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 dedicated KONUS beam dynamics [1] used for H-mode cavities results in long lens free sections, making the design of a superconducting 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 describe the design principles and give the cavity parameter range. First rf measurements of a room temperature low power model will be presented and the fabrication procedure for a prototype cavity will be discussed.

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 [2]. 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[3], the European Spallation Source ESS[4] or the Heavy Ion Inertial Fusion HIIF [5]) 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 superconducting cavities are superior to rt structures. By combining the advantages of CH-mode cavities with the benefits of superconductivity, effective ion acceleration at high duty cycle and at low injection energies will become possible. 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 and reviews the basic design constraints. The results from numerical simulations of three CH-cavities with different resonant frequencies and velocity profiles will be reported. These parameters will be compared to measured data taken recently at a rt rf model cavity.

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 [1], resulting in long, lens free accelerating sections housed in individual cavities, this opens the possibility to develop a superconducting multi-cell cavity. This cavity has at least 10 accelerating gaps. So far only 2 to 4 gap sc structures were realised for low beam velocities.

The three different prototype cavities discussed are modules of an accelerator design investigated for high current proton acceleration. The parameters of these prototype cavities are given in tab.1.

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 the MAFIA package.

Table 1: Parameters and expected performance of the different prototype cavities

Frequency (MHz)	352	433	700
Particle velocity (v/c)	0.17	0.17	0.5
Mode	H_{210} (CH)		
Gap number	18	18	10
Accel. gradient (MV/m)	6.7		
Length of the cavity (m)	1.43	1.01	1.07
Drift tube aperture (mm)	25	25	10
Transit time factor	0.8-0.85		
Tank radius (mm)	185	130	105
E_{max}/E_{acc}	4.1	3.9	5.2
B_{max}/E_{acc} (mT/(MV/m))	5.8	3.7	8.8
R/Q_0 (kΩ/m)	2.7	4.7	2.6
Q-factor (4K,Nb)	$4.3\cdot10^9$	$2.7\cdot10^9$	$1.4\cdot10^9$
Diss. power (4K,Nb) (W)	6.5	4.0	13.8
Shunt impedance (rt, Cu) (MΩ/m)	44	68	39
Stored energy (J)	12.6	4.1	4.3

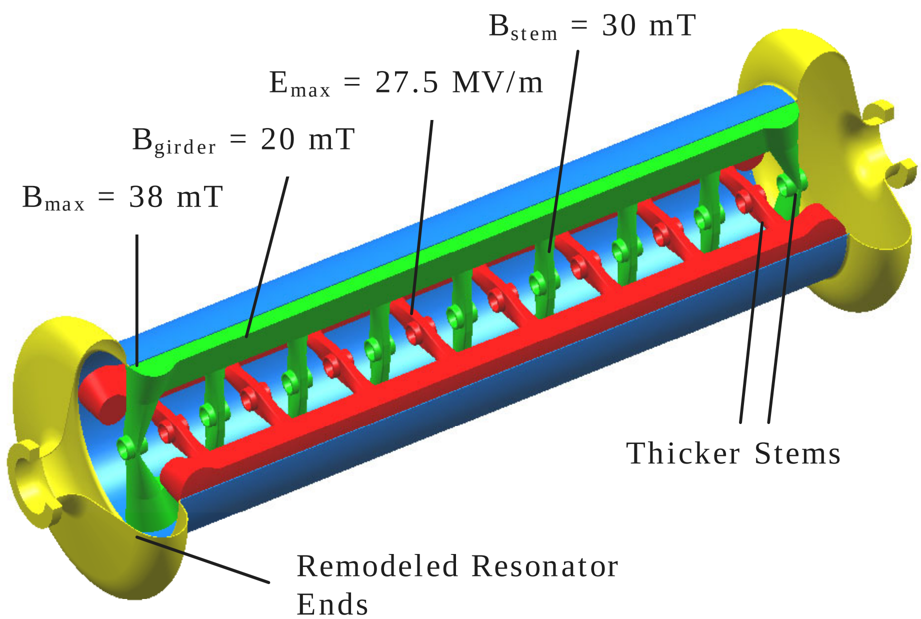

Figure 1: Three-dimensional view of a CH-mode cavity (352 MHz, β = 0.17). The cavity dimensions can be found in tab. 2. Also shown are some field values calculated with MAFIA assuming an accelerating gradient of 6.7 MV/m: The maximum value of the magnetic (38 mT) is reached at both resonator ends, the maximum of the electric field (27.5 MV/m) on the drift tube surface.

As a first step of the design process, only two accelerating gaps have been computed, the first results of these computations were presented at the last workshop [6]. Starting with a rt design the drift tubes and the shape of the stems were optimized. Special care was taken on the magnetic surface field trying to keep it well below the BCS-Limit of Niobium. By increasing the stem cross section, the magnetic surface field could be reduced by aprox. a factor of two, reaching up to 30 mT in the actual design.

This optimization process caused an increase in the capacitive load and thus lowered the shunt impedance by 20 %, which is no drawback in case of a sc cavity. The maximum electric field (27.5 MV/m) has been found at the drift tube curvatures.

After this optimization step the whole cavity was computed to study the impacts on the field flatness. As the magnetic flux being parallel to the beam axis along the resonator bends from one to the neighboring sector at its ends one expects high magnetic surface fields in this region. The girder undercuts, used in rt IH-mode and 4-vane cavities successfully to create the zero mode are not the right choice for a sc cavity. Therefore a careful redesign had to be performed.

The lowest surface fields were yielded by combining two modifications: The tank radius is increased by 17 % between the end flange and the first drift tube stem. To assure the field flatness, i.e. a constant accelerating field along the whole cavity, the local capacity at the cavity ends had to be further increased. This was attained by forming thicker stems. Following cavity production needs, the resonator ends were remodeled (compared to [7]) by giving them a re-entrant like shape. Figure 1 shows the actual layout of the cavity which is optimized with respect to reach minimum surface currents. Modifications due to fabrication constraints will still take place. Table 1 summarizes the results of the simulations.

Comparing these parameters of tab. 1 to that of existing cavities [8] 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.

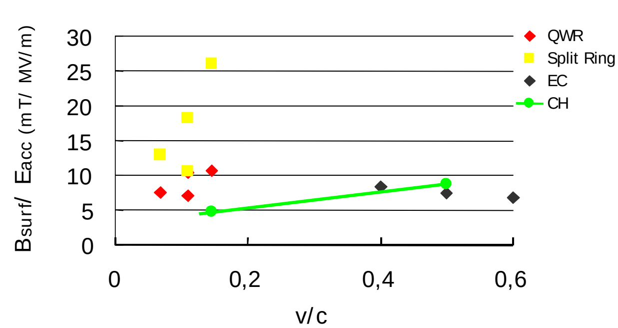

Figure 2: Magnetic to electric field ratio as a function of the particle velocity for different sc cavities. The data were taken from [8].

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.

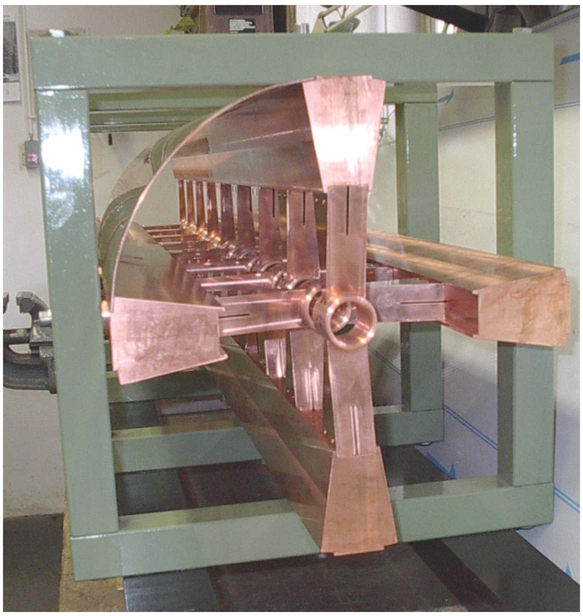

Figure 3: Photo of the CH copper model cavity. The end cells and part of the tank housing is removed

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. To increase the field at the cavity ends the tank radius in this region will be further increased. The fine tuning leading to a flat gradient can 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 [9]. The necessary modifications will be made within the next weeks.

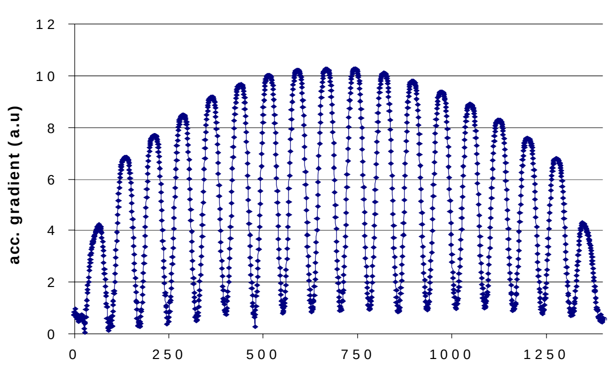

Figure 4: Accelerating on axis field distribution of the 350 MHz CH model cavity without any tuning processes.

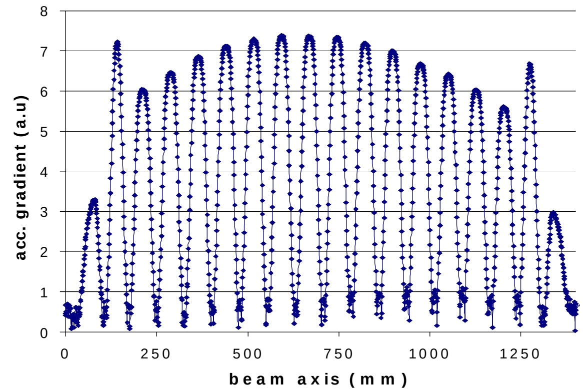

Figure 5: Accelerating on axis field distribution of the 350 MHz CH model cavity where the gap length of the second and the 17^{th} gap was decreased from 38 mm to 28 mm. This is an example of one tuning method.

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

Three different cavity fabrication options have been considered:

- lead plating onto a copper surface
- niobium sputtering onto a copper surface
- bulk niobium parts welded together

Because of the operational experience made elsewhere [10] the lead plating option was abandoned. Sputtering this complex geometry seems to be possible with some additional investigations needed.

It has been decided to build the first cavity out of bulk niobium parts that will be EB-welded together, a well established technology. This cavity will be built in cooperation with industry. Several production procedures are currently under investigation, a design study started recently. The first prototype cavity is expected to be delivered within 18 months.

5 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. One possibility may be a modification of the Darmstadt coupler [11] coupling to the longitudinal electric field at the resonator end. Also coupling to the magnetic field with a current loop, like it is done with rt IH-cavities seems to be possible.

6 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. Using state of the art technology the fabrication of a superconducting CH-mode cavity will be possible. A heavy ion linac based on these cavities is actually designed.

7 REFERENCES

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