DESIGN OF THE R.T. CH-CAVITY AND PERSPECTIVES FOR A NEW GSI PROTON LINAC*

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Abstract

The CH-Structure has been studied at the IAP Frankfurt and at GSI for several years. Compared with the IH structure (110-mode), the CH structure (210-mode) can operate at higher frequencies (150 - 700 MHz) and can accelerate ions to higher energies (up to 150 AMeV). Detailed Microwave Studio (MWS) simulations were performed for this structure. Since a multi-gap cavity can be approximated as a quasi-periodic structure, it is possible to analyse one βλ/2-cell at an energy corresponding to the cavity centre. A reduced copper conductivity of 85% was adopted in effective shunt impedance calculations. Geometry variations with respect to RF frequency and shunt impedance can be performed rapidly by that method in the first stage of optimization. Using the transit time factor calculated by the beam dynamics simulation code LORASR, effective shunt impedances from 100 MΩ/m down to 45 MΩ/m were obtained for the energy range from 6MeV to 66 MeV by this method. The RF frequency was 352 MHz. A systematic analysis of the influence of the cell number in long CH-cavities on the effective shunt impedance is presented. Actually, a 70 MeV, 70 mA, 352 MHz proton linac design for GSI Darmstadt is developed. About 12 CH-cavities will cover the energy range from 3 MeV up to the final energy, the DTL total length will be around 22m.

INTRODUCTION

The Interdigital H-type (IH) structure is well known for its high shunt impedance at low beta values. It is successfully used as front part for ion linacs like the Unilac at GSI [1] or the CERN Linac3 [2] and for rare isotope acceleration. Since a couple of years, a new type of H-structure was proposed and studied at IAP, Frankfurt and GSI, Darmstadt, that is the Cross Bar H-type (CH) structure. Compared with the IH-structure, the CH-structure is providing new features. Working in the H_{21} mode, the transverse cavity dimensions are significantly larger than that of the IH-cavity at a given frequency and velocity profile, thus it can work at higher frequencies up to around 700 MHz. This allows to close the velocity gap with respect to attractive structures at the low energy end of Coupled Cavity Linacs CCL. It can be designed for operation at about 350 MHz in the first section and at 700 MHz in the high-energy section up to about 150 AMeV. Furthermore, the CH cavity exceeds by far the mechanical rigidity of the IH cavity. This opens the possibility to develop superconducting multi-cell cavities as well [3].

A set of formulas based on a simple field model was derived for H-type structures to describe the main RF parameters as a function of the geometrical dimensions. A normal conducting 70 MeV, 70 mA proton injector based on a 3 Mev RFQ followed by a CH-DTL is designed for the future FAIR facility at GSI. The beam dynamics [4] and the cavity design are studied in parallel. The construction of a model cavity will start this year.

In the following sections we present the results got from cavity simulations for room temperature CH structures, the emphasis is put on the effective shunt impedance.

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SIMULATION METHOD

In general a high level of accuracy is needed in the simulation of multi-cell cavities to achieve relevant results and in particular with respect to the cell voltage distribution. However, many important aspects can be investigated already with single cell calculations, which are very fast and reliable. In case of a quasi-periodic H-structure the following strategy was applied:

- ✧ For every cavity a single cell optimisation with respect to shunt impedance was performed for the relevant beam velocity at the tank mid plane.
- ✧ The capabilities of these geometries with respect to mechanical stability, cooling etc. were checked.
- ✧ Simulation of multi-cell cavities with steadily increasing cell numbers. Investigation the dependence of the main parameters on the cell number.

GEOMETRY OPTIMIZATION

The geometry optimization has been done for a sequence of discrete energies from 3 MeV up to 70 MeV. Figure 1(a) schematically shows the 50 MeV cavity cell used in MWS simulations. Figure 1(b) shows a design alternative with a drift tube geometry relevant for tank 1. The main difference is the central ring around the drift tube similar to the superconducting version [3].

For the real multi-cell cavity, the transverse geometries are kept unchanged, but in longitudinal direction, the period length will change with the velocity profile of the beam. In the investigation of the dependence of the RF parameters on the cell number, however, a constant periodic length along the cavity is used. The zero-mode can be achieved by a simple end cell geometry like shown in fig. 2.

In order to test the validity of the cell-cavity approximation, we calculate the CERN Linac3, tank3 that is a 30-gap IH cavity with this method. The results are listed in table 1. From table 1 we can see that the measured effective shunt impedance is about 85% of the calculated one and the error in frequency is about 2%.

From this comparison resulted the reduction mentioned above to 85% in the estimated shunt impedance values from single cell MWS simulations. The factor includes the reduced efficiency at the cavity ends. It is assumed that the effects are comparable for IH- and CH-cavities.

Table 1: Cell cavity calculation results and measurement results for CERN Linac3 Tank3

	Measurement	Calculation
Frequency (MHz)	202.56	198.45
Q factor	15000	17225
$Z_{eff.}$ (M Ω /m)	150	184

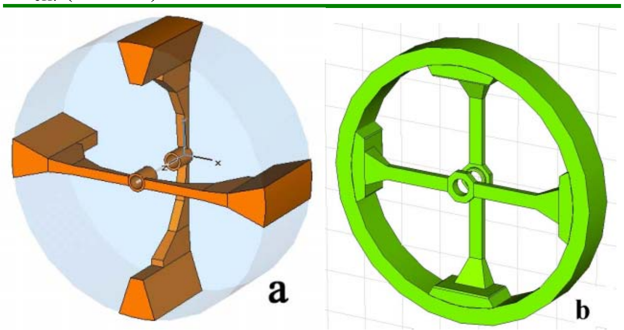

Figure 1: (a) A 50 MeV cell cavity, (b) multi cell design for low beam energies.

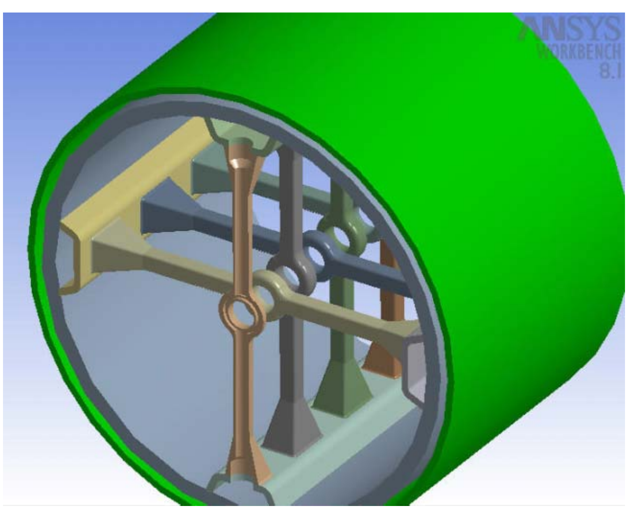

Figure 2: Mechanical design study of a CH-cavity at 3 MeV beam energy with directly water cooled stems.

SINGLE CELL SIMULATION RESULTS

The shunt impedance is one of the most important parameters for a room temperature linac. In our calculation, the effective shunt impedance is calculated by the following formula,

$$R_{shunt} = \frac{V^2}{\overline{P}^2 L} T^2 . \quad (1)$$

V is the peak value of the gap voltage, $\overline{P}$ is the average rf loss of the cavity, resulting from MWS simulations and corrected by the 85% conductivity value. L is the total tank length and T is the transit time factor calculated by the beam dynamics simulation code LORASR.

The effective shunt impedance and the radius of the tank as a function of the energy are shown in Figure 3. The effective shunt impedance changes from 100 MΩ/m down to about 43 MΩ/m while the energy XXXX from 6 MeV to 66 MeV. The tank radius changes from 165 mm up to 216 mm. The inner and outer drift tube diameters are 20 mm and 27 mm respectively.

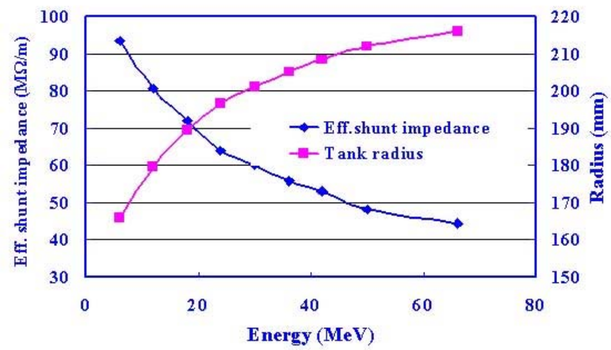

Figure 3: The effective shunt impedance and tank radius as a function of the beam energy.

DEPENDANCE OF RF PARAMETERS ON CELL NUMBERS

The cavity cell with magnetic boundary conditions is equivalent to an infinite long multi cell cavity, but ???

In the following we will investigate the dependence of the RF parameters on the cell number. The multi-cell cavity is constructed by the 50 MeV cell cavity. As figure 2 shows, all cells are the same with the exception of the end cells.

Resonance Frequency

The resonance frequency for cavities with different cell numbers is shown in figure 4. The horizontal pink line is the result from the cavity cell simulation. With increasing cell number, the frequency is approaching the simulation result. For a cavity with 12 cells, the difference is less then 1%. That means for cavities with more than 12 cells, the cell approximation method is rather valid for resonance frequency calculations.

Effective Shunt Impedance

The effective shunt impedances for cavities with different cell numbers are plotted in figure 5. The red dashed represents the effective shunt impedances obtained from cavity cell simulations and equal to the corresponding dot in figure 3. As mentioned before the cavity cell with magnetic boundary is equivalent to a cavity with infinite cells. The effective shunt impedance of multi cell cavity will approach to this line as cell number increasing, just as the red line in figure 5 shows. For a cavity with 16 cells, the difference is less than 3 MΩ/m. From figure 5 we can conclude that we can use the 90% of the cell cavity simulation results to approximate that of the multi cell cavity in beam dynamics design.

In figure 5 we also plotted the effective shunt impedance with different apertures. We can see, the effective shunt impedance for cavities with 20 mm aperture diameter is about 3 MΩ/m larger than that for cavities with 25 mm diameter. But even for cavities with 25 mm aperture, the effective shunt impedance is larger than 40 MΩ/m for cavities with more than 8 cells at 50 MeV.

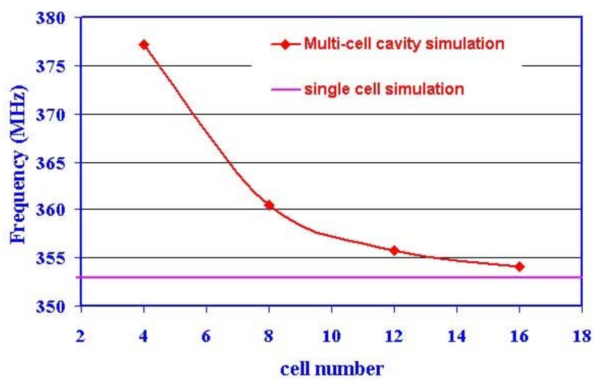

Figure 4: The frequency as a function of the cell numbers.

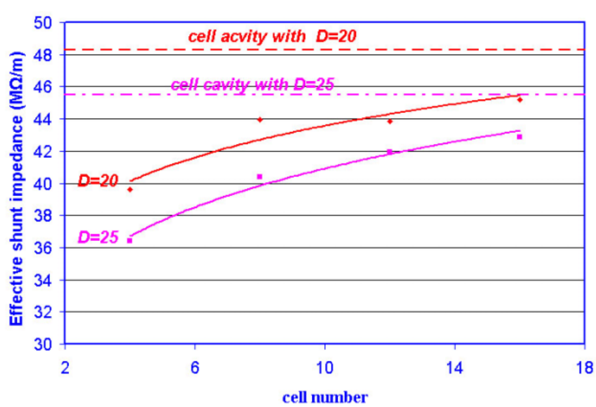

Figure 5: The effective shunt impedance as a function of the cell numbers.

GSI NEW PROTON LINAC

The future scientific program in GSI needs a dedicated proton linac. The frequency of the Linac is decided as 352 MHz since the existence of the klystron has the same frequency. This frequency is just within the range of the CH structure. Together with the KONUS beam dynamics, the DTL section is designed with the cell simulation results. The main cavity parameters are listed in table 2.

Table 2: Proton DTL structure parameters

Energy range	3 - 70 MeV
Beam current	70 mA
Total DTL length	21 m
Single tank length	0.6 - 2.2 m
Number of gaps	12 – 17
Accel. gradient	6.3 – 2.7 MV/m
Effective shunt impedance	100 – 45 MΩ/m
Rf power per tank	500 – 1100 kW
Minimum aperture diam.	20 mm

CONCLUSIONS

From the analysis above, we can draw the following conclusions:

- The cavity cell is an effective and efficient way for cavity optimization. The effective shunt impedance of the 352 MHz CH-cavity got from cavity cell simulation is from 100 MΩ/m down to 45 MΩ/m for the energy range from 6 MeV to 66 MeV.
- Considering the limited cell number of the real cavity, we can use 90% cell cavity simulation effective shunt impedance in design, and the error for frequency is about 1% for simple cavities.

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