THE COMPACT 20 MV IH-DTL FOR THE HEIDELBERG THERAPY FACILITY

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Abstract

A clinical facility for cancer therapy using energetic proton and ion beams (C, He and O) is under construction and will be installed at the Radiologische Universitaetsklinik in Heidelberg, Germany, starting in 2005. It consists of two ECR ion sources, a 7 AMeV linac injector and a 6.5 Tm synchrotron to accelerate the ions to final energies of 50-430 AMeV[1-3]. The linac is the combination of a 400 AkeV RFQ and a 20MV IH-DTL operating at 216.8MHz. The accelerator project is coordinated by GSI; IAP is responsible for the Linac cavities in cooperation with GSI. The different RF tuning concepts and tuning results for a 1:2 scaled IH-DTL model cavity are presented. Microwave Studio simulations have been carried out for the model and for the real power cavity. Results from the model measurements and the field simulations agree very well also for the higher order modes. The beam matching from the RFQ to the IH-DTL was optimised. The IH drift tube array was matched with the gap voltage distribution resulting from RF model measurements. Simulated RFQ output particle distributions were used in the final beam dynamics investigations along the IH cavity.

INTRODUCTION

By comparing cancer therapy with proton and carbon beams, one important aspect next to the medical efficiency is the treatment costs per patient. Since 1997 a very compact and efficient 7 AMeV C^{4+} linac has been developed. The status of the whole injector including ECR ion sources, linac, RF power system, and quadruple magnets will be discussed in another paper in this conference [4]. The beam matching from the RFQ to the IH-DTL ,the improved beam dynamics simulations with the software LORASR along the IH cavity as well as the RF tuning of the 1:2 scaled RF model cavity and accompanying simulations with Microwave Studio will be discussed in these proceedings.

KONUS BEAM DYNAMICS

The IH-DTL consists of four KONUS sections with a total of 56 gaps, and with three magnetic quadruple triplets, which are housed in one cavity with 3.77m in length and 0.32m equivalent cavity diameter. The beam dynamics simulations have been optimised with the code LORASR [5] for the beam matching from the RFQ exit to the IH-DTL with new geometry [6] and real particle distributions at the RFQ exit as calculated with the PARMTEQ code. The effective gap voltage distributions and real drift tube parameters are adapted from the results of the cold RF model cavity tuning measurements. RFQ internal buncher[7] effective voltage has been optimised to get normalized emittance growth factors as low as 1.18 in x-x', 1.05 in y-y' and 1.23 in w-z plane, respectively (Figure1). Figure 2 shows IH-DTL output particle distributions at the synchrotron injection point. The exit ellipses contain 95% of the particles. The transversal 98% envelopes up to the stripper foil are shown in Figure 3.

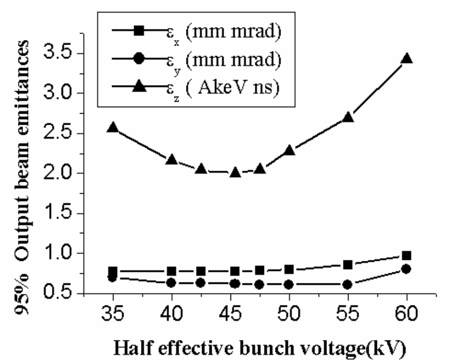
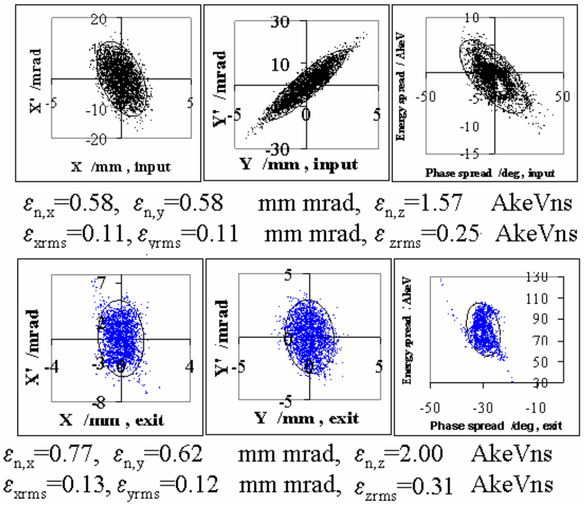


Figure 1: Output emittance at the stripper foil vs. the effective voltage of the RFQ internal 2 gap buncher.



$\varepsilon_{n,x}$=0.58, $\varepsilon_{n,y}$=0.58 mm mrad, $\varepsilon_{n,z}$=1.57 AkeVns
ε_{xrms}=0.11, ε_{yrms}=0.11 mm mrad, ε_{zrms}=0.25 AkeVns

$\varepsilon_{n,x}$=0.77, $\varepsilon_{n,y}$=0.62 mm mrad, $\varepsilon_{n,z}$=2.00 AkeVns
ε_{xrms}=0.13, ε_{yrms}=0.12 mm mrad, ε_{zrms}=0.31 AkeVns

Figure 2: Particle distributions at the RFQ exit and at the stripper foil behind of the IH-DTL ,normalized as well as rms emittance values.

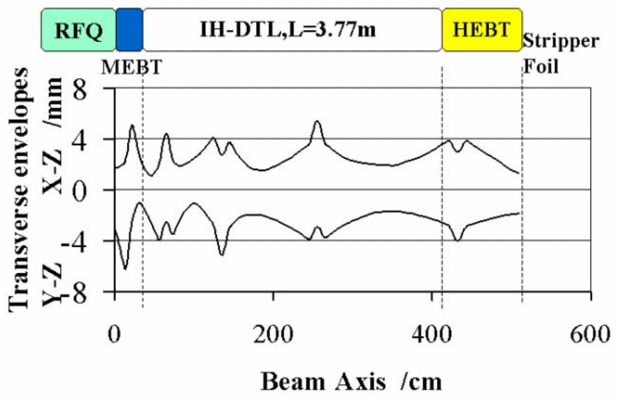


Figure 3: Transversal 98% beam envelopes Aperture in radius ranging from 6.0 to 10mm.

RF MODEL MEASUREMENTS

An IH-DTL 1:2 scaled model cavity was ready for measurements in Summer 2002. Four main tuning methods were applied to get the designed electric field distributions along the beam axis[8]. Figure4 shows the 3 out of 4 KONUS sections of the model cavity and its tuning concepts. Modification of the drift tube to periodic length-ratio along the tank is the traditional tuning concept to get a flat electric field distribution. Because of the extreme output/input energy ratio of 17.5 and of the cavity length to diameter-ratio of about 12, volume tuners are additionally needed to reduce locally the cavity cross sectional area, therefore to decrease the local inductance or to enhance the resonance frequency at the first and the second sections and to make the field in the last two sections larger. Undercut tuning is the most sensitive tuning at the end sections and with respect to the voltage balance along the structure. Lens coupling is an important tool to stabilize the operation mode and to change the coupling between neighbouring sections. After the tuning process, the measured resulting electric field, the difference of effective gap voltage distributions from the designed values in percent demonstrated the tunability of such a long structure (Figure 5). The finally needed level of agreement with the design distribution will be reached for the real cavity after a more careful tuning procedure.

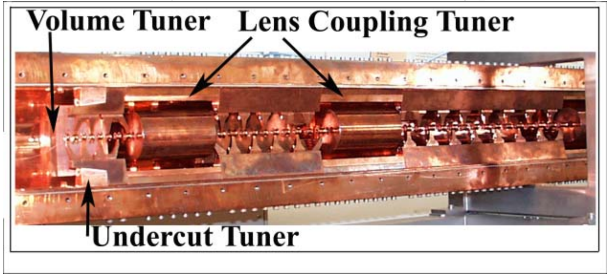


Figure 4: 1:2 IH model cavity and its tuning concepts.

The plunger with 30mm length and 74mm width in section 3 can lower the operating frequency by 1MHz, that is 0.23% of the frequency when it is moved in by 30mm depth. Figure 6 shows plunger tuning ability and its influence on the voltage distribution between the 4 sections. Because of that, the plunger range should be limited to about 15mm.

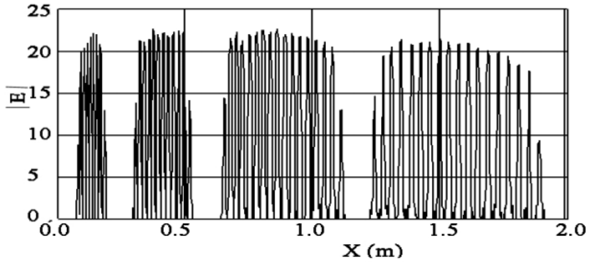


Figure 5a: Measured field distribution

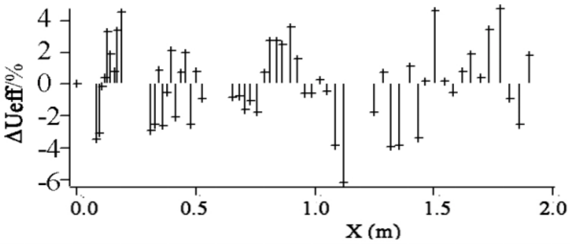


Figure 5b: Corresponding effective gap voltage difference between design and measurement.

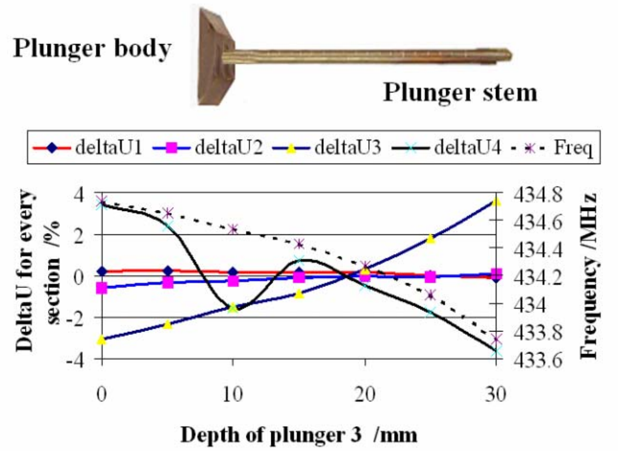


Figure 6: The detuning effect of plunger 3 on the voltage distribution of the 4 individual KONUS sections.

MICROWAVE STUDIO SIMULATION

In order to get higher simulated accuracy with limited mesh density and PC resources (Intel® Xeo 2.4GHz with 2.096GRAM), the asymmetric supporting stem of each triplet lens (Figure 7) is replaced by the mirror symmetric supporting cylinder. Figure 7 demonstrates this symmetrization, the RF current indicates the correct mode H_{110}, no or very low current is passing along the triplet stems, both geometries have the same local frequency. After the symmetrization, only one half of the cavity volume (upper or lower half in Figure 7) needs to be simulated by MWS, the minimum mesh size is 1mm, and the biggest mesh size is 6.0mm, there are a total 2.3million mesh points for the 1:2 scaled cavity simulation. The simulation takes about 12hours by the above-specified PC. Figure 8 shows the simulated and measured H_{110} mode electric field distributions of the 1:2 scaled IH model cavity. Figure 9 presents the simulated

H_{111} mode field distribution; it fits the IH model cavity measurements, as well as other higher order modes measurements and simulations [8]. The frequency separation from the fundamental mode H_{110} is 2.8MHz from the model measurement, this corresponds to about 201 half widths in units of the fundamental resonance.

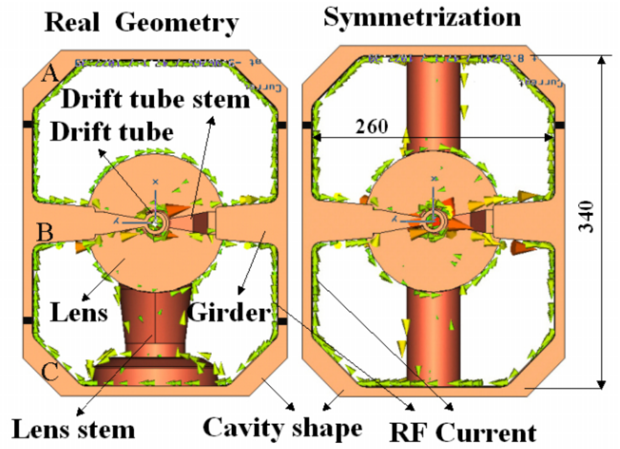


Figure 7: Symmetrization of the IH cavity at the magnetic lenses. Real IH cavity geometry consists of upper and lower half shells (A and C), central frame (B).

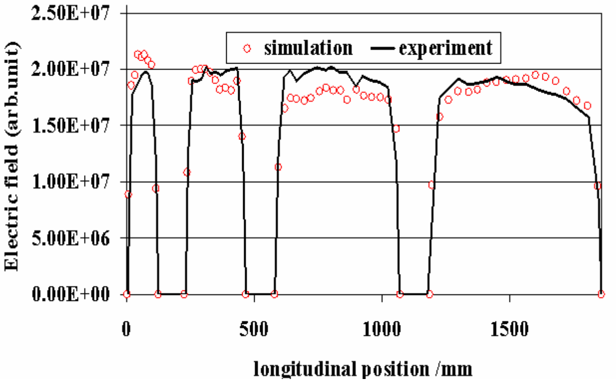


Figure 8: Simulated and measured the H_{110} mode electric field distribution for the 1:2 scaled model cavity.

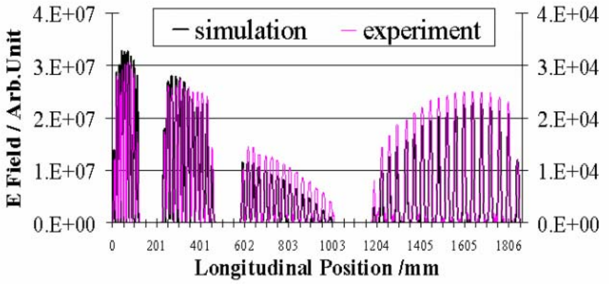


Figure 9: Simulated and measured electric field for H_{111} mode on the model cavity.

The simulation of the 1:2 scaled real power cavity is helpful to verify the real geometry design and to predict the RF performance of the cavity, such as quality factor, power dissipation, shunt impedance and so on. The electric field distribution is similar with that of model cavity that was shown in Figure 8. Figure 10 indicates the magnetic intensity H_z near by the cavity wall. After scaling to the real size of the IH cavity, the predicted main parameters for the IH cavity are listed in the table 1.

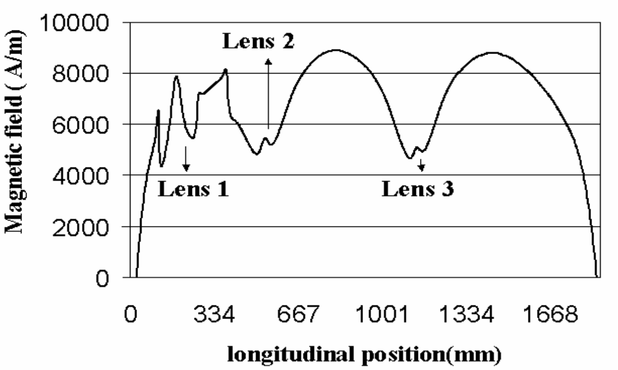


Figure 10: Magnetic field distribution H_z near by real cavity wall.

Table 1: Main parameters of the IH cavity

Accelerated ions	Proton, C^{4+},He^{2+}
Gap number	56
Input energy /AkeV	400
Output energy /AMeV	7
Equivalent diameter /m	0.32
Tank length /m	3.77
Quality factor	15600
Frequency /MHz	216.8
Averaged eff. Voltage gain [MV/m]	5.25
Shunt impedance Z_0 [MΩ/m]	200.3
Shunt impedance Z_{eff} [MΩ/m]	153.0
RF power dissipation (kW)	755

CONCLUSIONS

The KONUS beam dynamics for the 20MV IH-DTL with LORASR code has been optimised for the real PARMTEQ output particle distribution of the RFQ with respect to a low emittance at the stripper foil behind the IH-DTL. The RF tuning investigations on the IH model cavity resulted in a uniform electric field distribution and allowed to design the final IH power cavity. The Microwave Studio simulation of the IH model cavity fits well with the RF model measurements. Fine measurements on the power cavity are scheduled for September 2004.

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