CAVITY DESIGNS FOR THE CH3 TO CH11 AND BELLOW TUNER INVESTIGATION OF THE SUPERCONDUCTING HEAVY ION ACCELERATOR HELIAC*

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Abstract

New CH-DTL cavities designs of the planned Helmholtz Linear Accelerator (HELIAC) are developed in collaboration of HIM, GSI and IAP Frankfurt. The linac, operated in cw-mode with a final energy of 7.3 MeV/u, is intended for various experiments, in particular with heavy ions at energies close to the Coulomb barrier for research on SHE. Twelve sc CH cavities are foreseen, divided into four different cryostats. Each cavity will be equipped with dynamic bellow tuner. After successful beam tests with CH0, CH3 to CH11 are being designed. Based on the experience gained so far, optimizations will be made, which will lead to both an increase in performance in terms of reducing the peak fields limiting superconductivity and a reduction in manufacturing costs and time. In order to optimize manufacturing, attention was paid to design many parts of the cavity, such as lids, spokes, tuner and helium shell, with the same geometrical dimensions. In addition, a tuner test rig was developed, which will be used to investigate the mechanical properties of the bellow tuner. For this purpose, different simulations were made in order to realize conditions as close as possible to reality in the test bench.

INTRODUCTION

The HELIAC at GSI in collaboration between IAP, GSI and HIM is a superconducting cw-operated Linac to be built. Since UNILAC, which is currently being upgraded as part of the FAIR project, will no longer be suitable for superheavy element (SHE) synthesis experiments, HELIAC will replace it for these experiments [1]. For this purpose, a demonstrator cavity CH0 has already been designed, built and successfully tested [2]. After this two identical cavities CH1 and CH2 were designed, built and also successfully characterized in a cold test [3]. Through various experiments at GSI,HIM [2, 4-8] and IAP [9-17] as well as different adaptations and investigations of the CH cavity design, different experiences could be gained. The entire HELIAC will consist of a total of four cryomodules, each containing three superconducting CH cavities, one solenoid and two superconducting bunchers.

In august 2018 the design of nine 216.816 MHz sc CH-cavities (CH3 to CH11) for the HELIAC has started [18]. The design of these nine cavities is based on the design of the CH1 and CH2 cavities [3]. During this design process, various adjustments were made to the design. A modular cavity design for superconducting CH cavities was developed at IAP, which simplifies manufacturing and thus reduces both production costs and time. In addition to the design cavities, a bellow tuner test bench was designed, which will be used to test the mechanical properties of the bellow tuners made of niobium.

CAVITY DESIGN

The basic design of the nine 216.816 MHz sc CH cavities is the same for all cavities (see Fig. 1). They differ only in some parameters like the number of gaps, the gap lengths, the radius and the total length. All cavities are designed to incorporate two static tuners for frequency adjustment during manufacture and two dynamic bellow tuners for frequency adjustment during operation.
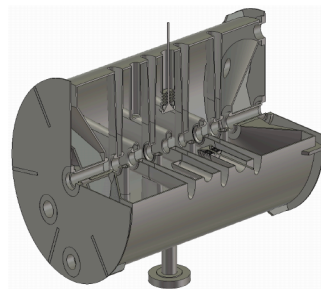

Figure 1: Layout of CH-cavity CH4 without helium vessel. The basic design of all cavities is the same except for the number of gaps, the gap lengths, the radius and the length.

The radius of the individual cavities increases steadily from CH3 to CH11, since the increasing beta causes the gap mean distances to increase from cavity to cavity and thus the capacity on the beam axis decreases. The total length of

the cavities, on the other hand, varies strongly, since the gap mean distances are larger, but the number of gaps decreases (see Fig. 2).
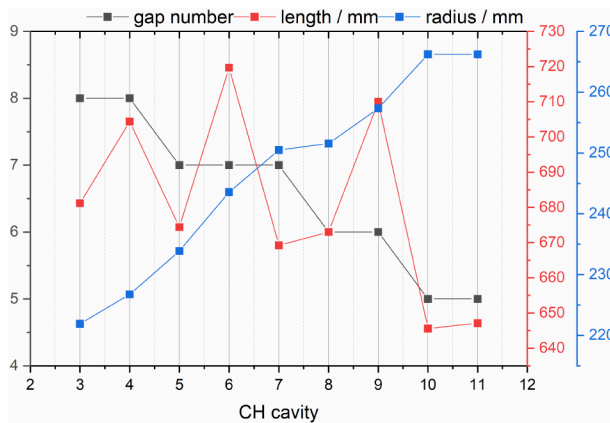

Figure 2: Graphic representations of the geometric differences of the cavities CH3 to CH11

Special attention was paid to optimizing the design of the new cavities in terms of performance. For this purpose, particular attention was paid to reducing the peak fields. Compared to the two predecessor cavities CH1 and CH2, the peak fields were significantly reduced in almost all cavities. Thus, CH1 and CH2 showed an $E_{peak}/E_a = 6.5$ and a $B_{peak}/E_a = 8.5$ [3]. The values for cavities CH3 to CH11 are shown in Fig. 3.
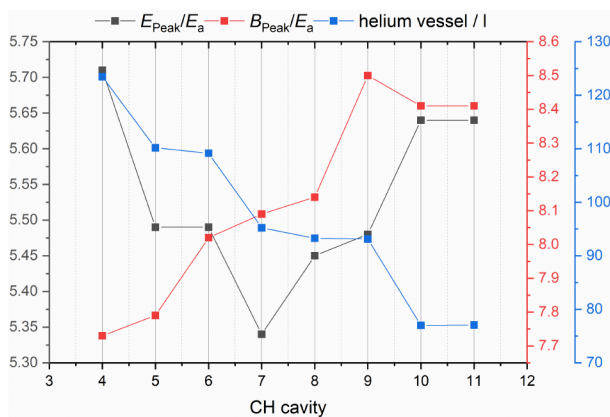

Figure 3: Plot of the values for E_{peak}/E_a and B_{peak}/E_a of the cavities CH3 to CH11 as well as the total volume of the helium reservoir in liter.

Modulare Design

In addition to optimization in terms of performance, great attention was paid to simplifying the manufacturing. After discussions with several manufacturers, a modluar cavity design was developed based on their experience. The spokes, the lids, the flanges, the tuners and the helium tank are all manufactured with the same geometry and then adapted to

the respective sizes of the cavities. This modular system allows to use the tools and supports needed for the production again and again, so that no additional costs or time are needed for the production of those. Figure 4 shows the geometry of the identical spokes and lids for all cavities. The excess material can then be adapted to the geometric requirements of the cavity.
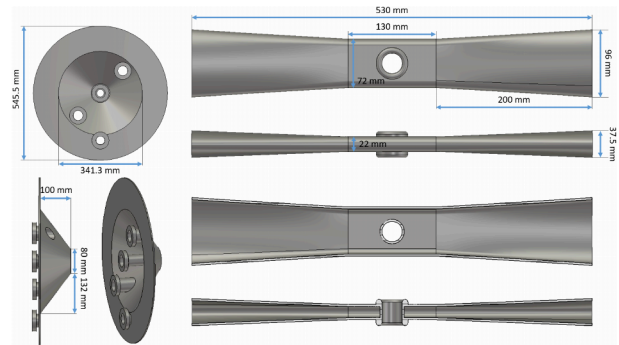

Figure 4: Representation of the spokes (right) and lids (left) of all nine cavities.

The helium tanks of all cavities will also have identical radii. They are designed to have the maximum possible diameter. The four cryomodules are designed for cavities with a total radius of 325 mm. So the radius of the helium tank is 320 mm, so that there is still sufficient space for work during assembly in the cryomodules. Since the cavities radii differ within the tanks, the amount of liquid helium decreases from CH3 to CH11 (see Fig. 3), however, the amount of liquid helium is sufficient for cooling to 4 K.

TUNER TEST BENCH

When the dynamic bellow tuners of cavity CH1 were measured for the first time, it was noticed that hysteresis effects already occur even with a slight overload. For this reason, it was decided to set up a bellows tuner test bench to investigate hysteresis effects due to material fatigue as well as the maximum load capacity of the material before fracture occurs. Since the dynamic bellow tuners of superconducting CH cavities are firmly welded to the cavity, damage to the bellow tuners means damage to the cavity, which would lead to a cost- and time-intensive repair and downtime. To set up the test bench, a pillbox cavity will be modified so that the tuner can be cooled with liquid nitrogen and the resonant frequency can be measured to determine the possible deformation.

The greatest difficulty of the modification is the required cooling. Since niobium becomes more flexible at low temperatures, it is necessary to operate the test bench at low temperatures in order to be able to make a realistic prediction for the later operation. It was decided to first operate the test bench with liquid nitrogen, since cooling with liquid helium represents an enormous financial and safety effort. In order to be able to operate the test bench safely with liquid

nitrogen, a filling system was developed with which the tuner can be filled with liquid nitrogen (see Fig. 5). This includes a filling lance, so that the tuner can be filled from below, and a nitrogen cup, which prevents uncontrolled spattering during filling.
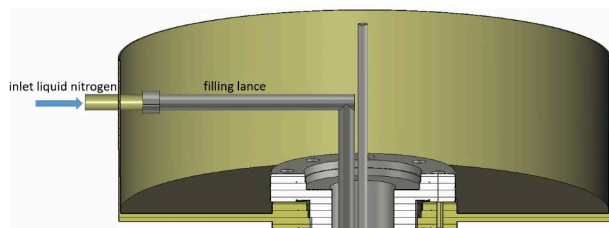

Figure 5: Planned filling system of the tuner test bench.

Since the intended pillbox cavity has a much larger radius than the later CH cavities, the bellow tuner to be examined must be adapted. Since the wall thickness of the tuner is only 1 mm, a thicker tube is used for the extension of the tuner than for the later tuners in order to exclude possible additional degrees of freedom (see Fig. 6).
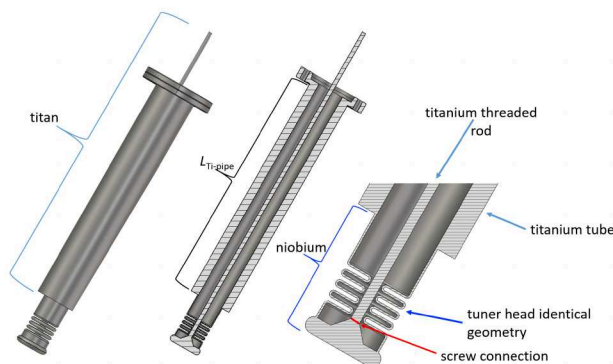

Figure 6: Bellow tuner adapted for tuner test bench.

In order to keep the manufacturing costs for the adapted tuner as low as possible, all parts that are not of interest for the actual investigation will be made of titanium, since titanium has a similar thermal expansion coefficient as niobium and is also less expensive. Thus, in the end, only the head and the bellows of the tuner will be made of niobium. Additional simulations were made to check whether the thickness of the titanium tube or the length of the niobium tube between the niobium head and the titanium tube has an effect on the validity of the test bench (see Fig. 7).

It could be shown that only the bellow is decisive for the displacement and the mechanical load of the tuner (see Fig. 8).

CONCLUSION

Based on the design of the CH1 and CH2 cavities, a total of nine new superconducting CH cavities were developed for the HELIAC at GSI in Darmstadt. A modular cavity design
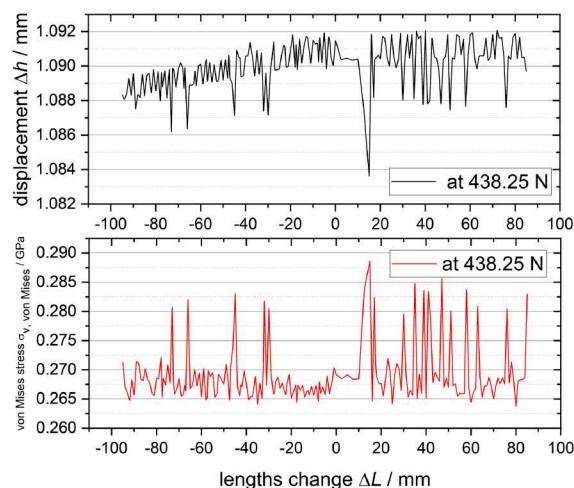

Figure 7: Simulation results done with CST Studio Suite [19] regarding the displacement and internal stress with respect to the length of the niobium tube between the niobium head and the titanium tube. The force of 438.25 N was thereby iteratively determined in simulations as the force required to displace the tuner ≈1 mm.
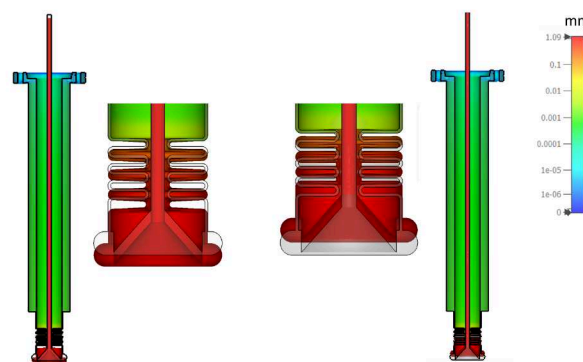

Figure 8: Simulation done with CST Studio Suite [19] of the displacement of the tuner in tension and compression. It can be seen that only the bellow contracts or expands under both forces.

could be developed, which allows to reduce the production costs as well as the production time of these nine cavities. In addition to this simplification of production, it was also possible to significantly increase the performance of the cavities. Also a bellow tuner test bench was developed based on an existing pillbox cavity. A cooling concept for liquid nitrogen was developed, which allows a safe and efficient operation of the test bench. The tuner to be tested was successfully adapted to the requirements of the test bench without compromising the validity of the test bench, which was confirmed in additional simulations.

ACKNOWLEDGEMENTS

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