

THE DESIGN OF LOW FREQUENCY HEAVY ION RFQ RESONATORS *

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Abstract

The development of the 4-Rod-RFQ as injector for low charged heavy ions has demonstrated that structures with spiral shaped and straight stems can be made highly efficient, very stable and compact. The design of the RFQ structures and results of impedance optimizations and the effects of monopole and dipole mode generation will be discussed.

I. INTRODUCTION

Because of improvements in ion source technology a new layout of the GSI High Current Injector can use higher charged ions: U^{4+} instead of U^{2+} , as used for the “old“ High Current Injector design. The old HCI was planned as a 27 MHz-RFQ for U^{2+} as injector for the Wideroe and a stripper for producing U^{10+} with a necessary current of 25 mA. In the new concept a beam current of only 10 mA U^{4+} is required, because a stripper is not needed any more, the beam will be injected directly into a new IH-Linac.

II. RF-CALCULATIONS

The specific parameters of the rf-properties of the different RFQ resonators have been checked by model measurements and calculations with the program MAFIA. Special considerations has been given to dipole effects, distribution of losses along the structure, and the influence of electrode-capacitance on the rf-parameters.

A. Capacitance of electrodes

The capacitance of the electrodes has a strong influence on the resonance frequency of the resonator. A resonator loaded with a big capacitance usually is less efficient, the Rp-value (shuntimpedance) is smaller. Although the vane-shaped geometry has 20 % more capacitance than the circular cylindrical one, the impedance is nearly equal, the greater surface produces less losses. Table 1 shows a comparison of resonators with vane- respectively rod-shaped electrodes. The numeric calculations of characteristic resonator-data was done with the programs MAFIA and OPERA. It is a question of manufacture and cooling, which shape of electrodes will be chosen. So mechanical parameters and costs may determine the choice.

| | Vanes | Rods |
|-----------------|-------|-------|
| Frequency / MHz | 30.50 | 32.24 |
| Quality-Factor | 12700 | 11500 |
| Shunt-imp./kΩm | 277.3 | 258.5 |

Table 1: RF-Parameters for different electrode-shapes.

B. Dipole effects

Dipole contributions in the electrode fields correspond to differences in the potential of the electrodes, e.g. the beam axis is not on zero potential. They can be a reason for beam losses, depending on their strength and beam emittances. Dipole-components of the electrode-voltage can be reduced by shaping the stems with an angle α as shown in fig. 1, which has been used in all operating four-rod RFQs [1]. With an inclination of about 45 degrees the dipole effect can be minimized to $(U-U_{AV})/U_{AV} = 0.4\%$ (see table 2), A dipole of 2 % or less is insignificant [2], it is below the experimental tuning tolerances of RFQs.

| Dipole / % | α / Degrees |
|------------|--------------------|
| 1.41 | 0 |
| 1.17 | 10.2 |
| 1.04 | 19.9 |
| 0.89 | 28.5 |
| 0.76 | 35.9 |
| 0.60 | 43.9 |
| 0.45 | 50.3 |

Table 2: Dipole-effects versus shape of stems.

The dipole-effects can be reduced by longer stems too, at a lower frequency. Table 3 shows the decrease of dipoles as function of the length of the stems (rectangular cross-section).

| Length of Stems / mm | Dipole / % |
|----------------------|------------|
| 600 | 1.27 |
| 622 | 1.22 |
| 644 | 1.18 |
| 666 | 1.14 |
| 688 | 1.10 |
| 710 | 1.06 |

Table 3: Dipole-effects versus length of stems.

* supported by the BMFT

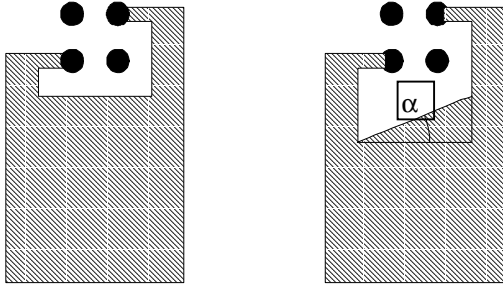


Fig. 1: Shape of four rod RFQ stems.

C. Alternative structures

Alternative structures are the spiral loaded RFQ, which has been successfully tested (27 MHz) and reached full beam current recently at GSI [3]. There, this structure was felt to be not stable enough, so that the structure with the linear straight stems discussed above was favoured at first.

Another structure was proposed, which can be characterized as an Interdigital-H-shaped resonator loaded with Four-Rod electrodes and supports [4]. To study this resonator, a model scaled to about 100 MHz has been built.

This model showed dipole effects of 8 %, what scales to 2 % at a frequency of 36 MHz. No distinctly advantage compared to the stems-type RFQ can be seen, whereas other technical difficulties may appear.

MAFIA-calculations may show different results for dipoles because of different paths of integration. Integration paths, shown in fig. 2, give voltage values, which are in good agreement with experiments. Direct integration on the beam axis typically has too small values, smaller than the errors of the MAFIA code.

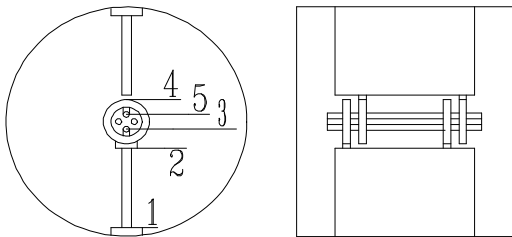


Fig. 2: Interdigital-H-structure.

III. COOLING CONSIDERATIONS

Due to the maximum duty factor of about 3 % the rf-power distribution has been checked. Less than 20 % of the losses appear on the electrodes. Nevertheless this is critical, because of the mechanical precision required. In a stem-RFQ with distances of 400 mm the electrodes will have to be cooled with water like at the HLI-RFQ, which operates at

25 % duty factor [5]. For omitting the cooling, the stems must be arranged with smaller distances, e. g. 250 mm.

Experiments with the 27 MHz Spiral loaded RFQ have shown that water cooled electrodes are not necessary anyhow, because the conduction of heat by the electrode carriers is sufficient [3].

For a higher frequency (e. g. 200 MHz at ESS- or ATW-projects) the average power is higher (5 % duty factor up to c. w., 5 - 100 kW/m). A high duty factor prototype with a frequency of 200 MHz is being built at IAP Frankfurt for experiments on cooling and stability.



Fig. 3: MAFIA-Plot of the stems-prototype.

A. Distribution of losses

Measurements with four-rod RFQs have been confirmed by MAFIA-calculations: The RFQ losses are distributed as follows: 17 % on the electrodes, 9 % on the blocks where the electrodes are fixed to the stems (electrode carriers), 58 % on the stems, 7 % on the base plate and only 9 % on the walls of the cavity, which is one of the big advantages for high power operation.

IV. BEAM DYNAMICS

The low input energy of 2.2 keV/N allows a relatively short RFQ with a sufficient number of cells to achieve a convenient beam formation for good beam quality. The RFQ has to be designed for a short bunch width and a small energy spread at the output and a minimum transverse emittance growth.

In figs. 4 and 5 the results of beam dynamics calculations are shown. The calculations have been done with the program PARMTEQ for an input beam with transverse waterbag distribution and no initial energy spread. In fig. 4 the emittances behind the RFQ are shown for a normalized input emittance of 0.3π mm mrad. The transmission is 90%, the emittance growth only 5.5%.

RFQ FOR U4, F=36.1MHZ, U=125KV
 NCELL=356, NPOINT=1810, NTOTAL=2000, Iin=15 mA

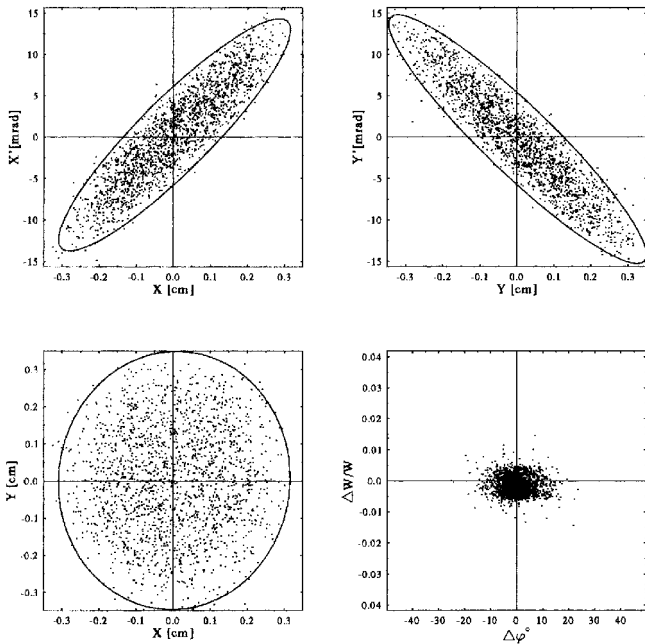


Fig. 4: RFQ output emittances, with space charge (15 mA).

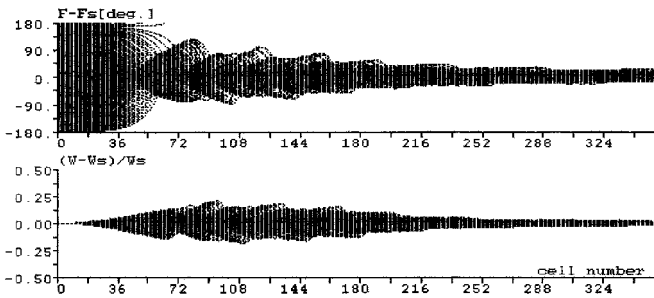


Fig. 5: Beam transmission along the RFQ.

A. RF-Power Requirements

An expected Rp-value of 500 kΩm enables the operator of an RFQ with a length of 9 meter (= 55 kΩ) to reach an electrode voltage of 125 kV with an rf-power of 280 kW.

Table 4 shows a comparison of different RFQ-resonators. The stems have rectangular cross-section with different width and length, except number 5 which has stems with a circular cross-section of 120 mm, and the IH-structure with 15 mm distance of the supports of the electrodes, according to the GSI design. [4]

The low power model has a simple geometry: The stems with a cross-section of 200 mm × 10 mm have a distance of 400 mm and a height of 400 mm. The electrodes are optional cylindric with a radius of 5 mm or vane-like with a shape of 10 mm × 20 mm, each 1240 mm long, the aperture is 10 mm. The resonator was only screwed, so bad contacts reduce the shuntimpedance. Table 5 shows the comparison between calculation and measurements.

| Stems | Frequency / MHz | Quality-Factor | Shunt-impedance |
|--------------|-----------------|----------------|-----------------|
| 400 x 400 | 30.7 | 10400 | 770 |
| 250 x 600 | 36.9 | 13000 | 790 |
| 250 x 700 | 34.6 | 12900 | 830 |
| 250 x rad 60 | 33.5 | 11500 | 840 |
| IH-Structure | 37.1 | 8000 | 360 |

Table 4: Properties of different RFQ-resonators.

| | Measurement | MAFIA |
|-----------------|-------------|-------|
| Frequency / MHz | 34.3 | 32.2 |
| Quality-Factor | 2900 | 10500 |
| Shuntimp. / kΩm | 270 | 770 |

Table 5: Comparison of calculated and measured properties.

V. CONCLUSIONS

Four-rod type RFQs for low frequencies have high efficiency, good mechanical stability, good operational characteristics and suffer no dipole mode problems, which has been shown in calculations, prototypes and operating structures. Spiral shaped and straight stems supports give compact resonators. GSI will go on working with the IH-driven four-rod RFQ, for which prototyping on a number of design issues is the next stage.

VI. REFERENCES

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