COUPLER DEVELOPMENT AND GAP FIELD ANALYSIS FOR THE 352 MHz SUPERCONDUCTING CH-CAVITY*

H. Liebermann, H. Podlech, U. Ratzinger, A. Sauer,
Institut für Angewandte Physik, Frankfurt, Germany

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. 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. A 19-cell, beta=0.1, 352 MHz, bulk niobium prototype cavity is under fabrication at the ACCEL-Company, Bergisch-Gladbach. This paper will present detailed MicroWave Studio [1] simulations and rf model measurements for the coupler development of the 352 MHz superconducting CH-cavity. It describes possibilities for coupling into the superconducting CH-cavity. First results of the measurements of different coupler concepts, e.g. capacitive and inductive coupling at different positions of the CH-cavity are reported.
Additionally the rf quadrupole content in CH-type gaps was investigated quantitatively.

INTRODUCTION

Present H-mode structures are all operated at room temperature. Many future accelerator projects require cw operation. But the achievable gradients of room temperature cw operated H-mode cavities are limited due to power losses and cooling problems. The superconducting CH-cavity can be realized in the frequency range from 150 to 800 MHz, the beam energy can be chosen between 5 AMeV and 150 AMeV which corresponds to a β-range from 0.1 to 0.5. The CH-structure can be used for proton as well as for heavy ion beams. The superconducting version seems to be quite attractive for high current proton linacs like XADS [2] or deuteron linacs like IFMIF [3].

SUPERCONDUCTING (SC) STRUCTURES

In sc cavities there is no cooling problem as in cw operated rt (room temperatur) linacs. In general, sc linacs can be operated at higher 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 less expensive 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. The cavity production started in 2003 and the delivery is expected in October 2004 [4]. The CH protoype with 19 gaps will be made of

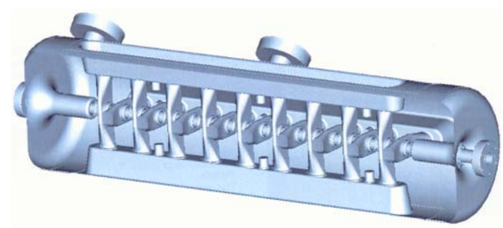

Figure 1: The sc 352 MHZ CH prototype with matched end cell geometry.

bulk niobium, 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 4 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 moderate value.

Table 1: Main design parameter of the s.c. prototype CH-cavity

β	0.1
Frequency [MHz]	352
Diameter [m]	0.28
Tank length [m]	1.05
$R_a/Q[\Omega]$	3220
E_p/E_a	6.59
B_p/E_a [mT/(MV/m)]	7.29
$Q_0(R_s = 150n\Omega)$	$3.7 \cdot 10^8$

METHODE FOR THE EXTERNAL Q VALUE

For calculation of the external Q value, we use the method described by Balleyguier [5]. If a lossless cavity is weakly coupled to an infinite line, this line drives out a certain RF power P and the energy stored in the cavity gradually decreases. The external Q then is:

$$Q_{ext} = \omega W/P.$$

If we assume, that the line mode is a TEM and the dielectric is vacuum: $\eta^2 = \mu/\epsilon$. Then, the external Q can be

* Supported by GSI Darmstadt, EU and by BMBF, contr. no. 06F134I
[1] ACCEL Company, Bergisch Gladbach, Germany

expressed as:

$$Q_{ext} = \frac{\omega \iiint_{cavity} |F|^2 dV}{c \iint_A |F|^2 dA}. \qquad (1)$$

F being either the electric (E) or magnetic (H) field. According to the superposition theorem, we can add these two solutions (fig. 2). So it is possible to solve these problem by two MicroWave Studio runs.

At the first run, the line can be terminated at the refer-

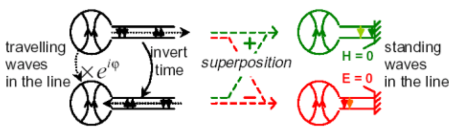

Figure 2: Transforming a travelling-wave problem into a standing-wave one [5].

ence plane with the appropriate boundary condition (perfect magnetic wall). Using the same formal expression as in equation (1), we can define the quantity Q as:

$$Q_1 = \frac{\omega \iiint_{cavity} |E_1|^2 dV}{c \iint_{ref.plane} |E_1|^2 dA} = \frac{|1+e^{i\phi}|^2}{4} Q_{ext}.$$

At the second run, the line can be terminated with other boundary condition (perfect electric wall). So we can define the quantity Q_2 as:

$$Q_2 = \frac{\omega \iiint_{cavity} |H_2|^2 dV}{c \iint_{ref.plane} |H_2|^2 dA} = \frac{|1-e^{i\phi}|^2}{4} Q_{ext}.$$

As for any value of ϕ, $|1+e^{i\phi}|^2 + |1-e^{i\phi}|^2 = 4$, we have then: $Q_{ext} = Q_1 + Q_2$.

CH CAVITY COUPLING

For coupling into superconducting structures the external Q-value must be between 10^6 and 10^9. If you want to reach these different kinds of couplers were examined with MicroWave Studio and measured at a copper model. First a capacitive coupling through the girder of the CH-structure (fig.3) was examined. The inner conductor of the coaxial line is facing a drift tube with opposite polarity.

It turned out that by this method external Q-values from 10^4 to 10^{11} can be achieved (fig.4). In order to verify the calculations with MicroWave Studio, measurements of the copper model were accomplished. These show a good agreement with the calculations.

After getting confidence in the simulations from the comparison with model measurements,calculations for the superconducting prototype of the CH structure were performed. The results of the calculations are represented in figure 5.

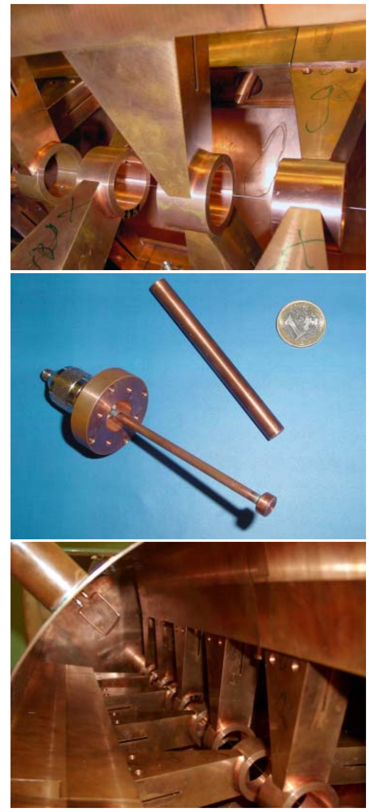

Figure 3: Capacitive coupling through one girder between two stems in the same plane (upper), Capacitive Couplers for the measurements at the copper-model (middle) and Inductive coupler at the CH-Copper-model (lower).

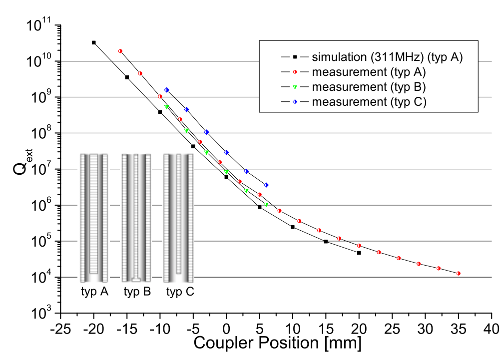

Figure 4: Calculations and Measurements for capacitive couplers for the Copper-model of the CH-Cavity. 0mm corresponds to the girder surface plane.

It showed that with a coupler position between -10 and +10 mm external Q-values between 10^5 and 10^9 can be achieved (fig.5). Additionally, magnetic coupling by a loop was investigated.Two positions were examined: In the midplane of the structure and at the cavity end. Both positions were located transversly between the girders under 45 degrees. In fig.6 the results of the calculations are showed.

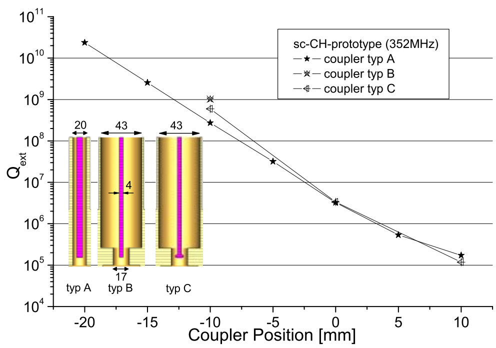

Figure 5: Calculations for capacitive couplers for the s.c. prototype of the CH-Cavity.

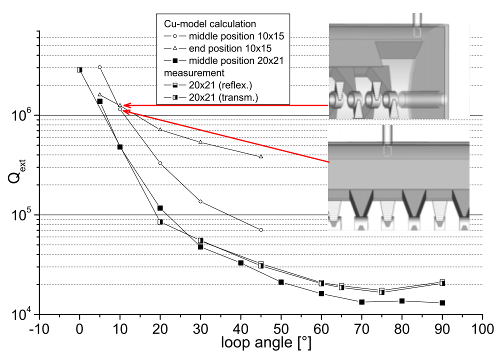

Figure 6: Calculations and Measurements for inductive couplers for the Copper-model of the CH-Cavity.

RF QUADRUPOLE CONTENT IN CH-GAPS

In the CH-DTL structure, the tubes are supported alternately in the X and Y planes, which generates quadrupole fields, as fig.7 shows. It means that two kinds of transverse

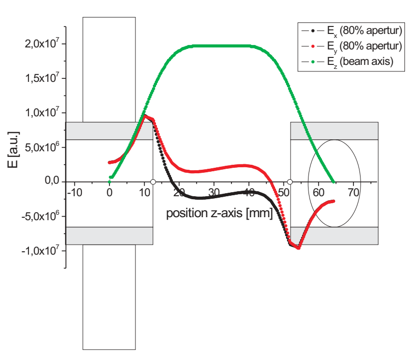

Figure 7: Schematic view of the CH-DTL.

fields exist inside the CH-gaps, which were generated by stems and tubes, respectively. The transverse total E-field consists of the cylinder-symmetrical and of the quadrupole field components.

$$E_{x,tot.}(z) = E_r(z) + E'(z) \cdot x + \ldots$$
$$E_{y,tot.}(z) = E_r(z) - E'(z) \cdot x + \ldots$$

$$\rightarrow E_{x,tot.}(z) - E_{y,tot.}(z) \simeq 2 \cdot E'(z) \cdot x$$

The stem orientation of the input drift tube defines the focusing quadrupole direction of each gap for accelerating rf phases between -90 and +90. In case of the CH-structure the quadrupole orientation is changed in every gap (FODO). The Quadrupole strength of one CH-gap can be written as:

$$\int_{CH} E' dz = \int_{CH} \frac{E_{x,tot.} - E_{y,tot.}}{2 \cdot x} dz$$

The quadrupole strength is compared to an idealized drift tube structure with quadrupole fingers, where the quadrupole is generated by the gap voltage amplitude $\pm$ V/2 at the aperture radius a along the gap length g. This result in a reference quadrupole strength $E' \cdot g = \frac{V}{a^2} \cdot g$ and in a related strength factor for the CH-gap with $\eta_Q = \frac{\int_{CH} |E'| dz}{\int_{CH} E_z dz} \cdot \frac{a^2}{g}$.

In Fig.8 η_Q is plotted against varying gap lengths.

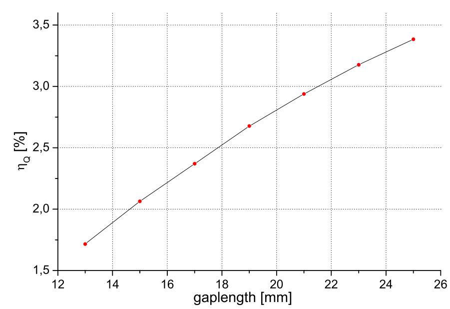

Figure 8: quadrupole strength factor η_Q at different CH gap lengths and constant period length $\beta\lambda/2 = 42.857mm$, stemm geometry like in Fig.1.

OUTLOOK

The calculations have shown that the best way to couple into the CH-structure is to couple with an antenna to the electric field, because we can reach external Q-value between 10^5 and 10^9 and it is the easiest method.

For the first cold tests it is planned to couple with an capacitive coupler of type B. The quadrupole content in the gap-fields of CH-structures were studied quantitytively and will be included in future beam dynamics calculations with LORASR.

REFERENCES

[1] http://www.cst.com

[2] Requirements for the XADS Accelerator and Technical Anwers, DAPNIA-02-302, September 2002, France

[3] A. Sauer, H. Deitinghoff, H. Klein, H. Liebermann, H. Podlech, U. Ratzinger, R. Tiede, End-To-End Simulations of a Superconducting Deuteron CH-DTL for IFMIF, Proceedings of the PAC 2003, Portland, OR, USA

[4] H. Podlech, Development of Superconducting and Room Temperature CH-Structures, these proceedings

[5] P. Balleyguier, External Q Studies for APT SC-Cavity Couplers, Proceedings of the LINAC 1998, Chicago, IL, USA