SUPERCONDUCTING CH-CAVITIES FOR LOW- AND MEDIUM BETA ION AND PROTON ACCELERATORS

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Abstract

The CH cavity is a multi-gap drift tube structure based on the H_{210} mode currently under development in a collaboration between IAP Frankfurt and GSI. Like the IH cavity (H_{110} mode) used at different places now for the acceleration of ions, this structure provides a high shunt impedance and allows the acceleration of intense beams at high accelerating gradients. The use of a dedicated beam dynamics results in long lens free sections, making the design of a super-conducting CH resonator possible. The results gained from numerical simulations show that the CH cavity can be a multi-gap alternative to the spoke-type or reentrant cavity structures up to beam energies around 150 MeV/u.

This paper will shortly review the parameter range of this cavity and presents first rf measurements of a room temperature low power model. As an example of possible applications for the CH cavity an accelerator scheme will be shown allowing efficient acceleration of ions up to the Coulomb-barrier.

1 INTRODUCTION

Linacs based on room temperature (rt) H-mode cavities (RFQ and drift tube structures) are used today in the velocity range from β=0.002 up to β=0.1. RF power tests show the capability of IH-cavities to stand about 25 MV/m on-axis field. Beside these high accelerating gradients H-mode cavities allow the acceleration of intense beams [1]. One aspect of the investigations started at GSI and IAP Frankfurt is to extend the velocity range of the H-mode cavities up to β=0.5 by using the H_{210} or CH-mode.

Many future projects (the Accelerator Driven Transmutation Project ADTP[2], the European Spallation Source ESS[3] or the Radio-active Ion beam Accelerator RIA[4]) are based on the availability of efficient accelerating cavities with properties like mentioned above, which additionally could be operated in cw mode. It is commonly accepted that above an energy of 200 MeV/u super-conducting elliptical cavities are superior to rt structures. Up to 20 MeV/u, 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 [5,6]. These cavities usually provide only a few

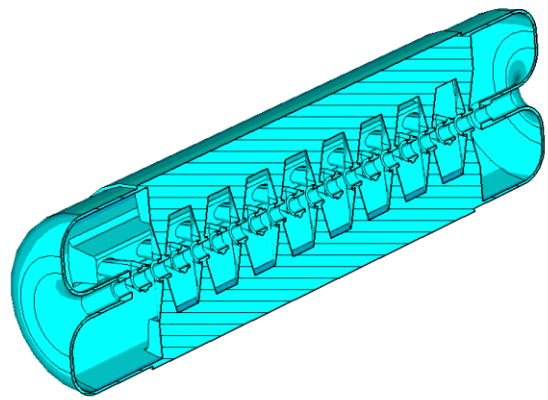

Figure 1: Three-dimensional view of a CH-mode cavity (324 MHz, β = 0.1).

accelerating gaps.

By combining the advantages of CH-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 10 MeV, while for heavy ions the injection energy may become as low as 1 MeV/u. The CH-structure is efficient for beam energies up to 150 MeV/u.

This paper describes the properties of CH-cavities cavities and reviews the basic design criteria. The results from numerical simulations of several CH-cavities will be compared to the data of other resonators. Measured data taken recently at a rt rf model cavity will be reported and a possible application of the CH cavity within an accelerator scenario will be shown.

2 CAVITY DESIGN

The CH-cavity exceeds by far the mechanical rigidity of IH-tanks, making it less sensitive to ground vibrations. Together with the application of the KONUS beam dynamics [7], 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 with at least 10 gaps even at low beam energies.

The RF behavior of the resonators was studied with an analytical model first, allowing a rough evaluation of the fundamental cavity parameters. The consequent numerical simulations of the resonators were done using MAFIA and CST-MWS©. One of the calculated resonator

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geometry is shown in fig. 1. The results of these calculations have been reported at the last conference [8]. In the mean time, further calculations have been performed for different applications including high current accelerators (see for example [9]) to evaluate the parameter range of the CH resonator leading to the values given in tab. 1.

Table 1: Parameter range for the CH cavity

Frequency (MHz)	200 - 800
Particle velocity (v/c)	0.05 - 0.5
Gap number	10 - 25
Accelerating gradient (MV/m)	5 - 8
Length of the cavity (m)	0.5 - 1.5
Drift tube aperture (mm)	10 - 60
Tank radius (mm)	185 - 130
E_{max}/E_{acc}	3.9 - 6.2
B_{max}/E_{acc} (mT/(MV/m))	3.7 - 8.8
R/Q_0 (kΩ/m)	2.6 - 4.7

Comparing the rf parameters to that of existing cavities [10] displays the potential of CH-cavities. One comparison is done in fig. 2 for a typical parameter: the maximum magnetic field on the resonator surface divided by the accelerating gradient. A small B_{surf}/E_{acc} ratio indicates, that the achievable accelerating gradient limit will be higher. For example with a gradient of 7 MV/m the maximum magnetic field on the resonator surface will be as low as 38 mT (433 MHz, β=0.17 resonator), giving a comfortable safety margin to the BCS-limit of 210 mT.

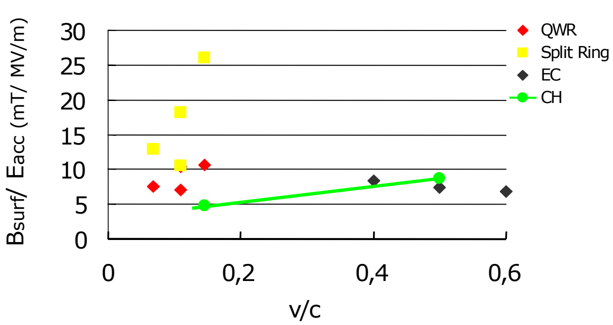

Figure 2: Magnetic to electric field ratio as a function of the particle velocity for different sc cavities. The data were taken from [10].

3 MODEL MEASUREMENTS

A copper model of one prototype cavity (352 MHz, β=0.17, shown in fig. 3) was built at the IAP Frankfurt to study the low-level rf behavior of the resonator.

The resonant frequency was found to be 350 MHz, which is less than 1 % below the predicted value. The on axis field distribution for the cavity measured with a bead pull setup is shown in fig. 4.

This distribution was yielded without any tuning procedure. The fine tuning leading to a flat gradient can

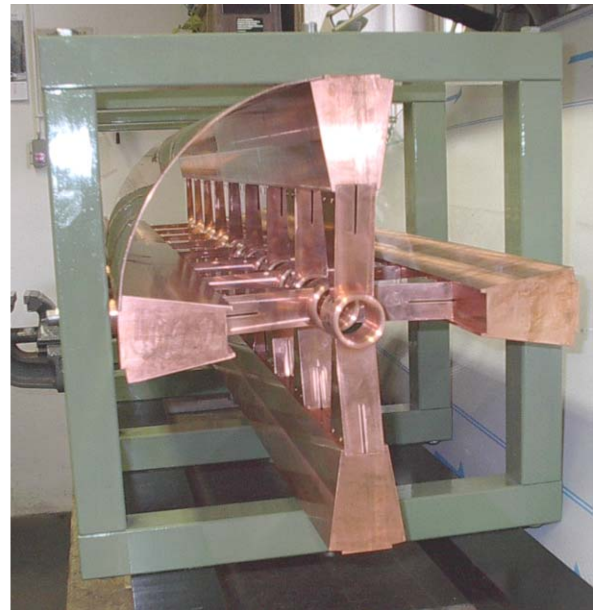

Figure 3: Photo of the CH copper model cavity. The end cells and part of the tank housing is removed

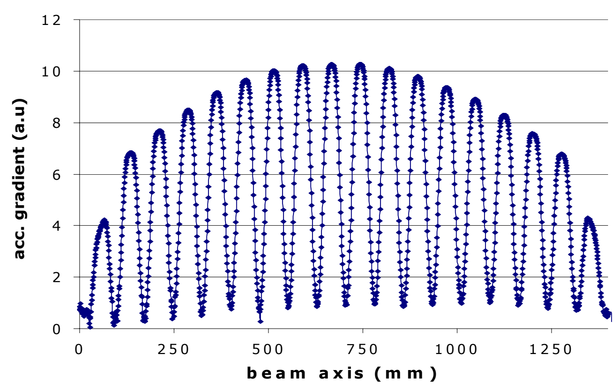

Figure 4: Accelerating on axis field distribution of the 350 MHz CH model cavity without any tuning processes.

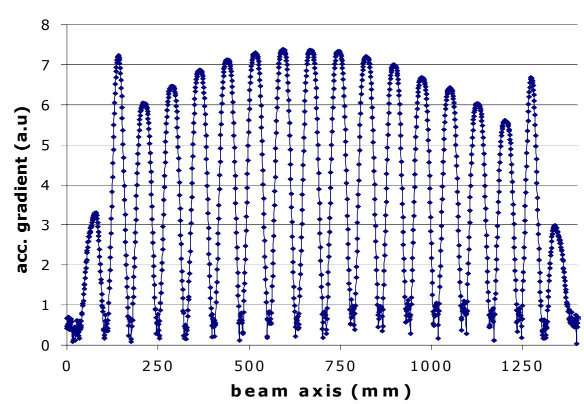

Figure 5: Accelerating on axis field distribution of the 350 MHz CH model cavity where the gap length of the second and the 17th gap was decreased from 38 mm to 28 mm. This is an example of one tuning method.

be achieved by varying the gap length along the structure accordingly. This procedure can be well included in the beam dynamics calculation. This principle is fully developed and has been found to be adequate [11]. The necessary modifications will be made within the next weeks. Figure 5 shows for example the effect on the accelerating gradient when the gap length for the second and the 17^{th} gap is decreased form 38 mm to 28 mm.

4 CAVITY FABRICATION

In principle, all three fabrication options (lead on copper, niobium on copper and bulk niobium) could be followed. For several reasons, it has been decided to build the first cavity out of bulk niobium parts that will be EB-welded together. This is a well established technology.

Several production procedures, welding and assembly steps have been under investigation, some of them lead to minor modifications in the cavity geometry changing the rf behavior only marginally. The design study done together with the ACCEL company was finished recently.

The cavity will be built in cooperation with industry, the first prototype cavity is expected to be delivered within 12 months.

5 A CW LINAC BASED ON CH-CAVITIES

To evaluate possible applications for a CH cavity, an accelerator scenario has been developed and studied exhaustively (see fig. 7). We assumed an ECR ion source delivering a beam with a mass-to-charge ratio A/q below 7. The final energy of the linac should allow for experiments at the Coulomb-barrier and has therefore be variable between 4.0 and 7.5 MeV/u. To reach high luminosities the linac operates in cw. Special care was taken to minimize the energy spread at the linac exit.

Up to an energy of 1.4 MeV/u the linac looks very much like the GSI high charge state injector (HLI): Behind the ECR ion source the particles are accelerated by a 4-rod RFQ up to 0.3 MeV/u, followed by a room temperature IH-resonator. The electrical power needed to feed the rt IH cavity with its high shunt impedance of around 300 MΩ/m is comparable to a super-conducting linac consisting of sc quarter wave resonators.

At 1.4 MeV/u the beam enters the super-conducting section of the linac. This part will house 7 CH-resonators of the type described above. The accelerating gradient

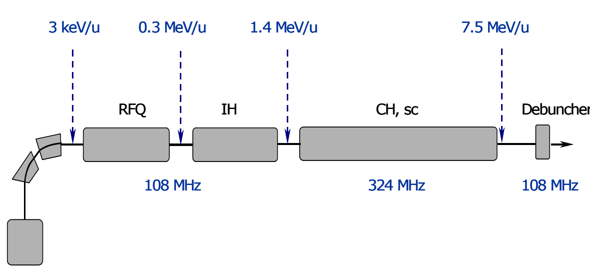

Figure 6: A linac based on CH cavities allowing acceleration of ions up to the Coulomb-barrier.

inside these resonators were assumed to be 6 MV/m even for cw operation, leaving a large safety margin.

The final energy adjustment (+/- 0.5 MeV/u) between the rough steps delivered from the CH-cavities (typ. 1 MeV/u) has to be done by using short cavities (quarter wave resonators) due to the large velocity acceptance needed. The energy spread at the linac exit was found to ne below +/-3 keV/u over the whole energy range (4.0 – 7.5 MeV/u).

6 FURTHER STEPS

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.

Currently a clean room and a cryogenic laboratory is under construction at the IAP Frankfurt to perform in-house testing of the prototype cavity.

7 CONCLUSIONS

Our investigations indicate that CH-mode cavities are well suited to design sc resonators. The results of the numerical simulation and the first measurements of a rt model cavity are very promising. Investigations performed together with the ACCEL company show that the fabrication of the cavity with the required accuracy is possible.

8 ACKNOWLEDGEMENTS

The continuous support of N. Angert and his interest in the progress of this work is greatly acknowledged. The authors would further like to thank W. Barth, L. Dahl, R. Tiede and A. Schempp for their contribution to the linac design presented within this paper.

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