status of the 325 MHz SC CH-Cavity at IAP Frankfurt", in *Proc. 2th Int. Particle Accelerator Conf. (IPAC'11)*, San Sebastián, Spain, Sep. 2011, pa,per MOPC082, pp. 265-267.

[8] F. Dziuba, M. Amberg, K. Aulenbacher, W. Barth, M. Busch, V. Gettmann, H. Podlech, U. Ratzinger, and S. Mickat, "A Superconducting 217 MHz CH Cavity for the CW Demonstrator at GSI", in *Proc. 16th Int. Conf. on RF Superconductivity (SRF'13)*, Paris, France, Sep. 2013, pp. 906-908. https://jacow.org/srf2013/papers/thp003.pdf

[9] M. Basten, K. Aulenbacher, W. Barth, M. Busch, F. Dziuba, V. Gettmann, M. Heilmann, Th. Kürzeder, M. Miski-Oglu, H. Podlech, M. Schwarz, and S. Yaramyshev, "First Measurements of the Next SC CH-Cavities for the New Superconducting CW Heavy Ion LINAC@GSI", in *Proc. 18th Int. Conf. on RF Superconductivity (SRF'17)*, Lanzhou, China, Jul. 2017, pp. 433-436. doi:10.18429/JACoW-SRF2017-TUPB022

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJO04

[10] A. Seibel, “Entwicklung und Test des 175MHz CH-Rebunchers für das FRANZ-Projekt”, master thesis, IAP, Goethe University, Frankfurt, Germany, 2013. urn:nbn:de:hebis:30:3-364730

[11] N.F. Petry, S. Huneck, K. Kümpel, H. Podlech, U. Ratzinger, and M. Schwarz, “Test of a High Power Room Temperature CH-DTL Cavity”, in *Proc. 8th Int. Particle Accelerator Conf. (IPAC’17)*, Copenhagen, Denmark, May 2017, pp. 2237-2239. doi:10.18429/JACoW-IPAC2017-TUPVA069

[12] H. Haehnel and U. Ratzinger, “First 3D Printed IH-Type LINAC Structure - Proof-of-Concept for Additive Manufacturing of LINAC RF Cavities”, in *Proc. 12th Int. Particle Accelerator Conf. (IPAC’21)*, Campinas, SP, Brazil, May 2021, pp. 654-657. doi:10.18429/JACoW-IPAC2018-MOPAB194

[13] G. Sattonnay, M. Alves, S. Bilgen, J. Bonis, S. Djelali, A. Gonnin, M. Guerrier, D. Grasset, S. Jenzer, F. Letellier-Cohen, B. Mercier, and E. Mistretta, “First 3D Printed IH-Type LINAC Structure - Proof-of-Concept for Additive Manufacturing of LINAC RF Cavities”, in *Proc. IPAC’19*, Melbourne, Australia, May 2019, pp. 2240-2243. doi:10.18429/JACoW-IPAC2019-WEXXPLS3