90°-apart-stem RFQ Structure for Wide Range of Frequencies

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Abstract

At present, many different resonant RFQ structures for accelerating both light and heavy ions are successfully used. Usually they are divided into two well known groups: 4-vane and 4-rod structures, each of them having its merits and drawbacks. In this paper a new resonant structure is considered, which combines the advantages of both. It may be seen as a 4-vane structure with holes ("windows") in the vanes, or as a 4-rod one having stems located 90° apart from each other and from the beam direction. Thus, changing the window size, such a structure can be modified from a typical 4-rod resonator, working at 50 MHz or less, to a typical 4-vane one, working at higher frequencies (up to 500 MHz) and having a better frequency distinction between operating and unwanted dipole modes, due to the magnetic coupling between neighbouring quadrants through the holes. It also should be noted that no voltage arises on the beam axis in the gap between end plate and electrodes, provided that horizontal and vertical windows have the same longitudinal position. Computer simulations with MAFIA codes are presented and compared with cold model measurements.

1 INTRODUCTION

The well known idea of "spatially uniform strong focusing", proposed by Kapchinsky and Tepljakov [1], is very widely used for accelerating both light and heavy ions.

A suitable arrangement of accelerating and focusing fields can be provided by different RFQ resonant structures, usually distinguished between resonant cavities (as 4-vane, Double-H and Split-Coaxial) and resonant LC-structures (as 4-rod, Spiral and Split-Ring) [2].

A new version of 90°-apart-stem RFQ structure, henceforth called "4-ladder", which combines the merits of 4-vane and 4-rod RFQ's, has been developed in the framework of a collaboration between ITEP and INFN-LNL in contact with the CERN design group of the "Lead Ion Linac Facility".

During 1992, a full scale cold model of a 100 MHz structure was built in ITEP (Fig. 1) and MAFIA simulations were carried out at LNL. Both simulations and measurements showed a reliable mode separation without any Vane Coupling Rings (VCR) and with a good RF efficiency.

2 4-VANE, 4-ROD AND 4-LADDER RFQ

The main parameters taken into account, for a proper design of an RFQ structure and its outer resonator, are:

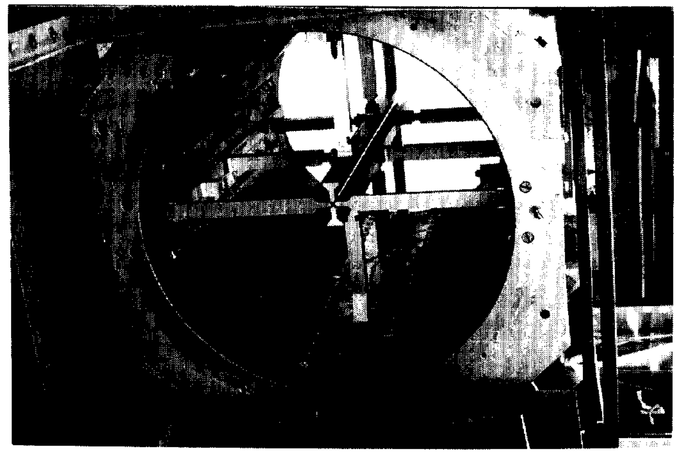

Fig. 1: Full scale 100 MHz cold model built at ITEP

- RF power losses (to be minimized);
- mode separation (to be maximized);
- end region effects (properly controlled);
- dimensions (feasibility);
- mechanical features (feasibility).

To reduce RF power losses, it is necessary to choose structures with a high shunt-impedance Z_{sh}, defined as V_e^2/P where V_e is the inter-electrode voltage and P is the dissipated power. In general, the 4-vane RFQ has an higher Z_{sh} with respect to the 4-rod one: in fact the whole inner tank surface is a part of the resonant system and this allows to decrease the current density and hence to reduce power losses. The same happens for our 4-ladder structure: from the point of view of RF efficiency, it should be just a little worse than a 4-vane.

The need for a negligible emittance growth requires a very stable RF field distribution inside the structure; it means first of all a good separation of the operating quadrupole mode from the dipole ones. It's known that a 4-rod RFQ (particulary a "double support" one) has absolute freedom from undesired dipole components, due to the coupling effect of the frames, so $f_{\rm dip}$ is quite higher than $f_{\rm quad}$ (even double). On the contrary, in a 4-vane RFQ the difference is only of a few percent (with $f_{\rm dip} < f_{\rm quad}$) and VCR or other coupling mechanism have often to be used to reject undesired dipole modes; furthermore, there are some problems with mode separation in long resonators ($L > 2\lambda$). In the 4-ladder structure this separation is expected to be rather larger than in the 4-vane resonator, due to the strong magnetic coupling between neighbouring quadrants through the windows.

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A correct end regions tuning is needed in order to guarantee a flat inter-electrode voltage distribution along the structure. Moreover, a recent investigation [3] showed that some types of 4-rod RFQ's have a longitudinal E_z component of the electric field on the axis in the region between end plate and electrodes; this effect is in principle negative as it perturbes the matching of the beam, nevertheless it can be controlled and even used to provide a velocity modulation of the particle beam in order to reduce the emittance growth in the accelerating channel [4]. From the point of view of end region effects, our 4-ladder structure is close to the 4-vane one, because the tuning may be obtained by changing the size of the last window; nevertheless we expect to have an E_z component, because of the shift between vertical and horizontal windows (i.e. of the shift of the points exciting the accelerating channel). This effect depends on the ratio between the distance of these points and the wavelength λ and we found that it is easily eliminated if we install the windows in the same longitudinal position.

The dimension of a 4-vane structure is larger in comparison with a 4-rod resonator, and it becomes impractically large at frequencies lower than 100 MHz. The 4-ladder structure is smaller in comparison with the 4-vane one and a little larger than the 4-rod one.

From the point of view of mechanical stability, rigidity and simplicity, the 4-vane resonator is more attractive, combining a very high accuracy in manufacture and alignment. The 4-rod structure, though being quite simple in manufacture, has many joints (by means of welding, brazing or bolt connections) between supports and electrodes. From this point of view, the 4-ladder structure is similar to a 4-vane, because it has no joints between electrodes and stems, thus keeping the same rigidity and accuracy of manufacture.

It should be noticed that a 90° arrangement had been used earlier in the low energy $\beta\lambda/2$ RFQ at Frankfurt, where two orthogonally placed stems with a connecting strip are a typical inductance (having in contrast to the "90°-apart-stem" structure practically no coupling with the tank) and in the Split-Coaxial Resonator, where stems are elements of joint that connect separated fingers to suitable RF potential points of the resonator [5]. Besides, during the comparison study of RFQ structures for the Lead-Ion Linac at CERN [6], a version of "90°-apart-stem" structure had been considered, having cylindrical stems located 90° apart from each other and from the axis, which connect opposite electrodes by means of frames.

3 NUMERICAL SIMULATIONS

Using the MAFIA codes [7], the structure shown in Fig. 2 has been studied with respect to all the previous features.

First of all it was optimized from the point of view of RF efficiency: the tank diameter was not changed, but both the size of the windows and their position were adjusted (keeping the same distance between their centers);

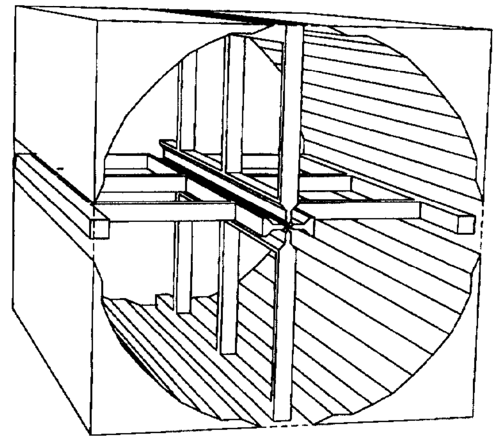

Fig. 2: MAFIA plot of the 100 MHz 4-ladder RFQ

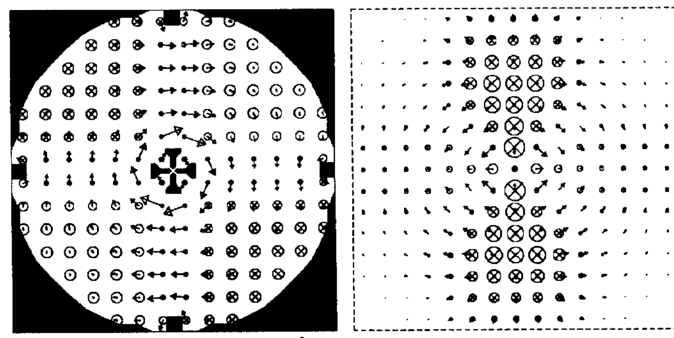

Fig. 3: MAFIA plot of $\vec{B}$ field through the windows (left) and detail of $\vec{E}$ field in the end region (right)

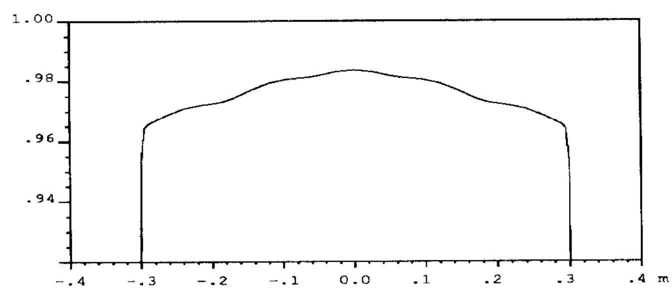

Fig. 4: MAFIA plot of normalized $V_e(z)$

actually three versions of the structure were tested. In the best case, the specific shunt-impedance $R_{sh} = 340$ kΩ·m was achieved, with Q = 1.5×10^4 (full copper structure).

As foreseen, the dipole modes were found more than 20 MHz higher than the quadrupole one; this separation is enough to guarantee their suppression. A plot of the harmonic magnetic flux density is presented in Fig. 3-left; notice the $\vec{B}$ lines coupling a quadrant to another.

An electric field E_z was found on the axis, in the gap between end plate and electrodes, as shown in Fig. 3-right; on the other hand, simulations confirmed that it can be eliminated by moving the horizontal and vertical windows to the same longitudinal position. The inter-electrode voltage distribution $V_e(z)$ is shown in Fig. 4; the small drop on the ends (~2 %) disappears with a proper tuning of the end regions.

In Tab. 1 the results from simulations are presented (copper tank and aluminium electrodes).

width×height (m)	f_{quad} (MHz)	f_{dip} (MHz)	Q-value (10^3)	R_{sh} (kΩ·m)
0.17×0.13	119.91	139.79	10.9	202
0.20×0.135	110.21	132.74	11.6	235
0.22×0.17	99.93	124.90	12.7	291

Tab. 1: Computed parameters in function of window size

This work is presently continuing for another structure, working around 400 MHz; first results show the possibility to tune end regions.

4 MEASUREMENTS ON COLD MODELS

In order to determine the accuracy of calculations, measurements were performed on the cold model shown in Fig. 1, (without modulation of the electrodes) using all the three simulated versions. The dimensions of that structure are:

- Inner tank diameter - 0.44 m
- Length of the structure - 0.64 m
- Length of the electrodes - 0.60 m
- Aperture radius - 0.003 m
- Curvature radius of electrode tip - 0.003 m
- Gap between end plates and electrodes - 0.02 m
- Distance between the centers of the windows - 0.24 m
- Material of the electrodes - aluminium
- Material of the tank (and end plates) - copper

Copper strips were used to connect the vanes to the tank by means of screws.

The electric field distribution between each pair of electrodes has been measured with the "bead-pull" technique. The measurement results are just coinciding with the simulation ones.

A small discrepancy ($\sim 3\%$) was observed concerning the calculation of frequencies: the measured ones are a little bit lower than the computed ones, mainly because the MAFIA approximation of the electrode tip was rather rough. Notice the split of the dipole mode into two distinct modes, due to mechanical asymmetries.

The measured Q-values are within $2.7 \div 3.9 \times 10^3$; this poor result is due to bad contacts. The same applies for specific shunt impedance.

In Tab. 2 the measurements results are presented.

width×height (m)	f_{quad} (MHz)	f_{dip} (MHz)	Q-value (10^3)	R_{sh} (kΩ·m)
0.17×0.13	116.03	135.0 135.8	3.9	76
0.20×0.135	106.60	128.5 128.9	3.3	70
0.22×0.17	97.06	124.0 124.3	2.7	63

Tab. 2: Measured parameters in function of window size

5 CONCLUSIONS

The investigation of the 4-ladder structure, as one of the possible versions of the 90°-apart-stem RFQ, showed that it can be used in accelerator technique: it has good RF efficiency (quite reliable mode separation and field distribution) and mantains such merits of a 4-vane structure as simplicity of manufacture and mechanical stability.

The idea of an orthogonal arrangement allows to design structures for wide range of frequencies; indeed, for low frequency RFQ, one can use spirals instead of stems. The stems can be connected directly to the electrodes without any frames, or by means of frames. In the first case, there is no limitation to install neighbouring orthogonal stems (in our case windows) at the same longitudinal position and hence to eliminate completely the E_z component on the axis in the end regions.

It should also be noted that MAFIA codes are a very good instrument of investigation for resonant structures, allowing to get reliable information about all the parameters of interest.

6 ACKNOWLEDGEMENTS

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