DESIGN STUDY OF A FOUR VANE RFQ FOR HIGH DUTY CYCLE OPERATION

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Abstract

The 4 vane RFQ structure has a homogeneous surface current density distribution which is a great advantage at high duty cycle operation. A serious problem remaining is the separation of the quadrupole mode from adjacent dipole modes to make the quadrupole mode resistant against small mechanical displacements during operation. A cavity design suited for high duty cycle operation has been developed and low level rf measurements on a model cavity have shown quantitatively the advantage of a new kind of mode separation technique. These results as well as a 108 MHz cavity design study for heavy ion acceleration will be presented and discussed.

Introduction

Stable operation of RFQ structures at high duty cycle is still a technical challenge. The mechanical tolerances in the alignment of the accelerating electrodes are typically around 100μm. On the one hand this tolerance limit is caused by the beam dynamics. On the other hand in case of the 4 vane RFQ even tighter tolerances have to be kept if no separation of dipole modes is implemented in the design. The 'standard method' of separating dipole modes from the quadrupole mode are <u>V</u>ane <u>C</u>oupling <u>R</u>ings (VCR) which short together diametrically opposed vanes near the tip [1]. Also a modified version [2] and an inductive coupling method [3] were investigated. Because of the local distortions in the capacitance and/or inductance per unit length which cause additional rf power losses and field flatness problems it is not trivial to apply these methods on devices which have to withstand high duty cycle. Therefore an alternative approach was investigated:
Shorting together diametrically opposed vanes by two drift tubes at the high energy end (Fig. 1, 2). These two drift tubes form a 3 gap $\beta\lambda/2$ structure. They short the dipole modes in the most direct way. Additionally the geometry can be optimized in such a way that the capacitance and inductance per unith length are identical to the equivalent 4 vane design. The transverse defocusing effect of that short drift tube structure is weak and can be easily compensated by a subsequent external focusing element.

This solution of the mode separation problem helps to make use of the main advantage the four vane structure provides in comparison to the four rod RFQ, namely the homogeneous current distribution on the cavity walls. As an example the design of a four vane RFQ with water cooling in the vanes and in the tank walls was developed. The new design was based on the experiency with an interdigital H-type structure (IH structure in the H_{111} mode), which has been operated succesfully with long duty cycles or even in cw mode [6]. Since the four vane RFQ operating in the H_{210} mode uses many components similar to parts of the IH structure, the new design should be well suited even for cw RFQ operation.

Dipole Mode Separation

The new mode separation technique was studied at a RFQ model, which was constructed and used before for rf measurements at CERN. Elaborate rf tuning techniques were developed there [4], [5] to balance the quadrupole mode without dipole suppressors.

This RFQ model cavity has been brought to GSI in spring 1993. The magnetic flux inducers at the high energy end were replaced by two drift tubes, which short-cut the two pairs of opposite vanes (Fig. 1). The combination of the modulated vanes with the drift tube section is shown in Fig. 2. The first two gaps have the full vane potential difference, while the third gap has only half of this value. The synchronous phase for beam acceleration can be continued from the RFQ into the drift tube section. Transverse defocusing in the drift tube section has only a

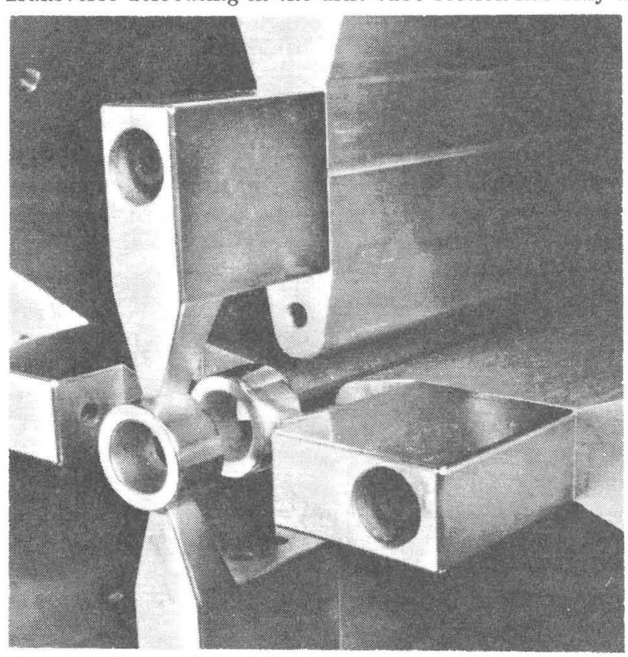

Figure 1: Separation of dipole modes by shorting together vane pairs at the high energy end with a drift tube.

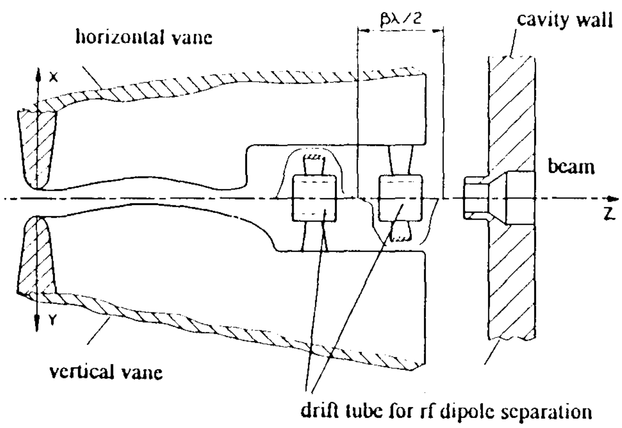

Figure 2: Sketch of the geometry at the high energy end of the modulated vanes.

small effect, and the drift tubes provide a larger aperture than the RFQ.

The rf measurements in the RFQ model structure have clearly shown the effect of the new mode separation technique. Without drift tube short-cuts the frequency of the H_{210} quadrupole mode was 211.6 MHz, while the adjacent dipole modes lay at 210.0 and 213.6 MHz. Installation of the drift tube short-cuts shifted the H_{210} mode to 213 MHz and the next dipole modes up to 223.0 and 219.5 MHz with adequate separation from the quadrupole mode.

Alignment Tolerances

The aim was to get the influence of a single vane displacement by an angle Θ on the ratio of the four vane-vane potentials. It means the determination of the parameter d in the following equation:

$$\frac{\Delta U_{max}}{U} = d \cdot \Theta; \qquad (1)$$

ΔU_{max} means the difference between maximum and minimum vane-vane potential, each averaged along the vanes. U is the average of all 4 inter vane potentials.

As the accurate measurement of small vane displacements along the whole length is difficult another method was used: The frequency shift in dependence from the position of two inductively acting cylindrical plungers inside the same quadrant and the influence on the 4 inter vane potentials is measured. This distortion can be compared with the displacement of a vane as shown by Fig. 3a, b. Equ.(2) describes the resonance frequency shift of a cavity caused by a small displacement of cavity walls. It can be applied to each RFQ quadrant separately. By that way one can correlate a individual frequency shift to a detuned quadrant which is four times bigger than the frequency shift of the cavity.

$$\frac{\Delta f}{f} = \frac{\Delta W_B - \Delta W_E}{2W}; \qquad (2)$$

$\Delta W_B, \Delta W_E$ are the magnetic resp. electric field energies in the volume of displacement. W is the total stored energy.

The following assumptions are made:

- A frequency shift $\Delta f/f$ of one quadrant causes an amount of distortion $\Delta U_{max}/U$ between vane-vane potentials which is independent of the kind of detuning mechanism.
- The magnetic field strength $|B_z|$ is constant over the whole cross section of each quadrant.
- The electric field has only an azimuthal component E_φ.
- Field distortions at the cavity ends and inside the RFQ aperture are neglected.

The field amplitude distribution is then approximated by

$$E_\varphi(r) = \alpha \cdot \frac{R^2 - r^2}{r}; \qquad a < r < R; \qquad (3)$$

$$B_z = const. \qquad (4)$$

R = outer radius of the cavity; a = aperture radius

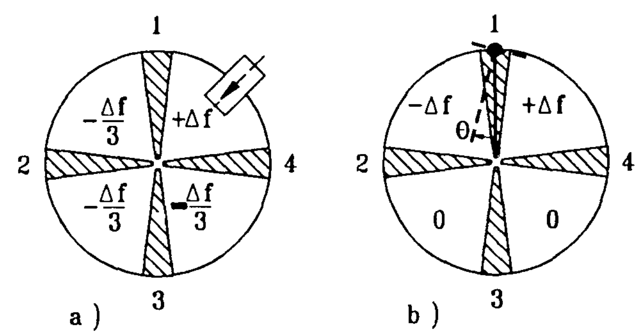

Figure 3: Comparison of two detuning mechanisms: (a) Detuning of one quadrant by a pair of cylindrical plungers; (b) Detuning of two quadrants by the displacement of one vane by an angle Θ.

With respect to alignment tolerances the cases of Fig. 3a (detuning by a plunger) and Fig. 3b (detuning angle Θ of vane 1) with the corresponding frequency shifts are compared as in Fig. 3a detuning angles $\Theta/3$ (vane no. 2), $\frac{2\Theta}{3}$ (vane no. 3) and Θ (vane no. 4) would compensate the effect of the plunger displacement, so the maximum occurring vane displacement angle Θ is identical in both cases. After a lengthy calculation, one gets from equations (2), (3) and (4) the dependence of $\Delta f/f$ on Θ.

Results

The effect of detuning one RFQ quadrant by two cylindrical plungers on the vane-vane voltage potentials is shown

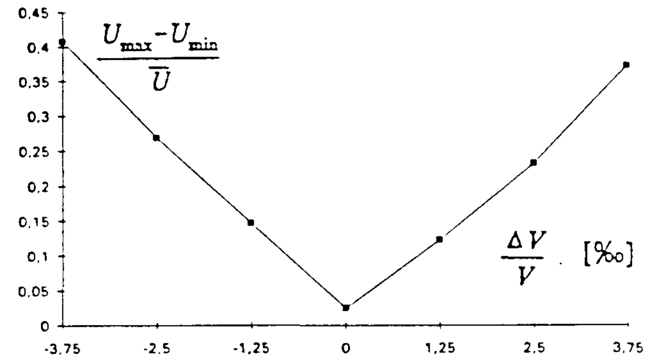

Figure 4: Effect of the relative volume change $\Delta V/V$ inside one quadrant on the maximum relative deviation of the four vane-vane potentials, without drift tubes; volume changed by plungers.

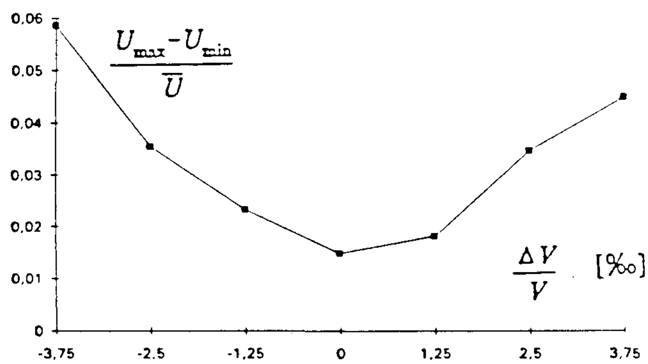

Figure 5: Same measurement as shown in Fig. 4, but with drift tubes mounted.

in Fig. 4 without resp. in Fig. 5 with dipole mode suppression by the drift tubes as shown in Fig. 1.

One can clearly see the improvement of the stability of the quadrupole mode against detuning effects by about one order of magnitude. At the same time the field distribution along the z-axis was not influenced by installing that kind of dipole mode suppression.

Applying the procedure as described above the parameter d in equ. (1) was deduced, and is given in table 1.

Table 1 additionally shows the transversal displacement s of a single vane tip which causes a distortion $\frac{\Delta U_{max}}{U} = 0.05$ in the vane-vane potentials, using the vane height of 167.5 mm (eff. aperture radius 5 mm, vane length 960 mm).

Table 1: Effect of the dipole suppressors on the mechanical tolerances

	d	s$\rightarrow \Delta U_{max}/U = 0.05$
without drift tubes	350	$\pm$ 24 μm
with drift tubes	34	$\pm$ 250 μm

Cavity Design

The proposed tank design (Fig. 6) with its water cooling circuits follows the concept as developed for the IH cavity [6]. To achieve the high mechanical precision and to keep it under operation much care has to be taken especially in the construction of the upper and lower half shells. The acquired precision of the vane contact surfaces belonging to the center frame was achieved already at the corresponding drift tube contact surfaces of several IH tanks ($\pm$ 40 μm).

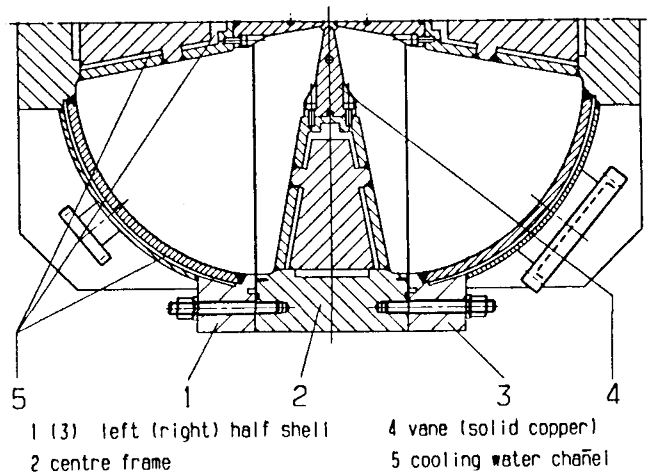

Figure 6: Conceptual design study - lower half cross section of the proposed 4 vane RFQ.

Acknowledgement

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