A 90°-apart-stem Low Frequency RFQ *

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Abstract

A new version of 90°-apart-stem RFQ resonant structure, which can be used at low frequencies to accelerate heavy ions, is considered. Having smaller transverse dimensions in comparison with the original one, this new structure allows to keep both good rf efficiency and simplicity of manufacture. Results of computer simulations with MAFIA codes and of measurements on a cold model built at ITEP are presented.

1 INTRODUCTION

Radio Frequency Quadrupole (RFQ) structures are widely used nowadays as initial stage of particle accelerators for fusion research, ion implantation, nuclear medicine and in any area where low and medium energy of ions is required. The used frequencies range from a few MHz to a few hundred of MHz.

Because of the great interest in low-β RFQ structures, which are used for accelerating heavy ions, development of new resonant structures for low frequencies is still actual.

The upgrade of ITEP's heavy ion RFQ was started having as a goal to replace the existing 6 MHz RFQ structure (accelerating particles with charge to mass ratio of 1/60 up to 36 keV/u) by a 27 MHz RFQ, which can accelerate ions with the same charge to mass ratio up to 110 keV/u.

2 THE RING-CONNECTED RFQ

The design of RFQ resonant structures at low frequencies is always a compromise between compactness and rf efficiency, which is higher when the dimensions of the structure are larger. Using cavity resonant structures, such as 4-vane, is impracticable owing to large dimensions; resonant LC structures such as 4-rod, Spiral and Split-Ring are more suitable.

Our investigations of a "4-ladder" structure [1] showed that it can be used at low frequencies as well: it has a good rf efficiency, smaller dimensions in comparison with 4-vane and a reliable separation between quadrupole mode and dipole ones. Nevertheless, it is a little larger than 4-rod and other LC structures.

We modified this structure in order to reduce its dimensions and to make it more suitable for working at low frequencies. As a result, a new resonant structure, using a 90°-apart-stem arrangement and having small transversal dimensions, was developed and tested on the scaled (1:2) cold model shown in Figure 1, whose design frequency is 54 MHz.

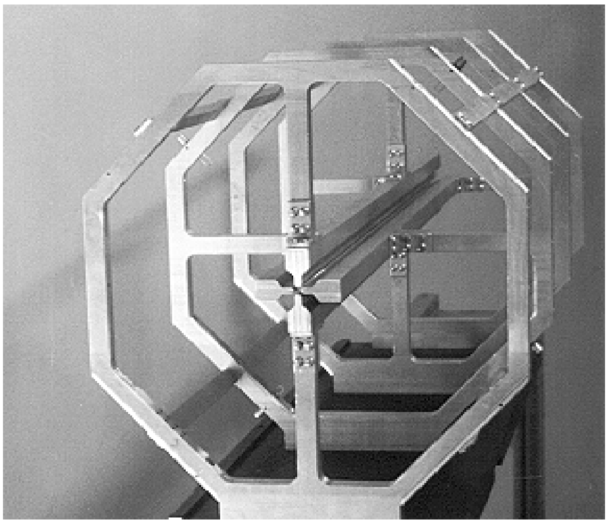

Fig. 1: The scaled 54 MHz cold model built at ITEP

This new RFQ structure, henceforth called "Ring-connected", has the same stem arrangement as our 4-ladder RFQ, i.e. neighbouring pairs of stems are perpendicular to each other and to the beam direction. Also in this case, a combination of quadrupolar and coaxial modes is then excited in the structure, which provides a reliable separation between operating mode and dipole ones.

In contrast with the 4-ladder RFQ, there are rings connecting the stems and rods connecting the rings. Since both the rings and the rods have a much higher inductance than the tank of the 4-ladder structure, they allow to lower the resonant frequency with respect to it.

3 NUMERICAL SIMULATIONS

The new RFQ structure will be installed into the existing vacuum tank, having inner diameter of 1.2 m and length of 12 m. Before manufacturing the full scale RFQ, numerical simulations with MAFIA codes [2] were carried out for a 54 MHz 3-cell structure in order to test all its characteristics (Figure 2).

In fact, the so-called rings have an octangular shape, in order to simplify the manufacturing. It should be noticed that the shape of the rings can be different, for example circular

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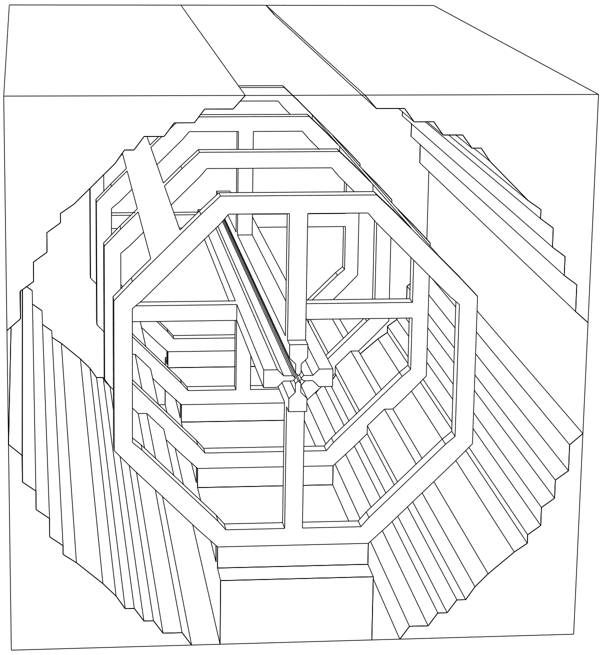

Fig. 2: MAFIA plot of the 54 MHz 3-cell RFQ

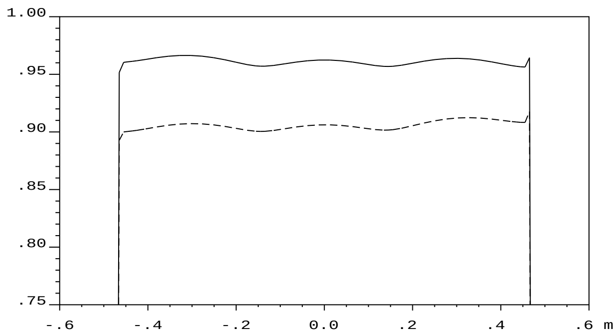

Fig. 3: MAFIA plot of normalized $V_e(z)$

rings allow a higher shunt impedance.

Figure 3 shows the longitudinal distribution of the voltage V_e between the upper (—) and lower (- - -) pair of electrodes; the 5–6% difference is due to the asymmetry introduced by the ring supports. Flatness of longitudinal inter-electrode voltage distribution is also provided by end cell tuning, i.e. by changing the length of the electrodes and their distance from the end plate, as in [1].

Figures 4 and 5 show the distribution of the magnetic field in two transverse sections of the structure, in the middle of a cell and of a ring respectively. Figure 6 shows the distribution of the magnetic field in a longitudinal section in the horizontal plane.

As it can be seen from Figures 4, 5 and 6, the Ring-connected RFQ is an "open" structure because fields are not closed completely inside it, but fill the whole tank. It means that power dissipation on the tank walls should be taken into account.

Nevertheless, results of MAFIA simulations, presented in Table 1 for copper and steel tank wall (but full copper structure), show that losses cause only a small ($\approx$ 3%) reduction of the specific shunt impedance R_{sh} and of the quality factor Q. One advantage of this structure is then the possibility of using a steel tank without any copper plating of its inner surface, even if its conductivity is only 18% of the copper one.

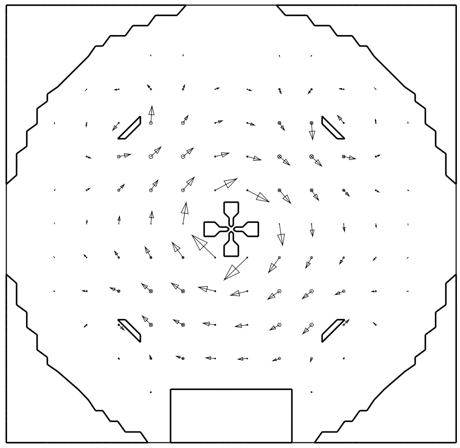

Fig. 4: MAFIA plot of the magnetic field in a transverse section in the middle of a cell

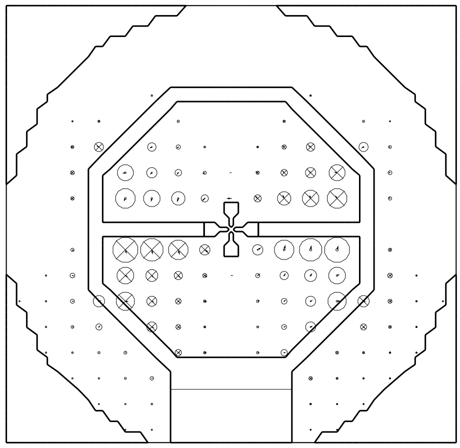

Fig. 5: MAFIA plot of the magnetic field in a transverse section in the middle of a ring

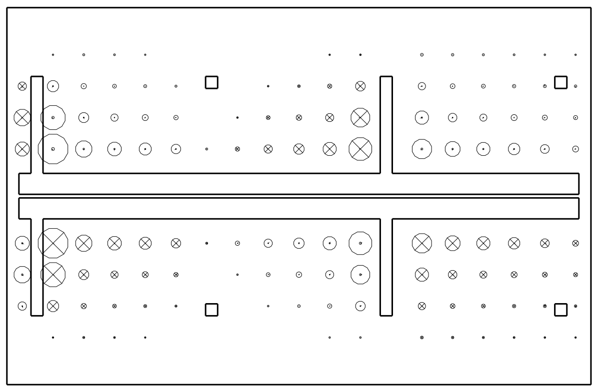

Fig. 6: MAFIA plot of the magnetic field in a longitudinal section at y= 0

Table 1: Simulated parameters

	copper tank	steel tank
$R_{\rm sh}$	531.3 kΩ·m	514.3 kΩ·m
Q factor	12.19×10^3	11.80×10^3

4 COLD MODEL MEASUREMENTS

An aluminum scaled (1:2) cold model with unmodulated electrodes was manufactured to check the characteristics of the 54 MHz structure as predicted by numerical simulations. The dimensions calculated by MAFIA codes in order to get the right resonant frequency are the following:

Table 2: Scaled model computed dimensions

Length of the structure	970 mm
Inner tank diameter	600 mm
Distance between rings	290 mm
Internal ring diameter	360 mm
External ring diameter	400 mm
Ring width	20 mm
Ring-connecting rods cross-section	20×10 mm
Electrode supports cross-section	20×20 mm
Length of the electrodes	930 mm
Aperture radius	3 mm
Curvature radius of electrode tip	3 mm

The manufactured structure has been put into an existing tank with an internal diameter of 630 mm instead of 600 mm. This difference has a negligible effect on the resonant frequency $f_{\rm q}$, which decreases by only 0.05%, according to MAFIA simulations.

Moreover, the ring width is 19 mm instead of 20 mm, the electrode supports have a cross-section of 18×19 mm instead of 20×20 mm and the inner ring diameter is 364 mm instead of 360 mm. This decision of having smaller dimensions (and lower $f_{\rm q}$) allows for tuning both the resonant frequency and the field distribution by means of additional strips, which permit to increase $f_{\rm q}$. Tuning may also be obtained by changing the cross-section of the rods which connect the rings.

Four couplers were installed at the rings for exciting the structure and for measurements. Results of preliminary cold model measurements, without end plates, are shown in Table 3 together with results of additional MAFIA simulations carried out for the above new dimensions and under the same experimental conditions (full aluminum structure, no end plates).

The measured frequencies are slightly lower than the simulated ones (about 5% for $f_{\rm q}$ and 4% for the dipole modes). This discrepancy may be due, at least partly, to the rough MAFIA approximation of the electrode tips, which leads to under-estimate the inter-electrode capacitance and therefore to over-estimate the frequency. The splitting of dipole modes results from the asymmetry of the structure due to the ring supports; the simplest way to overcome this effect is to place similar supports in the upper part of the structure, making it symmetrical.

Table 3: Measured and simulated parameters

	Simulation	Measurement
Resonant freq. $f_{\rm q}$	52.64 MHz	50.01 MHz
Dipole freq. $f_{\rm d}$	73.70 MHz	70.62 MHz
	74.51 MHz	71.40 MHz
Separation $f_{\rm d}-f_{\rm q}$	21.06 MHz	20.61 MHz
	21.87 MHz	21.39 MHz
Q factor	9.73×10^3	1.66×10^3
$R_{\rm sh}$	426.2 kΩ·m	78.3 kΩ·m
$V_{\rm e}$ uniformity	1.25%	1.5%

The measured Q factor is about 6 times smaller than the computed one; this poor result is due to bad contacts. The same applies to the specific shunt impedance.

The electric field distribution between each pair of electrodes has been measured by means of a “bead-pull” technique. The results of measurements are practically coinciding with the simulation ones.

5 CONCLUSIONS

The investigation of the Ring-connected RFQ, which can be considered as a version of 4-ladder RFQ, showed that it has good rf efficiency, smaller dimensions than the 4-ladder RFQ, reliable frequency separation between quadrupole and dipole modes, and simplicity of manufacture. It is therefore a good candidate for the acceleration of heavy ions at low frequencies.

We are going to continue the study of this structure in order to eliminate the dipole effects, to optimize it from the point of view of the manufacture technology (mechanical stability, cooling...) and to use the obtained results for building a 27 MHz full scale Ring-connected RFQ to accelerate U^{4+} ions.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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