Electromagnetic Design of an 80.5 MHz RFQ for the RIA Driver Linac

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Abstract

The Rare Isotope Accelerator (RIA) [1] requires a high power linac capable of accelerating all ions through uranium to energies $\geq$400 MeV/u with a beam power of 100 to 400 kW. The first accelerating structure would be an RFQ. Elecrodynamic simulations using the MAFIA code [2] have been performed to optimize the RFQ resonator. We present the design of an IH-RFQ (Interdigital H-Type) and of a 4-Rod RFQ. The operation frequency is 80.5 MHz and the resonator has a length of 493 cm. Because of the specified cw operation, optimization of the shunt impdance and the cooling requirements are major issues. It was determined that an RF power of 20 kW/m (IH RFQ) and 26 kW/m (4-Rod RFQ) would be required to reach the design voltage of 60 kV.

1 INTRODUCTION

4-rod RFQ accelerators are well established and are the most common structure for the acceleration of heavy ions between 80 and 200 MHz [3]. The resonance structure consists of a linear array of stems carrying the electrodes. Two stems form a basic cell that is a $\lambda/2$ resonator. In order to charge the electrodes correctly, neighbouring basic cells have to oscillate in the π-mode. Figure 1 shows two basic cells of a 4-rod RFQ. The main advantages of 4-rod RFQs

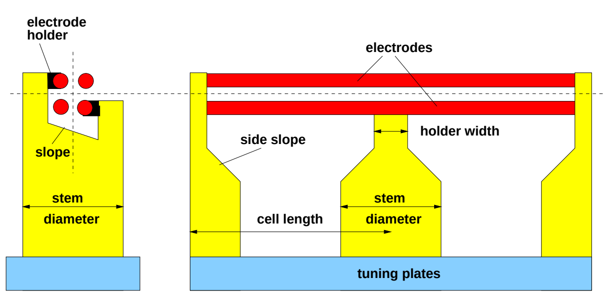

Figure 1: 2 basic cells of a 4-rod RFQ.

are

- reliable resonators
- relatively inexpensive
- excellent tuning possibilites.

IH RFQ accelerators are a relatively new development. The first IH RFQ has been commissioned successfully in 1999 at GSI/Germany [4]. In the IH cavity the $TE_{11(0)}$ is excited. The resonance structure consists of two girders carrying the support rings and mini-vane like electrodes

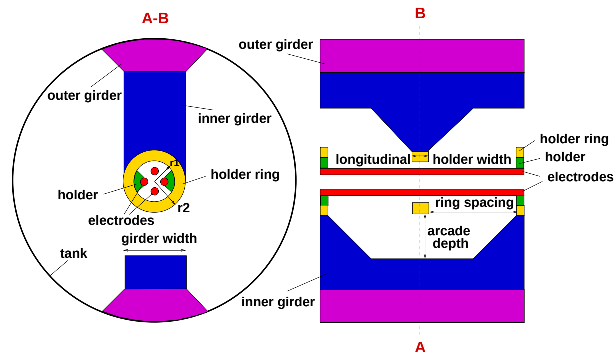

Figure 2: 'Slice' of an IH type RFQ.

(See fig. 2). Due to the small distance between the support rings ($\approx$10 cm) the losses on the electrodes are very small which reduches the cooling requirements compared to a 4-rod RFQ. The main advantages of IH type RFQ resonators are

- high shunt impedance
- excellent distribution of losses
- good tuning possibilites
- high field symmetry
- high mechanical stability.

All electrodynamic simulations have been performed using the MAFIA code. To optimize the main resonator properties, it is usually sufficient to simulate a basic cell of a 4-rod RFQ or a slice of an IH RFQ. Then one has to use magnetic boundary conditions in the x-y-plane. The whole structure has been simulated only to optimize the field flatness.

2 THE 4-ROD RFQ

Figure 3 shows the MAFIA geometry of a 2-cell 4-rod RFQ. The following resonator parameters have been optimized (See fig. 1):

- length of a basic cell
- slope of the stems (dipole component)
- holder width
- tank diameter

The most important parameter of a 4-rod RFQ resonator is the length of a basic cell or the number of cells per unit length. For these simulations, the cell length (i.e. the distance of the stems) has been varied while keeping the frequency constant. With increasing cell length, one has to

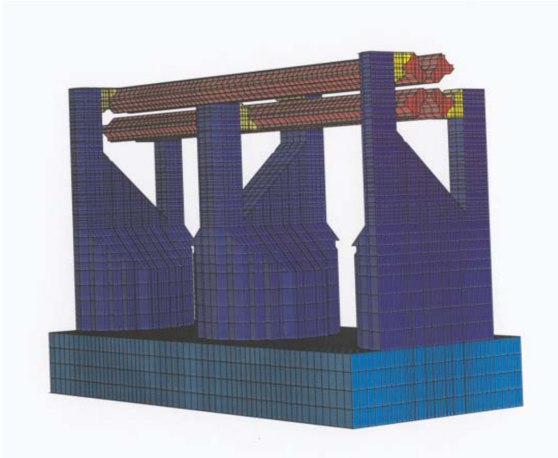

Figure 3: 2 basic cells of a 4-rod RFQ.

lower the stems to keep the inductance of the cells constant.
Figure 4 shows the result of these simulations. As expected, the required stem height drops with increasing cell length. The shorter the cell length the smaller is the required current to load the electrodes. This reduces the losses. Therefore the shunt impedance increases with shorter cell length. But if the distance of the stems becomes too small, the influence of the capacitance between the stems becomes increasingly important. This reduces the shunt impedance. That means that there is an optimsl cell length when the shunt impedance has a maximum. The simulations showed that we can expect a shunt impedance of about 145 kΩ for the optimized resonator. This takes into account the fact that the MAFIA value is typically a factor of two too high for 4-rod RFQ resonators.
Due to a lack of perfect quadrupole symmetry a 4-rod RFQ

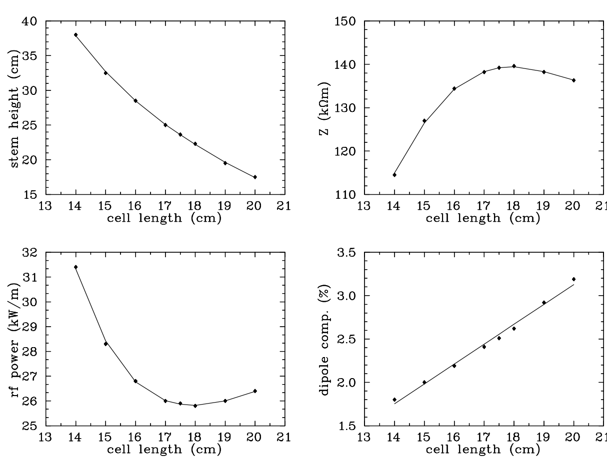

Figure 4: Stem height, shunt impedance R_p, required RF power P and dipole component as function of the cell length.

has a dipole component. Larger currents on the electrodes lead to a higher dipole component. This can be reduced by changing the center slope of the stems. The typical value is between 2 and 3 % of the field level of the quadrupole mode.
Due to cw operation power losses, power densities and cooling requirements are one of the most important issues of the normal conducting RFQ. With the expected shunt impedance, a power of 25 kW/m is required to load the electrodes to their design voltage of 60 kV. Figure 5 shows the simulated average power densities of different structure components. The highest values occur on the electrode holder. The peak values are about 3 times larger.

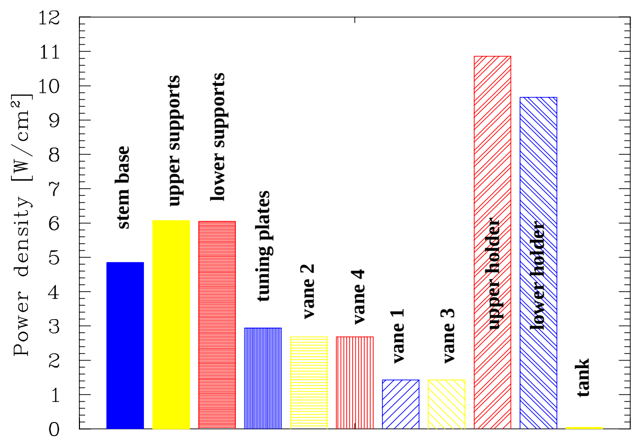

Figure 5: Average power loss densities on different structure components in W/cm^2 of the 4-rod RFQ.

3 THE IH-RFQ

Figure 6 shows the geometry of a slice of an IH RFQ with three support rings. The following resonator parameter have been optimized (See fig 2):

- tank radius
- ring spacing
- longitudinal ring width
- arcade depth
- ring radius
- radial ring width

One of the most important parameters for IH RFQ resonators is the spacing between the support rings. If the spacing is too small, the capacitance between the rings lowers the shunt impedance. If the spacing is too large, the capacitance of the electrodes lowers the shunt impedance. There is a maximum of the shunt impedance for a spacing of about 9 cm (see fig. 7). The expected shunt impedance is about 180 kΩm which results in a required power of 20 kW/m. This takes into account that the realistic value for the shunt impedance is only 70-75% of the MAFIA value for this kind of structures. Due to the small distance between the rings the losses per ring and on the electrodes are very small (≈5%).
Although an IH RFQ does not provide a perfect quadrupole

Figure 6: MAFIA model of the IH RFQ.

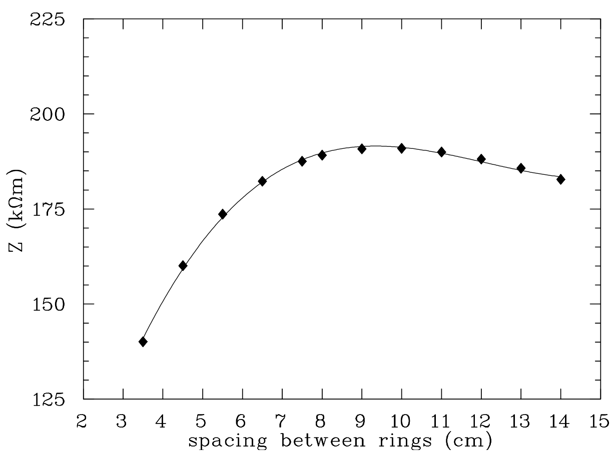

Figure 7: The shunt impedance R_p as function of the spacing between the support rings of the IH RFQ.

symmetry the dipole component is quite small, typically 0.5% of the field level of the quadrupole mode. The power loss distribution has been simulated. About 50% of the losses occur on the tank walls which can be cooled very efficiently. Figure 8 shows the average power loss density on different structure components. The peak values are about 8 times higher. The highest values occur on the outer side of the girders where the magnetic flux is maximal.

4 COMPARISON AND SUMMARY

We have optimized a 4-rod RFQ and an IH-type RFQ resonator for the RIA driver linac. Table 1 shows the most important parameters of the two resonators. With the expected shunt impedance of 145 kΩm (4-rod) and 180 kΩm (IH-type), the required rf power (thermal load) is 26 kW/m

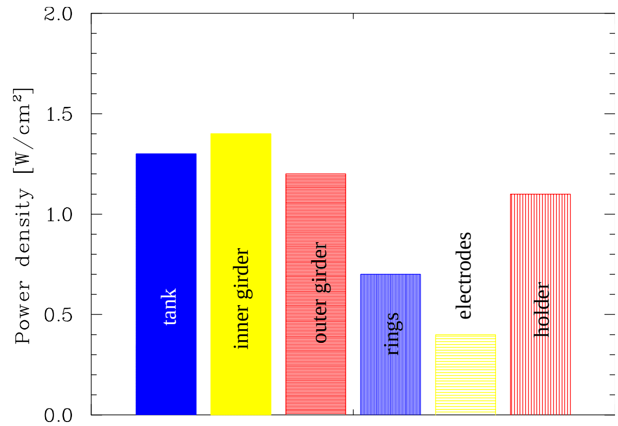

Figure 8: Average power loss density on different structure components of the IH RFQ.

(4-rod) and 20 kW/m (IH). Both RFQ resonators are suitable candidates for the RIA driver linac. However due to the higher shunt impedance, smaller dipole component, and much better loss distribution, the IH RFQ seems to be the better choice especially for cw operation. The Kilpatrick ratio for both resonators is only 1.1 and the maximum electric surface field E_p has a moderate value of 156 kV/cm. The next step could be the construction of a cold model to verify the main electromagnetic properties.

Parameter	**4-rod**	**IH-type**
Frequency (MHz)	80.6	80.5
Diameter (cm)	40	38
Length (cm)	493	493
Av. aperture (mm)	4.64	4.64
Vane tip radius (mm)	4.0	4.0
R_p (kΩm)	145	180
P/L (kW/m)	25	20
Total power (kW)	125	98
Dipole (%)	2.5	0.6
P density ρ_{max} (W/cm^2)	12	30
Kilpatrick ratio	1.1	1.1
E_p (kV/cm)	156	156

Table 1: Comparison of important resonator properties of the 4-rod and the IH RFQ.

5 REFERENCES

[1] http://srfsrv.jlab.org/ISOL/

[2] www.cst.de

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[4] U. Ratzinger, The New High Current Ion Injector at GSI and new Perspectives for Linac Design based in H-Mode Cavities, Proc. of the EPAC 2001, Vienna, Austria