DESIGN OF A 40 MHZ RFQ FOR A POST ACCELERATOR AT THE COUPLED CYCLOTRON FACILITY AT NSCL

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Abstract

Since 2001 the Coupled Cyclotron Facility (CCF) with its new A1900 fragment separator has been in operation at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University [1]. Presently a helium gas cell is beeing commissioned to stop the fragmentation products [2]. As a consequence, a preliminary evaluation has been done of a post accelerator that could deliver rare isotope beams with an energy up to 5 MeV/u. The post accelerator could consist of an RFQ, an IH drift tube structure, and 36 superconducting Quarter Wave Resonators (QWR). A cw RFQ capable of accelerating ions with a charge to mass ratio of 1:40 to 120 keV/u was specified. Electrodynamic simulations using the MAFIA code [3] have been performed to optimize the RFQ resonator. We present the results of the MAFIA simulations and of the beam dynamics of an IH-type RFQ and a split ring RFQ with an operation frequency of 40 MHz, an electrode voltage of 90 kV and a length of 717 cm.

1 INTRODUCTION

One possible 40 MHz RFQ could be a split ring RFQ very similar to the RFQ which has been built for the ISAC project [4]. A split ring RFQ consists of a linear array of split rings acting as $\lambda/2$ resonators. Two split rings form one module (See fig. 1).

The other possible option could be an IH RFQ. IH RFQ

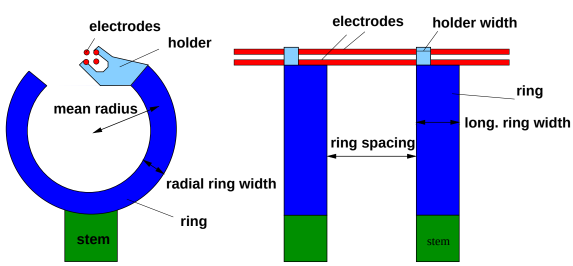

Figure 1: One module of a split ring RFQ.

accelerators are a relatively new development. The first IH RFQ has been commissioned successfully in 1999 at GSI/Germany [5]. 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 (See fig. 2). Due to the small distance between the support rings (≈10 cm) the losses on the electrodes are very small which reduces the cooling requirements compare to a split ring RFQ.

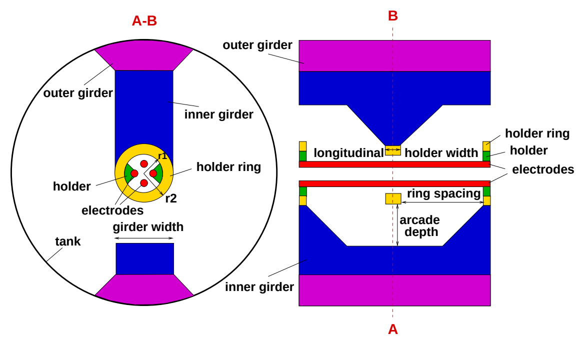

Figure 2: ’Slice’ of an IH type RFQ.

All electrodynamic simulations have been performed using the MAFIA code. To optimize the main resonator properties it is usually enough to simulate one module of a split ring RFQ or a slice of an IH RFQ.

The beam dynamic has been optimized using the new optimization program ’RFQopt’ [6].

2 THE SPLIT RING RFQ

Figure 3 shows the MAFIA geometry of a 1-module split ring RFQ. The following resonator parameter have been optimized or investigated (see fig. 2):

- ratio r/R of radial ring width r and mean ring radius R
- module length (spacing between rings)
- longitudinal width
- longitudinal holder width
- tuning techniques
- multi module simulations
- tank diameter

The length of a module or the number of split rings per unit length, is one of the most important parameters of a split ring RFQ. For these simulations the module length (or the distance between the rings) has been varied. The frequency has been kept constant by adjusting the mean ring radius. Figure 4 shows the result of these simulations. The shorter the module length the smaller is the required current to load the electrodes. This reduces the losses. Therefore, the shunt impedance increases with shorter module length. But if the distance of the rings becomes too small, the influence of the capacitance between the rings becomes increasingly important. This reduces the shunt impedance. That means that there is an optimal module length when the shunt impedance has a maximum. The simulations showed that we can expect a shunt impedance of about 330 kΩm for

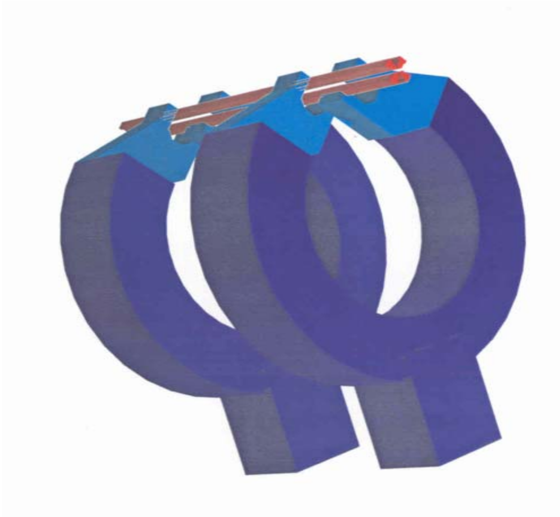

Figure 3: 1 module of a split ring RFQ.

the optimized resonator with a ring spacing of about 20 cm. This takes into account that the MAFIA value is typically a factor of two too high for split ring RFQ resonators.

Due to cw operation power losses, power densities and

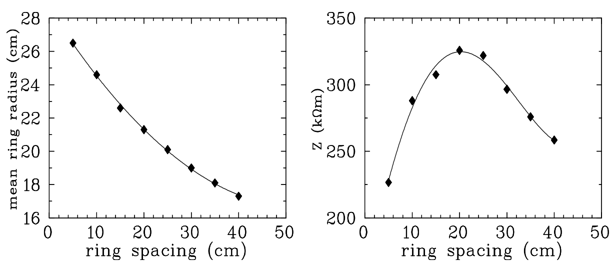

Figure 4: Mean ring radius and shunt impedance R_p as function of the spacing between the split rings.

cooling requirements are one of the most important issues of the normal conducting RFQ. With the expected shunt impedance, a power of 24.5 kW/m is required to load the electrodes to their design voltage of 90 kV. About 60% of the power is dissipated on the main rings and 25% on the electrode holder. Figure 5 shows the simulated average power densities on different structure components. The highest values occur on the electrode holder with 3.3 W/cm^2. The peak values are about 6 times larger.

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

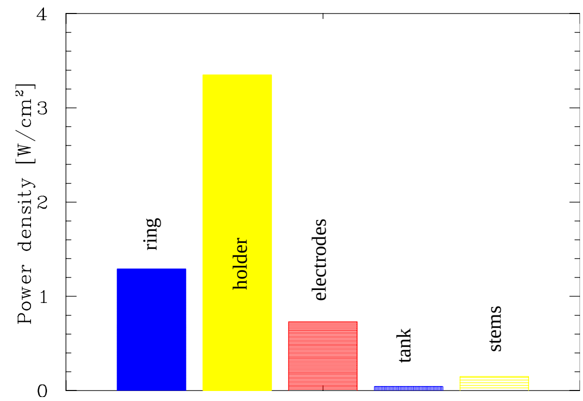

Figure 5: Average power loss densities on different structure components in W/cm^2 of the split-ring RFQ.

- radial ring width

Figure 6: 3 ring slice of an IH RFQ.

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 520 kΩm which lead to a required power of 15.6 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 structure. Due to the small distance between the rings, the losses per ring and on the electrodes are very small (≈5%).

The power loss distribution has been simulated. About 50% of the losses occur on the tank walls which can be

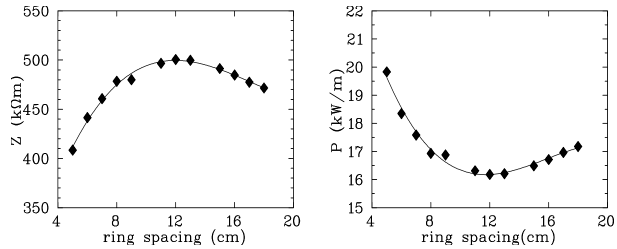

Figure 7:

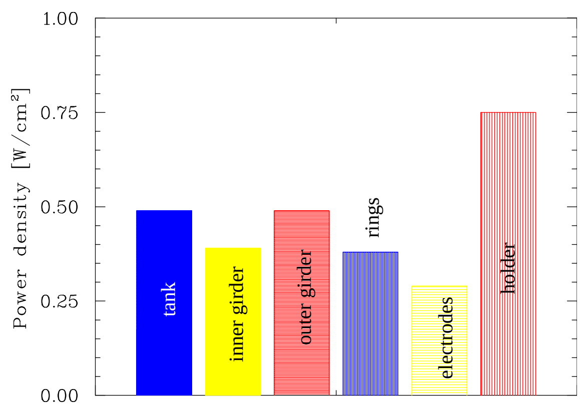

Figure 8: Average power loss density on different structure components of the IH RFQ.

cooled very efficiently. Figure 7 shows the average power loss density on different structure components. The peak values are about 8 times higher. The highes values occur on the outer side of the girders where the magnetic flux is maximal.

4 BEAM DYNAMICS

We have designed the electrode geometry using the optimization program RFQopt [5]. Figure 9 shows the parameter curves (m,φ_s, aperture) and the phase space at the exit of the RFQ. The normalized transverse acceptance is 1.3 πmm·mrad. An external multi harmonic Buncher operating at 20 MHz is foreseen.

5 COMPARISON AND SUMMARY

We have optimized a split ring RFQ and an IH-type RFQ resonator for a possible CCF post accelerator. Table 1 shows the most important parameters of the two resonators. With the expected shunt impedance of 330 kΩm (split ring) and 520 kΩm (IH-type), the required rf power (thermal load) is 24.5 kW/m (4-rod) and 15.6 kW/m (IH). Both RFQ resonators are suitable candidates. However due to the higher shunt impedance, much better loss distribution and better tuning possibilities the IH RFQ seems to be the better choice especially for cw operation. The next step could be the construction of a cold model to verify the main electromagnetic properties.

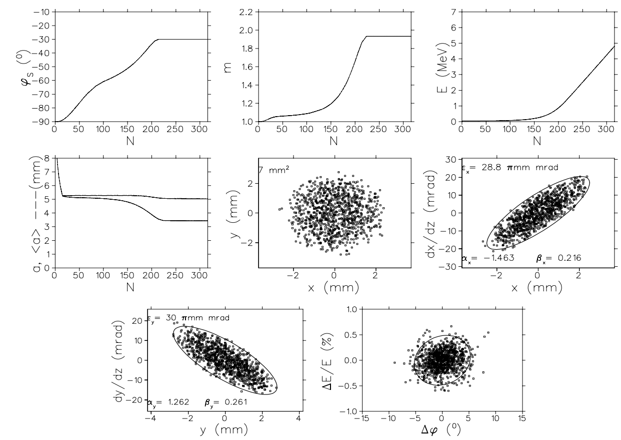

Figure 9: Parameter curves and phase space of the 40 MHz RFQ.

Parameter	**split ring**	**IH-type**
Frequency (MHz)	40	40
q/A	1:40	1:40
Input energy (keV/u)	1	1
Output energy (keV/u)	120	120
Diameter (cm)	90x80	74
Length (cm)	722	722
Av. aperture (mm)	5.1	5.1
Vane tip radius (mm)	4.4	4.4
R_p (kΩm)	330	520
P/L (kW/m)	24.5	15.6
Total power (kW)	175	112
P density ρ_{max} (W/cm^2)	20	7
Kilpatrick ratio	1.5	1.5
E_p (kV/cm)	200	200
Max. modulation	1.93	1.93
Focusing	4.9	4.9
Synchronous phase	-30°	-30°

Table 1: Comparison of important resonator properties of the split ring and the IH RFQ.

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