DEVELOPMENT OF FINGER DRIFT TUBE LINACS*

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Abstract

At higher particle energies the efficiency of RFQs decreases. At higher energies DTL structures in combination with magnetic quadrupoles are used. A novel approach at IAP combines the advantages of RFQs and DTLs. To avoid the defocusing effects of a DTL structure, the accelerating gaps of a spiral loaded cavity were equiped with small fingers. These fingers arranged in a quadrupole symmetry provide an additional focusing field component. The beam dynamics of such a cavity has been studied with RFQSIM. Simulations of the rf properties have been done using Microwave Studio. A prototype of a spiral loaded cavity with finger drift tubes has been built and low power measurement were made. Results of the calculations as well as low level and bead pertubation measurements are presented in this contribution.

INTRODUCTION

At energies higher than $\beta > 5\%$ the efficiency of RFQ accelerators decreases. Therefore DTL structures are used in this region. Spiral loaded cavities which are a special type of DTL have been built successfully at IAP for many years with a wide range of applications. The main features of these structures are a compact design and a large energy acceptance. For protons and deuterons RFQ accelerators can be used up to 2 MeV/u. A 4 m long RFQ length in combination with a DTL booster was planned for the COSY SCL upgrade [1]. For the acceleration of deuterons from 2 MeV/u to 2.5 MeV/u an overall voltage of 1 MV is needed in the booster.

Table 1: parameters of the booster cavity

Length:	300 mm
Diameter:	280 mm
Aperture:	20 mm
Gap / total voltage:	250 kV / 1 MV
Power consumption:	150 KW
$\beta\lambda/2$	62 mm

As an option for the booster cavity a spiral loaded cavity with finger drift tubes was designed. The finger electrodes in the four gaps provide an additional focusing field which compensates for the rf defocusing. Figure 1 shows the original structure and the finger drift tubes.

Figure 1: spiral loaded cavity and finger drift tubes

BEAM DYNAMICS

The RFQSIM code was used to investigate the focusing effect of finger electrodes in the accelerating gap of a DTL structure. An accelerator layout consisting of a 4 m RFQ and a small booster cavity of 0.5 m length was investigated. The RFQ accelerates protons and deuterons to a final energy of 2 MeV/u while the booster increases the energy to 2.5 MeV/u. The results of the calculations using a normal DTL is shown in figure 2.

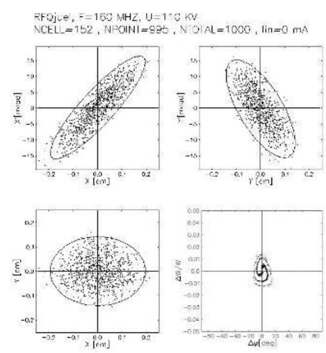

Figure 2: RFQSIM results with drift tubes

In contrast to this calculation a gap design with finger electrodes was analysed. The field distribution of a gap which simultaneously accelerates and focuses the beam cannot be calculated analytically. Therefore a new module was implemented in RFQSIM which enables the user to use an arbitrary field distribution [2]. The field distribution can be generated by an excel macro using the successive over-relaxation method. It is a three dimensional static voltage distribution. The RFQSIM code then calculates the electric field components at the position of the particle. Figure 3 shows the voltage distribution at the end of one drift tube with finger electrodes.

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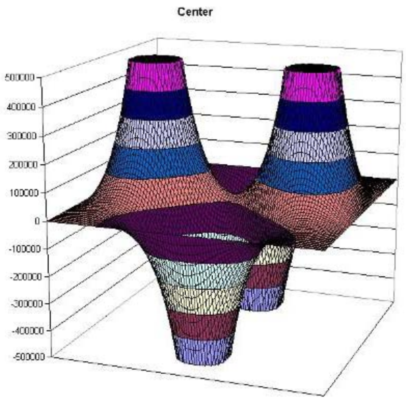

Figure 3: Voltage distribution of finger drift tube

The results of the calculations using the new module to simulate an accelerating gap with an energy gain of 0.5 MeV/u and a focusing effect is shown in figure 4. Both calculations include a drift section after the booster cavity. Comparing both results, the beam ellipses in the x and y plane are changed with the focusing fingers. This result corresponds to a focusing effect in one plane and a defocusing in the other as it was expected.

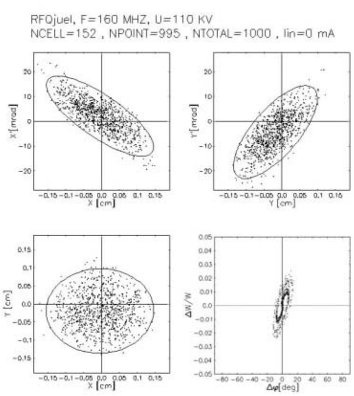

Figure 4: RFQSIM results with finger drift tubes

MWS FIELD SIMULATIONS

Calculations with Microwave Studio [3] have been done following two purposes. The resonance frequency of the structure must be adjusted and the quality of the electric field in the gap has to be analysed. Due to the capacitive load in the accelerating gap the frequency changes with the length of the finger electrodes. In figure 5 the frequency of the first resonant mode is plotted against the length of the fingers. The length is varied from zero to 20 mm which corresponds to 3/2 of the overall gap width (βλ/2 = 62 mm). The accelerating efficiency of the cavity also decreases slightly with increasing finger length due to the capacitive load. This effect which is expressed through the shunt impedance of the cavity is also shown in figure 5.

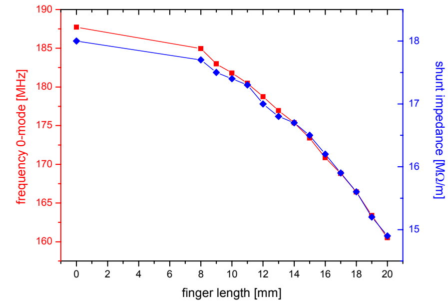

Figure 5: Resonance frequency and shunt impedance as a function of the finger length

The magnitude of the z component of the electric field on the beam axis, which is used for the acceleration of the beam, is not affected by the added fingers. In figure 6 this field component is compared for the two analysed structures.

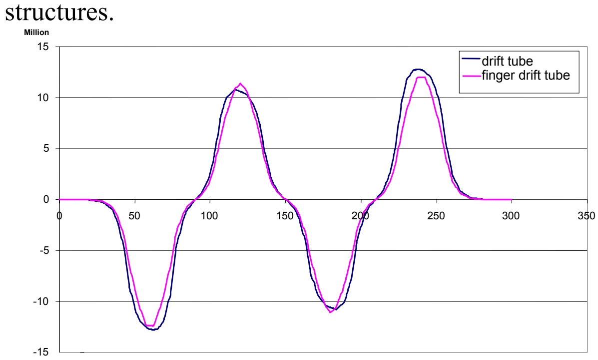

Figure 6: Comparison of accelerating fields on beam axis

To examine the quality of the electric field, both x and y component of the field were evaluated on a circle in transverse planes. With those, the radial field component can be calculated. Using a fast Fourier transformation, the transverse field can be developed into a polynomial [4]. An ideal focusing structure should have only the second order quadrupole component.

$$T_N(x) = \frac{a_0}{2} + \sum_{l=0}^{p-1}\left(a_l \cos\left(2\pi \frac{lx}{L}\right) + b_l \sin\left(2\pi \frac{lx}{L}\right)\right) + \frac{a_p}{2}\cos\left(\frac{2\pi p x}{L}\right) \quad (1)$$

The Fourier analysis has been done in equidistant planes between the drift tubes. Figure 7 shows the first eight multipole components in the centre of the gap. In this plane all components except the quadrupole are below 1% with respect to the quadrupole. It is nearly an ideal quadrupole.

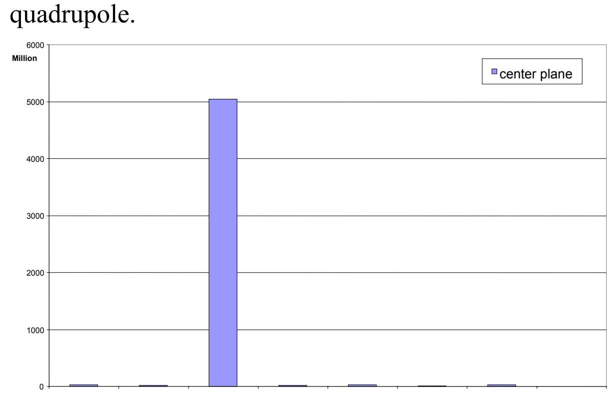

Figure 7: multipoles in the central plane

Looking at the distribution of the multipoles in all planes, all unwanted multiples (dipole, sextupole, octupole…) are hardly present. But a monopole component is rising at both end of the gap, as it is shown in figure 8. This effect is also present in a drift tube structure without fingers. The monopole corresponds to a point charge on the beam axis and is a result of the curvature of the field due to the drift tube geometry.

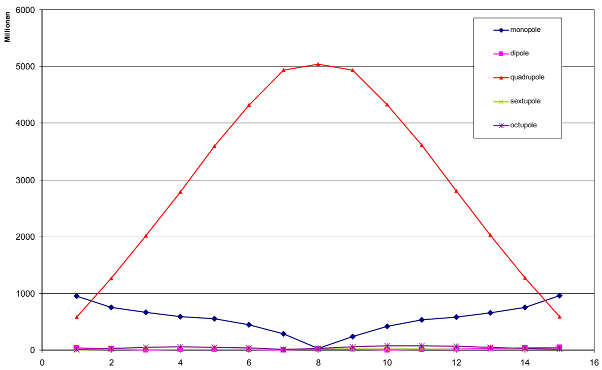

Figure 8: Multipole components in the gap

BEAD PERTURBATION RESULTS

A prototype of the structure described above has been built and tested with low power. The low power measurements showed that the two resonant modes of the cavity, the 0-mode and the π-mode are separated by a few MHz only. The π-mode where both spirals resonate with a phase shift of π has the lower frequency. For an efficient acceleration of particles the 0-mode is needed. Therefore, the original structure was modified. First the spirals were mounted in the same orientation. The result was a change in frequency of the two modes. But still the difference between them was quite small. To get rid of the unwanted π-mode, the two spirals were shortened with a copper bridge. The 0-mode, where both spirals are in phase, is unaffected by this bridge while the frequency of the π-mode is increased about 150 MHz due to the decrease of the inductivity.

Table 2: Resonance frequency of different structures

	Original structure	Turned spiral	Turned spiral with bridge
f_r 0-Mode	162.14 MHz	157.54 MHz	153.97 MHz
Q 0-mode	1680	1980	1880
f_r π-mode	159.30 MHz	160.78 MHz	248.34 MHz
Q π-mode	2200	1500	700

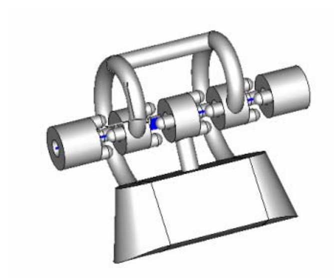

Figure 9: spiral loaded cavity with short-circuit bridge

The turning of the spiral and the short-circuit bridge between the two spirals resulted in a strong coupling of the two spirals. Therefore the voltage on the drift tube is balanced and the operation is stable. Preliminary results of bead pull measurement on the above structure are shown in figure 10.

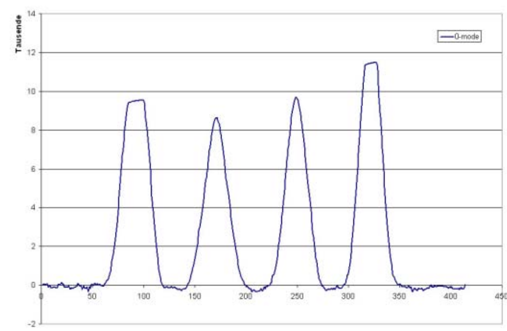

Figure 10: measured field on the beam axis (preliminary)

CONCLUSIONS

The benefits of this new spiral loaded cavity at higher energies were demonstrated for the first time. The field distributions measured with the bead pull method are in good agreement with the simulations. The beam dynamics and the simulations done with RFQSIM and Microwave Studio give promising results for the application of a finger drift tube structure as a booster cavity.

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