DESIGN STUDY OF A HIGH FREQUENCY PROTON LADDER RFQ

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Abstract

For the research program with cooled antiprotons at FAIR a dedicated 70 MeV, 70 mA proton injector is required. In the low energy section, between ion source and main linac an RFQ has to be designed. The 325 MHz RFQ will accelerate protons from 95 keV to 3.0 MeV. This particularly high frequency for a 4-Rod type RFQ creates difficulties which are challenging in developing this cavity. In order to define a satisfactory geometrical configuration for this resonator, both from the RF and the mechanical point of view, different designs have been examined and compared. Very promising results have been reached with a ladder type RFQ, especially concerning the dipole component of the accelerating fields, which is almost neglectable. This paper will show 3D simulations of the general layout and manufacturing techniques demonstrating the potential of a ladder type RFQ. In low duty factor applications the RFQ efforts might be significantly reduced when compared to a 4 vane RFQ . This layout may find a first realization at the FAIR Proton Injector.

Figure 1: 3D-Sketch of a ladder RFQ, consisting of the tank, stems, carrier rings and mini-anes.

INTRODUCTION

Originally, the 4-ladder RFQ was developed in the late Eighties [1] and was realized two times successfully for the 101 MHz CERN Linac3 [2] as well as at the 202 MHz CERN antiproton decelerator ASACUSA [3]. As mentioned, the challenging situation in the present case is to design a 4-Rod type proton RFQ at a frequency as high as 325 MHz with geometrical dimensions large enough to have a comfortable manufacturing and assembling situation. The mini-vane integration and alignment concept as shown in Fig. 1 is adapted from the successfully operated GSI-HSI-RFQ [4].

There are at the same time investigations on the classical 4-Rod RFQ going on at IAP Frankfurt to see, whether an extension towards 325 MHz may become feasible [5].

RF DESIGN

Size and Frequency

The cavity parameters were optimized to allow for the proposed mechanical concept with carrier rings for connection and precise alignment of the mini-vanes. The beam dynamics layout was done earlier already [6]. Table 1 shows also the beam dynamics related parameters, which are the curvature and aperture radius as well as the length of the mini-vanes. Around those parameters the layout of the stems and the outer tank had to be defined with respect to convenient dimensions, including a concept for frequency and field flatness tuning.

Table 1: Main Parameters of the Ladder RFQ.

No of Cells	52
Energiy Gain [MeV]	0.95 - 3.0
Q Value (sim.)	8000
Frequency [MHz]	325.224
Inner Length [mm]	3200
ρ [mm]	2.56
r_0 [mm]	3.415
Height [mm]	240
Width [mm]	160
Cell Length [mm]	60
Stem Thickness [mm]	20

The main geometrical parameters were varied during the design process and the effect on different parameters were investigated.

Figure 2 shows the behavior of the resonance frequency in dependence of the geometrical parameters listed in Table 1. The fact, that the height (left) and the width (right) of the stems influence the frequency in opposite directions very efficiently was a main outcome. This makes it very convenient to find an adequate size for the cavity and stem structure, just fitting to the individual design needs. In this case, a wide stem to house the carrier rings is attractive. The parameter space for reasonable designs at a given frequency is astonishingly large.

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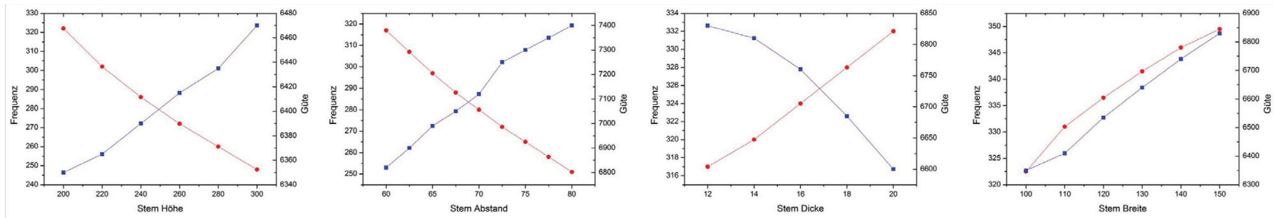

Figure 2: Dependence of frequency and Q value on the main geometrical cavity parameters.

Dipole Component

In classical 4-Rod RFQ designs with stems pointing to one direction only one has to care for the electric dipole fraction in the accelerating field. This effect is suppressed by special stem and mini-vane connector geometries and is getting difficult at very high frequencies [5]. The situation is quite more relaxed in case of the ladder-RFQ.

Figure 3 shows a view along the beam axis with the 4 mini-vanes and the electric field in absolute values. A quantitative result is plotted in Fig. 4. It shows the absolute value of the electric field along a curve around the beam axis. With this plot one can easily determine the content of the dipole component by integrating along that curve:

$$E_{Dipole}/E_{Quad} < 0.01.$$

The integral directly gives the amount of dipole component within the accelerating field. In case of the ladder RFQ it is clearly smaller than one percent.

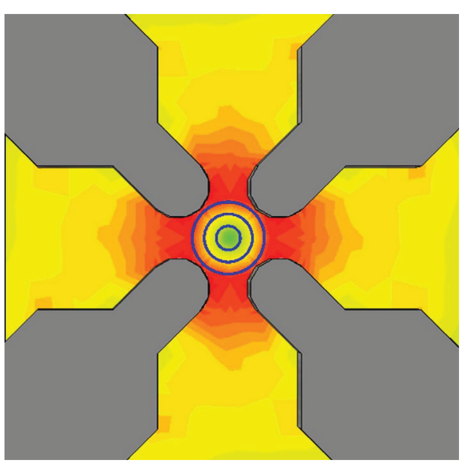

Figure 3: View along the beam axis with a contour color plot of the absolute electric field values. One can see qualitatively that all vanes are on the same absolute field level.

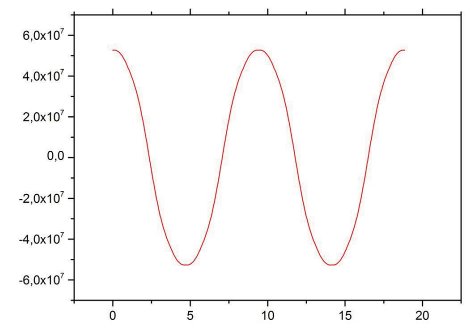

Figure 4: Plot of the absolute electric field along a curve around the beam axis.

MECHANICAL DESIGN

Resonating Structure

The concept of the ladder RFQ not only has opportunities on the RF point of view but also on the mechanical design of the components. The cavity will consist of an inner structure from massive copper housed in a stainless tank. The copper structure may be cooled by heat conduction into the outer tank only - in low duty factor cases like the FAIR proton injector. The advantage is a conservation of the original copper hardness. In Fig. 4, plot of the absolute electric field along a curve around the beam axis, high duty factor cases water pipes might be connected to the copper structure. Finally, in high duty factor cases water channels integrated in the copper structure are feasible, with the disadvantage of loosing in hardness after vacuum brazing.

The mini-vanes will be splitted into three parts each having a length of about 1m which are connected by springs as developed for the GSI-HSI-RFQ. These mini-vanes will be screwed into carrier rings in a way that every second ring is connected to the same pair of mini-vanes. The mini-vanes and the rings are fixed against movement with the concept of slot and key, which means that every mini-vane and ring is locally grooved to give longitudinal and transverse precision.

The Carrier rings together with the mini-vanes will then be positioned on the lower half of the copper structure (Fig. 5) and will be fixed by screwing the upper halfshell on the lower one. In this case there are guide pins to get the needed precision.

The concept of assembling can be derived from Fig. 5. The carrier ring concept has already been proven successfully at the IH-type RFQ at GSI [4]. No additional alignment procedure is needed with this method, because the precision is given by the precise central bore hole with a diameter of about 90 mm in case of the 325 MHz RFQ design.

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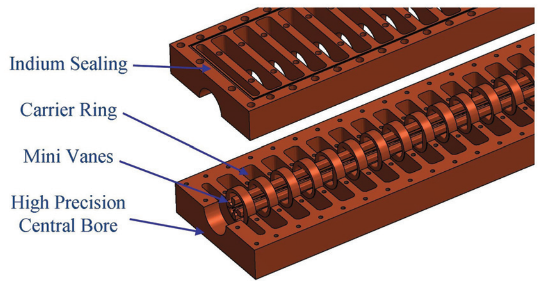

Figure 5: 3-D view of the copper structure showing the components and the assembly concept.

The Outer Tank

The copper structure is the central rf resonator. The outer tank wall gives the boundary condition and effects the resulting resonance frequency and Q value. In this design the outer shell has to fulfill the following tasks:

- Providing vacuum at the 10-8 hPa level
- Rf contact between copper structure and tank
- Heat contact to cool the copper structure

The outer tank will consist of two parts. The lower base will hold the resonating copper structure and is placed horizontally on a support. The upper shell surrounds the copper structure and will tie down the copper structure to the lower shell by bolts. Between the outer tank and the resonating structure there will be indium sealings providing good heat and rf contact, so that it is possible to have only cooling channels in the outer shell at low duty factor applications.

Figure 6 illustrates the different parts of the cavity including the outer tank and shows the horizontal position of the outer tank which allows to open the cavity easily for maintenance reasons.

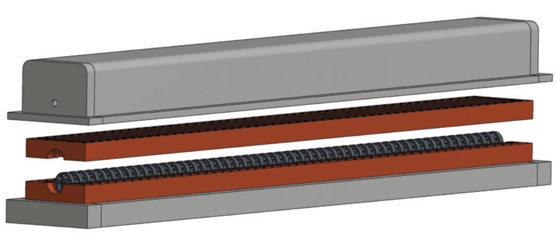

Figure 6: 3-D view of the complete cavity demonstating the assembling concept.

TUNING

The tuning for this ladder RFQ can be separated in three different parts: The overall flatness tuning of the cavity, the detailed flatness of the 52 cells and the frequency tuning before and during operation.

The coarse flatness will be reached by designing the height of three cells at the entrance and exit of the cavity. This is not done after measurements but will be simulated beforehand and implemented in the production of the cell geometry.

The cell by cell flatness tuning can then be done by the carrier rings, which are supporting the mini-vanes. These carrier rings can be replaced or reduced in their longitudinal extension. This has a capacitive effect on the cell and therefore changes directly the voltage distribution locally. This process is done after production of all the main parts and it is expected that the tuning process will be a two step procedure. This has already been shown at the GSI IH-RFQ.

Finally, the cavity will be equipped with static and moving tuners which are capable of allowing a fine tuning and of keeping the frequency at the design value during operation. The final design of the moving tuners is not yet defined but will be similar to already existing designs.

CONCLUSION

This paper has shown a new type of RFQ and a possible way of building and tuning such a cavity. The simulations gave very promising results concerning the RF properties and the reliability. Together with the rotated orientation of the mini-vanes this design shows great advantages against the conventional design. Especially in the high frequency range for proton acceleration the ladder RFQ should be considered a good alternative.

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