DESIGN OF A SUPERCONDUCTING CH-CAVITY FOR LOW- AND MEDIUM BETA ION AND PROTON ACCELERATION*

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Abstract

The cross-bar H-type (CH) cavity is a multi-gap drift tube structure based on the H-210 mode currently under development at IAP Frankfurt and in collaboration with GSI. By use of the KONUS beam dynamics long lens free sections can be realized, making the design of a superconducting multi-cell CH resonator possible. Numerical simulations and rf model measurements showed that the CH-type cavity is an excellent candidate to realize s.c. multi-cell structures ranging from the RFQ exit energy up to the injection energy into elliptical multi-cell cavities. The reasonable frequency range is from about 150 MHz up to 800 MHz. A 19-cell, β=0.1, bulk niobium prototype cavity is under construction at the ACCEL-Company, Bergisch-Gladbach. This paper will present detailed MicroWave Studio simulations of the superconducting CH cavity.

INTRODUCTION

Linacs based on room temperature (rt) H-mode cavities (RFQ and drift tube structures) have become a standard solution in the velocity range from β=0.002 up to β=0.1 [1]. RF power tests show the capability of IH-cavities to stand about 25 MV/m on-axis field [2]. Moreover H-type cavities allow for the acceleration of intense beams [3]. One new aspect of investigations started at GSI and IAP Frankfurt was to extend the velocity range of the H-mode cavities up to β=0.5 by developing the CH-DTL [4]. Many future projects (Accelerator Driven Transmutation Project ADTP [5], European Spallation Source ESS [6], Experimental Accelerator-Driven System XADS, the International Fusion Materials Irradiation Facility (IFMIF) or the Radioactive Ion beam Accelerator RIA[7]) are based on the availability of efficient accelerating cavities with properties like mentioned above, which additionally can be operated in cw mode. It is commonly accepted that above an energy of 100 $A \cdot MeV$ super-conducting elliptical cavities are superior to rt structures. Up to 20 $A \cdot MeV$, super-conducting (splitring and quarter wave) cavities were used in heavy ion accelerators. In the energy range in between, the development of spoke-type resonators started just some years ago [8, 9]. These cavities usually provide only a few accelerating gaps. By combining the advantages of H-mode cavities with the benefits of superconductivity, effective ion acceleration with multi-gap structures will become possible. Our investigations show that for high current proton beams the injection energy will be around 5 MeV, while for heavy ions the injection energy may become as low as 1 $A \cdot MeV$. The CH-structure is efficient for beam energies up to 150 $A \cdot MeV$.

SUPERCONDUCTING (SC) STRUCTURES

The sc CH-structure could be an excellent choice for a cw operated ion linac. In sc cavities there is no cooling problem like in cw operated rt linacs. In general, sc linacs can be operated at higher voltage gradients above a certain duty factor. On the other hand, at low duty factors and high beam currents rt structures are very favourable because they are cheaper and can tolerate dark current contributions. To demonstrate the capabilites of the CH-DTL, it is foreseen to test a sc CH cavity prototype. A design and engineering study has been performed in close cooperation with industry[1]. This study shows the feasibility of the production of superconducting CH cavities. After a call for tenders the CH prototype has been ordered. The cavity is expected to be delivered in January 2004. To test the cavity a new cryogentic lab has been established at the IAP in Frankfurt. This includes a vertical 600 l cryostat, two 250 l transport dewars for liquid helium, a laminar flow box (class 100) and a magnetic shielding to avoid trapped flux from the earth magnetic field in the cavity surface during cool down.

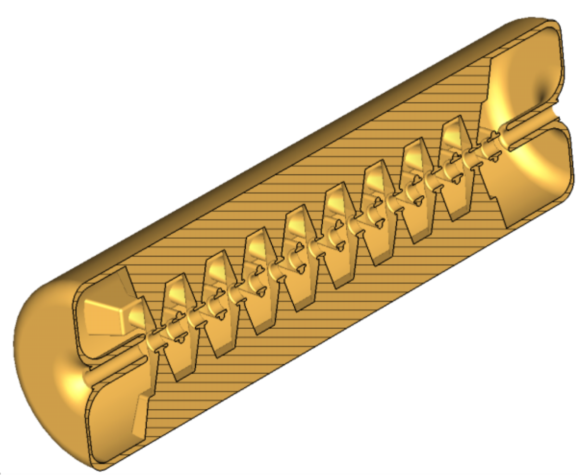

Figure 1: The sc 352 MHZ CH prototype with matched end cell geometry

The CH protoype with 19 gaps will be made of bulk nio-

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bium, the diameter is 28 cm, the length is 105 cm. At an operation frequency of 352 MHz, this corresponds to a particle β of 0.1. One important issue during the design phase was the minimization of the electric and magnetic peak fields to reduce the risk of field emission and of thermal break down. An accelerating gradient of 5 MV/m results in an electric peak field of 26.4 MV/m and in a magnetic peak field of 30 mT which is a very moderate value.

CH CAVITY DESIGN

The CH-cavity exceeds the mechanical rigidity of other multi cell structures at similar β and operation frequencies, and it exceeds by far the rigidity of IH-tanks (110-mode). Together with the application of the KONUS beam dynamics [10], resulting in long, lens free beta graded accelerating sections housed in individual cavities, this opens the possibility to develop a super-conducting multi- cell cavity [11]. The RF behavior of the resonators was studied with an analytical model first, allowing a rough evaluation of the fundamental cavity parameters.

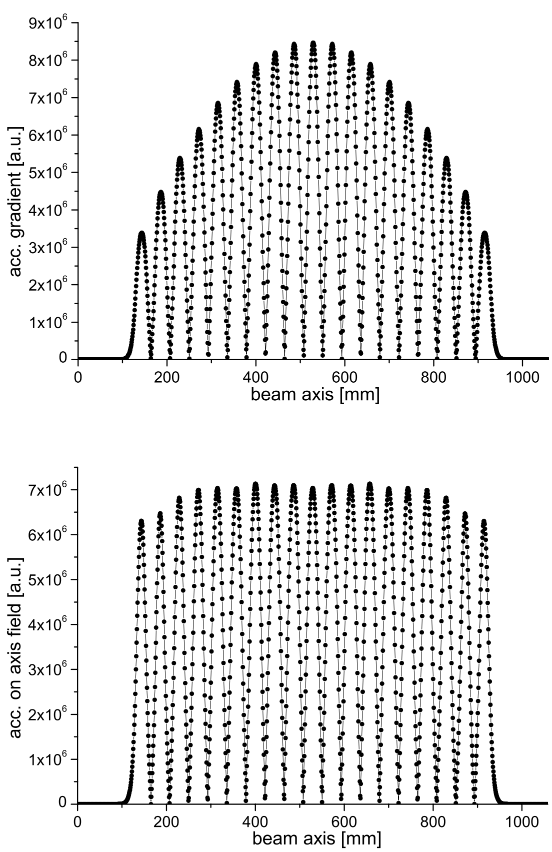

Figure 2: Accelerating on axis field distribution of the 352 MHz CH cavity without (top) and with (bottom) gap length variation

The consequent numerical simulations of the resonators were done using CST-MWS©[12]. One of the calculated resonator geometries is shown in fig.1. The results of these calculations are shown in tab.1. Fig.2 shows the accelerating on axis field distribution of the 352 MHz CH cavity before and after field optimization.

To get a flat field distribution, the length of each gap along the CH cavity was optimized. Fig.3 shows the resulting gap length distribution.

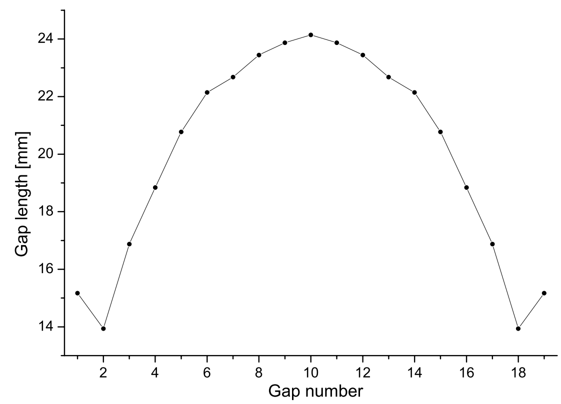

Figure 3: Gap length distribution along the CH cavity at a constant periodical length of 42.857 mm

frequency [MHz]	351.628
beta	0.1
R_a/Q [kΩ]	1.61
E_{peak}/E_a	6.59
B_{peak}/E_a [mT/MV/m]	7.29
cavity length [m]	1.048
gaps	19
aperture diameter [mm]	25
tank diameter [m]	0.28
at E_a=5 MV/m :	
E_{peak} [MV/m]	32.95
B_{peak} [mT]	36.45

Table 1: Parameters of the prototype cavity

A small B_{peak}/E_a ratio indicates, that the achievable accelerating gradient limit will be higher. For example with a gradient of 5 MV/m the maximum magnetic field on the resonator surface will be as low as 36.45 mT (352 MHz, β=0.1 resonator), giving a comfortable safety margin with respect to the BCS-limit of 210 mT. At an $E_a = E_0 \cdot T$ of 5 MV/m, the corresponding stored field energy is 4 J.

Fig.4 shows the magnetic field on the surface of the CH cavity.

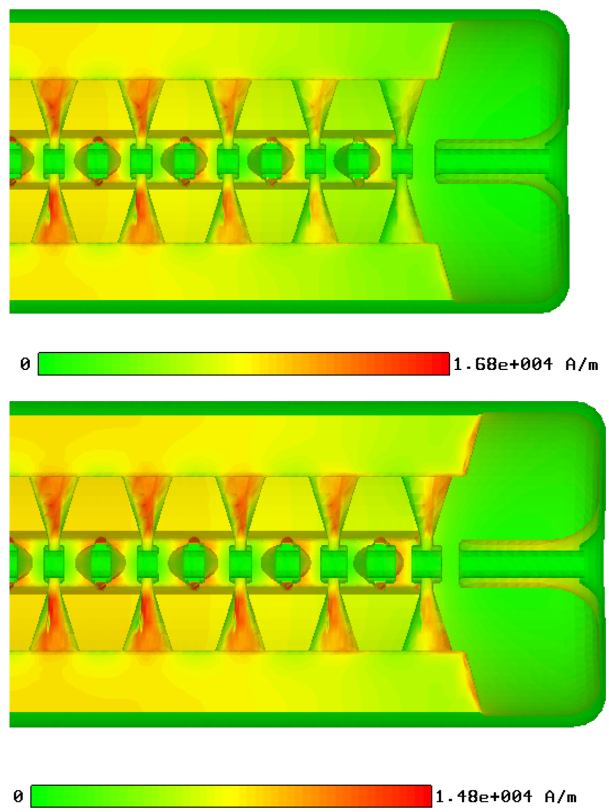

Figure 4: Magnetic field on the surface of the 352 MHz CH cavity without (top) and with (bottom) gap length variation. The stored field energy of 1 J is identical in both simulations

CH CAVITY TUNING

For tuning the frequency as well as the voltage distribution during the fabrication process it is planned to incorporate cylindrical blocks on the girders between adjacent stems (fig.5).

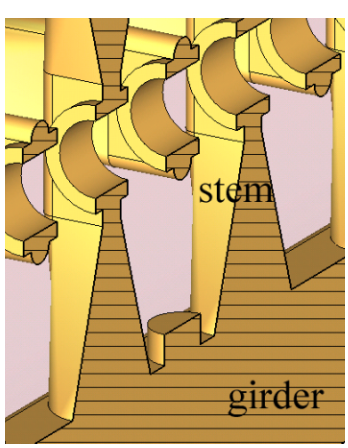

Figure 5: Tuning the 352 MHz CH cavity with cylindrical niobium blocks along the girders

Fig.6 shows that up to a height of about 3 mm the tuner acts inductively while longer cylinders act capacitively. The total tuning range $\Delta f/f$ at a cylinder diameter of 20 mm and at a maximum height of 10 mm corresponds to $2.5 \cdot 10^{-4}$.

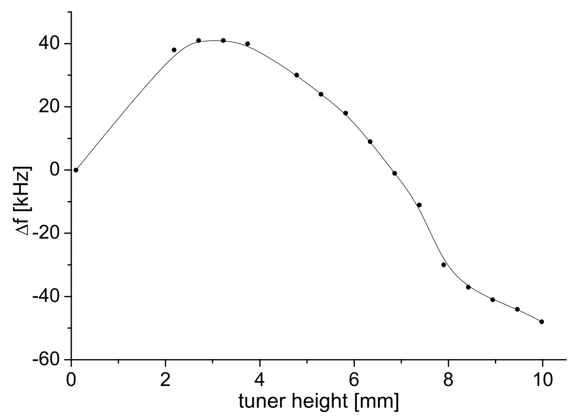

Figure 6: Frequency tuning of the CH cavity by a cylinder as shown in Fig.5 with variable height

OUTLOOK

Using the rt model cavity, further investigations will start soon. A mechanism for tuning the cavity (fast und slow) has to be developed. This can be done either by deforming the re-entrant shape geometry or by deviating from the round tank cross section. In a next step, possible high power input coupler geometries have to be studied. The aim is to design a coupler, which should provide a variable coupling factor even in the cold state.

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