STATUS OF THE INTEGRATED RFQ-DRIFTTUBE-COMBINATION FOR THE MEDICINE-SYNCHROTRON IN HEIDELBERG*

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Abstract

Design and construction of the RFQ including an integrated rebunching section as a part of the LINAC system is our contribution to the medicine project in Heidelberg. The building of the machine has been finished, first rf-measurements at low power have been done. The concept of assembling, especially the alignment of the electrodes, and the results of the rf-measurements will be presented.

1 INTRODUCTION

A common solution for matching the longitudinal properties of a beam after an RFQ to the acceptance of a following drift tube structure is a separate buncher cavity in a suitable distance. We have developed a new concept: A drift tube is mounted directly to the last RFQ stem at the high energy end forming a boosting or bunching unit, depending on the HF-phase it is operated with [1] (fig. 1). The advantages of an integrated solution like this are a very compact and easy to use machine, which saves building and operating costs, no extra power supply and control-unit is needed. The loss of flexibility for example in adjusting phase and amplitude independently, which might be of interest in physical laboratories is unimportant in a clinical surrounding. Once the machine is switched on, it should operate with high reliability, without the need to do further adjustments.

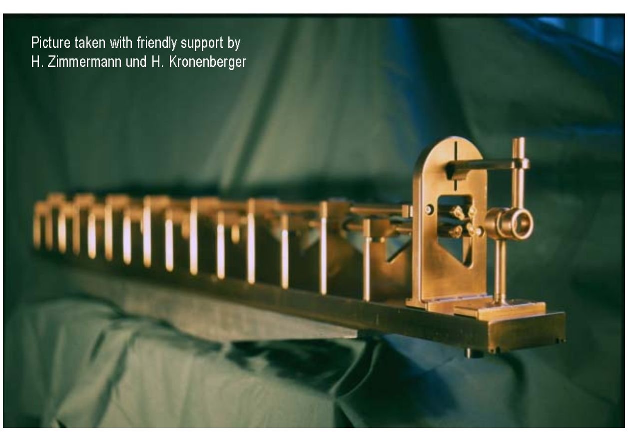

Figure 1: The adjusted RFQ-Drifttube-Combination right before its installation into the tank.

The 217 MHz RFQ will be a part of the accelerator complex, which is generally divided into two parts: a linac-section for pre-acceleration of $^{12}C^{4+}$ up to 7 MeV/u and the following synchrotron ring-structure for acceleration of stripped $^{12}C^{6+}$ to final energies between 50 and 430 MeV/u. The linac consists of an IH-type drift tube structure [2] following the RFQ. The main parameters of the RFQ are listed in Table 1. The Ions are coming from two separate ECR sources, to switch between two different ion species very fast.

2 RFQ DESIGN

At the generation of the RFQ structure the simulation program PARMPRO uses the well known two term potential:

$$V(r,\varphi,z) = A_{0,1}\left(\frac{r}{a}\right)^2 \cos(2\varphi) + A_{1,0}\, \mathrm{I}_0(kr)\cos(kz),$$

where k is the wave number of the modulation, I_0 is the modified Bessel function of order 0. $A_{0,1}$ and $A_{1,0}$ are functions of k, a and m and are scaling with the electrode voltage U. Fig. 2 shows the ideal electrode shape in a transverse intersection for modulation $m = 2$, based on the two term potential.

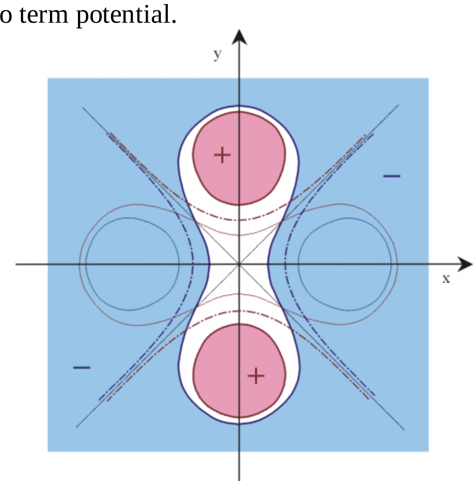

Figure 2: transverse intersection of the ideal electrode shape for modulation $m = 2$, based on the two term potential. Intersections in three different planes at the beginning, in the middle (ideal hyperbolic shape) and at the end of the cell are printed.

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Each curve of the surface of ideal electrodes, which reaches closer to the beam axis is closing behind the other ones. As it is impossible to manufacture an electrode like this, one has to find an approximate solution.

Two types of electrodes are widely in use with the 4-rod-RFQ: The so called mini-vane type and the original rods. In the case of the rods, the modulation is done by changing the diameter periodically, which fits very well to the geometry shown in fig. 3, while the mini-vanes are milled and the transverse diameter is kept constant throughout the whole cell. Indeed simulations with Los Alamos PARMTEQ indicate a slightly better transmission of about 1 % with rod type electrodes in some cases. On the other hand one has much more freedom to vary the modulation or the aperture along the structure with the mini-vane electrodes without causing to many trouble in view of the alignment. However mini-vanes do have a higher capacity, which leads to a higher power consumption of the whole structure.

The medicine-RFQ has been manufactured by the use of mini-vane type electrodes, the main parameters of the RFQ are listed in table 1.

Table 1: Main RFQ parameters.

Ion species	$^{12}C^{4+}$, protons
Length of the electrodes	1,28 m
Length of tank	1,40 m
Tank diameter	250 mm
# of RFQ cells	219
# of matching in cells	8
Min. aperture	2.63 mm
Max. modulation	1.867
Max. focusing strength *B*	4.84
Input energy	8 keV/u
Input emittance	$\varepsilon_{x,y}$=150 π mm mrad
Electrode voltage	70 kV
Exp. Power consumption	165 kW
Current	max. 2 mA H^+
Output energy	400 keV/u
max. beam angle at the exit	±20 mrad (in both planes)
Phase width at IH entrance	$\Delta\varphi \leq \pm 15°$

3 ALIGNMENT

As the beam axis should be congruent with the tank axis, the first step of alignment was to determine the position of the ground plate mounted inside of the tank relative to the tank axis defined by the centers of the two end-flanges (fig. 3) [3]. Stems and electrodes where adjusted afterwards with respect to these measurements outside of the tank (fig. 4). The adjustment has been done by silver plated shims vertically and by shifting the electrode horizontally to equalize manufacturing tolerances with an accuracy of less than 30 µm.

Figure 3: A line of special flange inserts as a connecting surface for the ground plate on the left. Determination of the exact position of the ground plate inside of the tank in the middle. And the tank axis defined as the two centres of the whole circles of the two end-flanges.

Figure 4: Adjustment of the electrodes outside of the tank on the left. Electrolytic process of silver plating and plated distant plates on the right.

4 MEASUREMENT OF BASIC RF-PROPERTIES

After the installation of the RFQ-structure into the cavity, first measurements of basic rf-properties have been done. First of all the resonance frequency was measured to f_0 = 193 MHz, which is about 10 % below the desired frequency of 217 MHz. This is a very comfortable result as it gives enough space to equalize inhomogeneities of the voltage distribution along the electrodes of about 20 % [1]. A first fine tuning has already been done by movable short circuit plates between stems near the end stems of the structure.

The quality factor was measured with the 3 dB method to Q = 2500. Together with R_p = 30 kΩ, which is the shunt impedance divided by the length of the structure measured with a perturbation capacity of 1 pF, and an electrode voltage of $U_{el.}$ = 70 kV the expected power consumption of the RFQ-Drifttube-Combination will be 165 kW.

5 VOLTAGE VARIATION OF THE INTEGRATED BUNCHER

One of the main aspects of the RFQ-Drifttube-Combination is the variation of the bunching voltage by adjusting the height in which the second drifttube is connected to the last oversized RFQ-stem, as one can see in fig. 5.

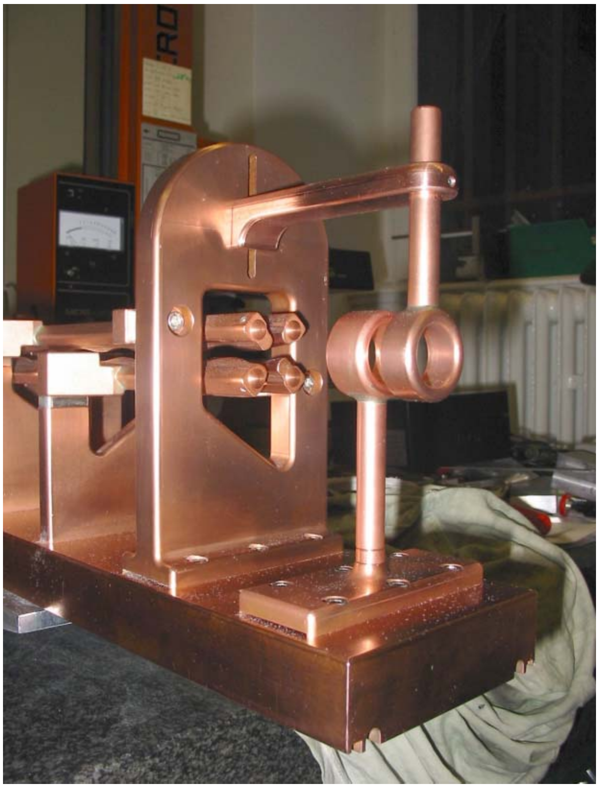

Figure 5: The integrated buncher unit.

To determine the range in which the voltage is adjustable, we just had to measure the ratio between the voltage of the electrodes and the drifttubes. This has been done by the bead perturbation method where a peace of matter with an $\varepsilon > 1$ is moved along an interesting path always parallel to the electric field components while watching the phase shift caused by its presence. Because $\Delta\varphi \sim E^2$, which is true for little perturbations, the phase shift at a certain point gives information about the strength of the electric field.

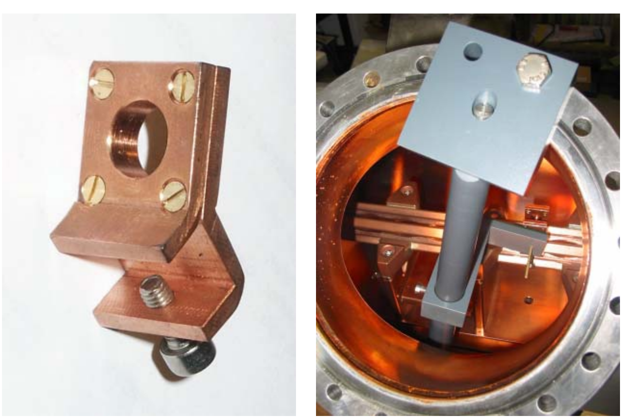

Figure 6: A special electrode top for the transition of the bead on the left and the whole measuring device on the right.

In our case the measurements have been done with a bead made of copper, 5 mm in diameter. Because of the very limited geometrical conditions inside of the tank, the ball was speared on a small wooden stick, not as usual where it is fixed on a nylon string. The special measuring device inside of the tank for supporting the stick (fig. 6) was made of PVC and is not effecting the measurement very much, because almost all of the electric fields are concentrated between the electrodes. The results of these measurements are shown in fig. 7. The calculated total cap voltage of ca. 86 kV [4] has to be corrected by the transit time factor of the exact drifttube geometry and will be in the end about 20 % higher, which is no problem.

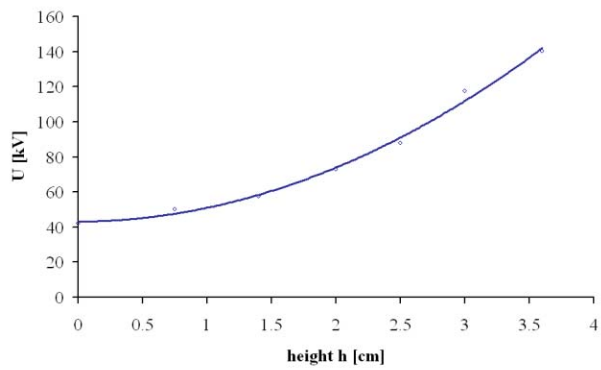

Figure 7: Measured total bunching voltage as a function of the height in which the drifttube is attached to the last RFQ-stem.

6 CONCLUSIONS

The rf-measurements on the now aligned and installed medicine RFQ are promising as they are very close to the desired specifications of the machine. Next step will be the conditioning of the structure at higher power levels. A final adjustment of the bunching unit will be done in the course of a beam test in the near future.

REFERENCES

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