THE IH CAVITY FOR HITRAP

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Abstract

RFQs are already successfully used to decelerate ions and to match them to ion traps. Within the Heavy Ions TRAP project HITRAP at GSI a combination of an IH drift tube cavity operating at the $H_{11(0)}$ mode and a 4-rod RFQ is proposed to decelerate the 1 µs long heavy ion bunches (up to U^{92+}) from 4 A·MeV to 6 A keV after storage ring extraction. The transition energy from the IH into the RFQ is 0.5AmeV. The operating frequency is 108.408 MHz. The A/q range of the linac is up to 3.

A 4-gap quarter wave resonator working at 108.408MHz provides the micro bunch structure for the IH. The transmission mainly defined by the buncher is about 30%. An alternative 2^{nd} harmonic bunching section, which allows higher transmission and/or smaller longitudinal emittance, will be discussed.

By applying the KONUS dynamics, the 2.7 meter long IH cavity will perform a high efficient deceleration by up 10.5 MV with 200kW rf power. The beam dynamics performed with the LORASR simulation code will be shown. It is aimed to reach an effective shunt impedance around 220MΩ/m for the IH cavity.

IH CAVITY

General Parameters

The HITRAP decelerator will enlarge the variety of decelerated ion beams to Highly Charged Ions up to U^{92+}. The decelerator linac will be installed in the re-injection beam line between ESR and synchrotron SIS. The decelerator is designed for a A/q range up to 3. The HCI are extracted from the ESR at 4 AMeV in a 1 µs long cooled bunch [1]. As for such an A/q range the input energy is too high for an efficient RFQ solution, an IH cavity is proposed to decelerate to an intermediate energy of 0.5 AMeV. A 4-rod RFQ performs the deceleration down to 6AkeV. The chosen intermediate energy allows for a design of an IH tank with one internal lens. Only the IH cavity will be discussed in this paper. The succeeding RFQ will be of the 4-rod type and is designed at IAP as well. The needed repetition time is approximately 10 seconds at a low duty cycle of 0.15%. Intermediate rf pulses may be needed to keep the linac in resonance.

Table1: General IH parameters

	IH LINAC	
	input	output
W [A.MeV]	4	0.5
β	0.0924	0.0328
frequency in MHz	108.408	
duty factor	0.15%	

Beam Dynamics

IH drift tube linacs using the KONUS beam dynamics concept [2] (KOmbinierte NUll grad struktur) are used as injectors for the Alvarez section of UNILAC. The same beam dynamics concept can be applied for beam deceleration.

Within the KONUS scheme particle bunches are decelerated in successive gaps with 180° synchronous phase in order to reduce the transverse defocusing effect. This allows the use of slim drift tubes without any optical element. Consequently the decelerating H mode cavity using the Konus dynamics is composed by:

-One main decelerating section with 180° synchronous phase.

-One quadrupole triplet to focus the beam.

-One short section with positive synchronous phase, typically 215° to focus longitudinally and match the beam.

Due to the rf buncher ahead of the cavity, the micro-bunch is convergent in the first gaps of the IH. To avoid over focusing, which could lead to beam instability, the 145° synchronous phase is used in the first gaps to “defocus” the bunch.

Deceleration of 10.5MV is then achieved within the 2.7m long IH cavity; Figure 2 shows the 98% transverse envelopes in the cavity calculated with LORASR, which is an adequate code to study the KONUS dynamics. As the beam is cooled in the ESR, transverse emittances are very small. The beam radius in the IH tank is less than 4mm.

Figure 3 shows the longitudinal output emittance obtained for an arbitrary reference input emittance. For such emittance the beam dynamics is rather safe as the acceptance of the IH is twice.

The simulations of the matching section were performed in order to match micro bunches into this emittance.

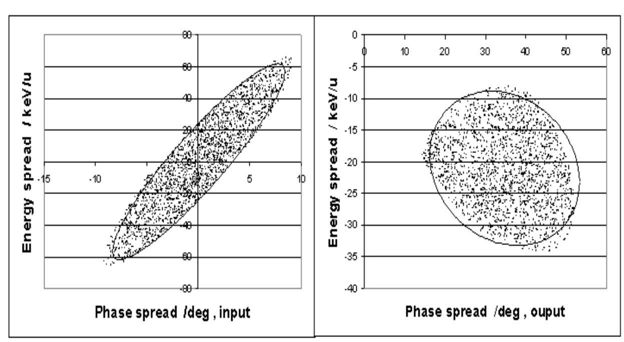

Figure 1: 98% input (left) and output (right) longitudinal emittance.

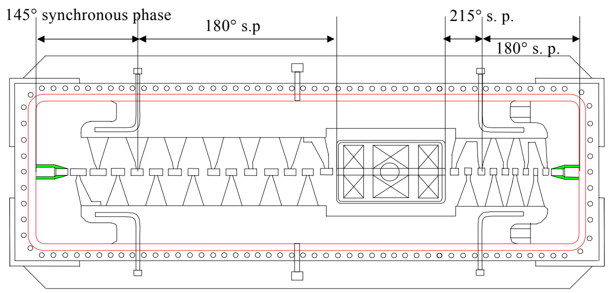

Figure 2: Schematic drawing of the IH cavity design with one internal lens.

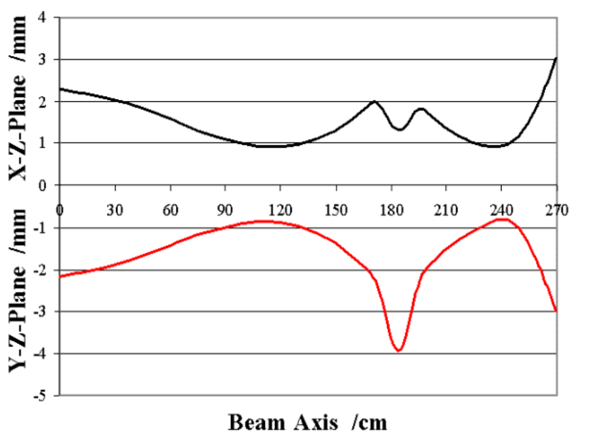

Figure 3: 98% transverse beam envelopes along the IH tank.

Cavity Design

The IH tank rf power supply is already available at GSI. This is a transmitter with rf power levels up to 200 kW. To reach the 10.5MV deceleration, the expected effective shunt impedance is 220MΩ/m for an estimated 180kW rf power loss. Since HLI operates at the same frequency with very high shunt impedance, the HITRAP IH cross-section geometry is intended to be similar. The small transverse dimension of the beam (<6 mm) allows the use of small drift tube aperture diameter (12-10mm).

As no model cavity is planned, the electromagnetic simulation of the cavity performed with Microwave Studio simulation will be an important issue. Table 2 lists the main cavity parameters.

Table 2: Cavity and beam parameters

W [A.MeV] input /output	4 / 0.5
A/q	3
input/output normalised transverse emittance [mm.mrad]	0.18 / 0.25
input/output normalised longitudinal emittance [AkeV/ns]	5.2 / 5.7
frequency in MHz	108.408
U_0 [MV]	10.5
Z_0 in [MΩ/m]	305
aperture radius [mm]	6 - 5
number of cells	25
L [m]	2.70
P [kW]	180

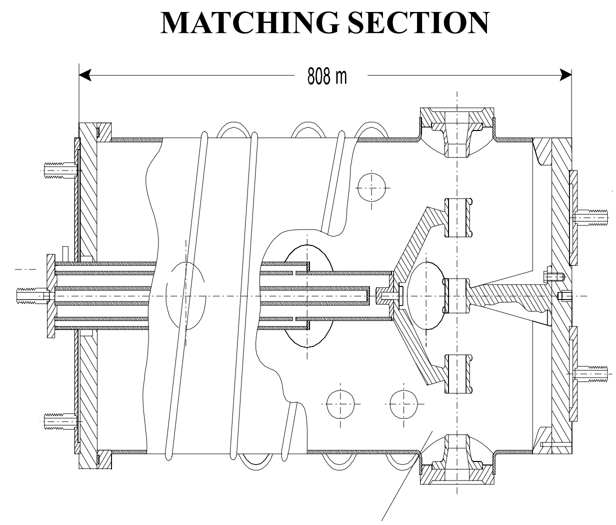

Figure 4: 108.408 MHz Quarter wave resonator at 4 AMeV.

First Harmonic Drift Buncher

A first matching section is needed to match the 1µs macro pulse from the ESR into the emittance shown in figure 3. A first matching section consisting in a one harmonic buncher and in one quadrupole triplet was considered. This option allows the most compact decelerator design but reduces the decelerator beam transmission to about 28%.

The buncher used is a 108.408 MHz 4-gap quarter wave resonator and is located 4 meters ahead the IH tank [2]. The quadrupole triplet provides the transverse matching. Only the use of multiple harmonic bunching can increase the bunching efficiency and/or can reduce the S-shape of the longitudinal emittance. As a Double Drift Buncher DDB is easier to drive and is more flexible than one cavity with several harmonics, only the DDB solution was considered.

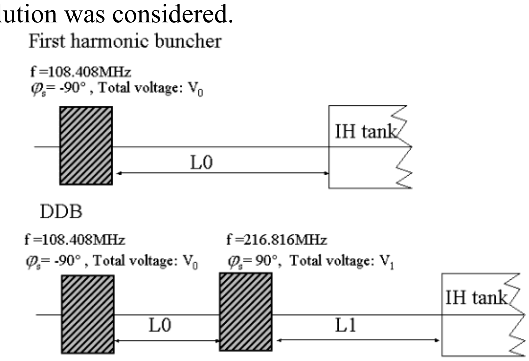

Figure 5: Scheme of first harmonic buncher and DDB.

Double Drift Buncher

The double drift buncher consists of two bunchers separated in space, independently driven and phase locked together [3]. The second buncher is driven at twice the frequency of the first one. The bunching efficiency for such a DDB is better than what is expected for a single buncher driven with three harmonics.

According to the available space and for beam stability reasons (phase and energy deviation) the matching section length, i.e. the distance between the first buncher and the

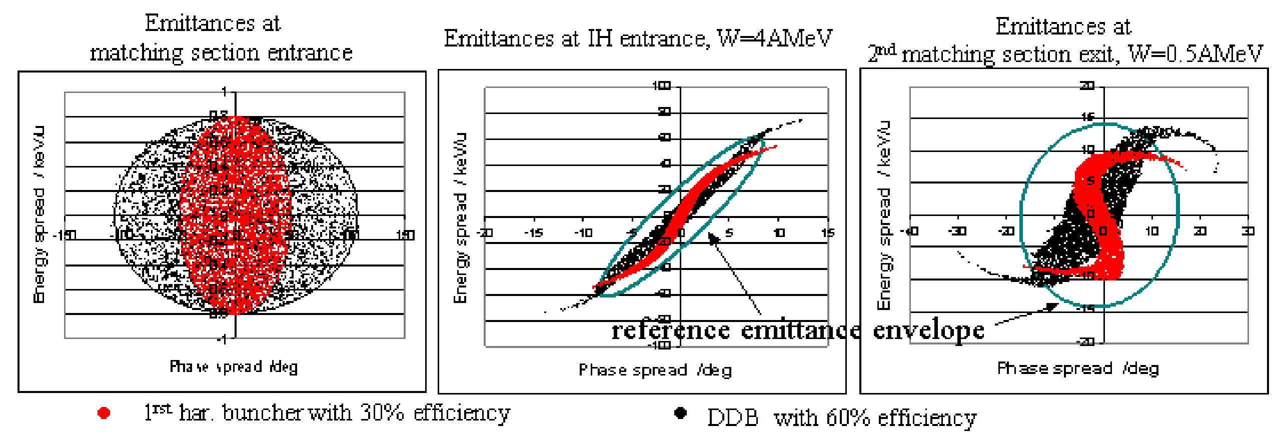

Figure 6: Longitudinal emittance at different locations for the both buncher designs. The envelope of the 98% reference emittance at the IH entrance (middle) and at the exit (right) of the RFQ matching section is plotted.

cavity shouldn't exceed 8m. Furthermore, at the IH entrance the energy spread of the bunched beam should be kept within ±60AkeV. These two parameters give the maximum voltage achievable in the two bunchers. For a conventional DDB, a bunching efficiency of around 80% is achievable. Nevertheless to get such high efficiency with smaller energy spread than 60AkeV, the total length needed is higher than the upper limit.

By reducing the efficiency to 60%, the bunched beam matches the IH longitudinal input emittance plotted in figure 1 with a reduced S-shape. The matching section length is then 7.5 m. Transverse beam envelopes for both matcher designs are shown in figure 7. The settings of the both bunchers are listed in table 4. The simulation also includes the RFQ matching section consisting in one spiral resonator and one quadrupole triplet [1].

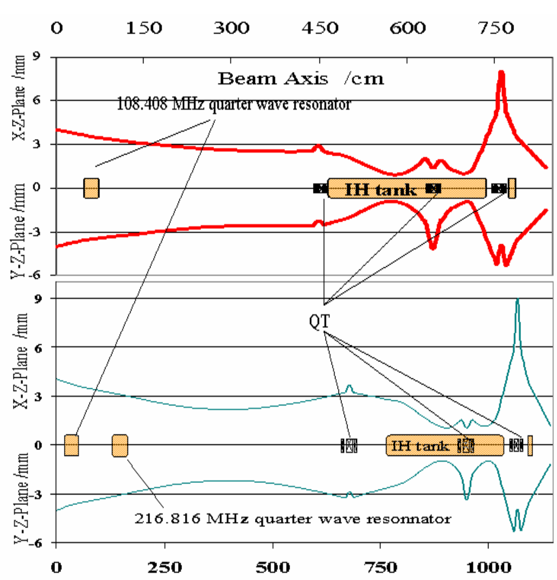

Figure 7: 98% transverse beams envelope for a first harmonic buncher (upper plot) and for the double drift buncher design (lower plot).

Table 3: 98% transverse and longitudinal emittance, the input corresponds to the entrance of the buncher ahead of the IH cavity and the output to the exit of the RFQ matching section

	First har.	DDB	Ref
ε_x (98%,norm) in mm.mrad input/output	0.21/0.29	0.21/0.29	0.17/0.27
ε_y (98%,norm)in mm.mrad input/output	0.21/0.30	0.21/0.27	0.17/0.26
ε_{long} (98%,norm) in AkeV/ns input /output	1/5.79	2.2/7.0	5.23/5.95

Table 4: First harmonic buncher and DDB main parameters

First harmonic buncher	
frequency in MHz	108.408
V0	255
L0	4
Zeff/ MΩ /m	80
Prf	<2kW
bunching efficiency	< 30%

DDB		
frequency in MHz	108.408	216.816
V0 / V1 in kV	256	78.5
L0 / L1 in m	0.8	5.95
Zeff/ MΩ /m	80	57
Prf	<2kW	
bunching efficiency	60%	

SUMMARY AND OUTLOOK

A double drift buncher increases the transmission; nevertheless the high theoretical bunching efficiency couldn't be reached. The fast extraction of the 4 AMeV beam from the ESR is planned to be tested in September 2004. The stability of the extracted beam should be checked with respect to the transverse beam stability.

REFERENCES

[1] *HITRAP technical design report,* GSI-10/2004.

[2] U. Ratzinger, Habilitationsschrift, Frankfurt University, July 1998, Germany.

[3] V.S Pandit, optimisation of the parameters of an ion beam buncher, NIM A276 1989