THE HITRAP DECELERATOR PROJECT AT GSI*

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Abstract

The trap for heavy highly-charged ions (HITRAP) at GSI is a funded project since 2004. Highly charged ions up to U^{92+} provided by the GSI accelerator facility will be decelerated and subsequently injected into a Penning trap for further cooling almost to rest. A combination of an IH- and an RFQ-structure decelerates the ions from 4 MeV/u down to 6 keV/u. In front of the decelerator a harmonic double drift-buncher provides for phase focusing and a final debuncher integrated in the RFQ-tank reduces the energy spread to improve the efficiency for beam capture in the cooler trap. The report gives an overview of the final beam dynamic design of the entire decelerator. Besides the construction status of the cavities, particular beam diagnostic features due to the short pulses of 1µs and 108 MHz bunch frequency, and concepts for technical and controls integration into the existing GSI accelerator complex are presented. Finally the recent time schedule and considerations for commissioning are described.

INTRODUCTION

Up to now, GSI is the world unique facility providing highly-charged ions up to U^{92+} for atomic-physics experiments. The high energy, necessary for stripping the ions up to bare nuclei, is obtained by two accelerating stages (Fig. 1). First acceleration of Uranium to 11.4 MeV/u takes place in the UNILAC (Universal Linear Accelerator). Through a transfer line the SIS18 (Heavy Ion Synchrotron) is fed with macro pulses of 100 µs length which are accelerated up to 400 MeV/u. During the transfer to the ESR (Experimental Storage Ring) a copper sheet stripper of 40 mg/cm² enables a high yield of U^{92+}-ions.

In a multi-stage process the ESR [1] decelerates the U^{92+}-beam down to 4 MeV/u. Intermediate application of stochastic cooling and electron cooling prepares high quality beams for injection into the HITRAP [1] decelerator. At 5 MeV/u an U^{92+} -beam intensity of $1{\cdot}10^6$ particles per cycle was measured and $2{\cdot}10^5$ particles at 3 MeV/u. The corresponding momentum spreads were $dp/p = 2.4{\cdot}10^{-4}$ and $dp/p = 1{\cdot}10^{-4}$, detected by Schottky diagnostics. The normalized transverse emittances were measured with $\varepsilon_x = 0.093$ mm·mrad and $\varepsilon_y = 0.06$ mm·mrad.

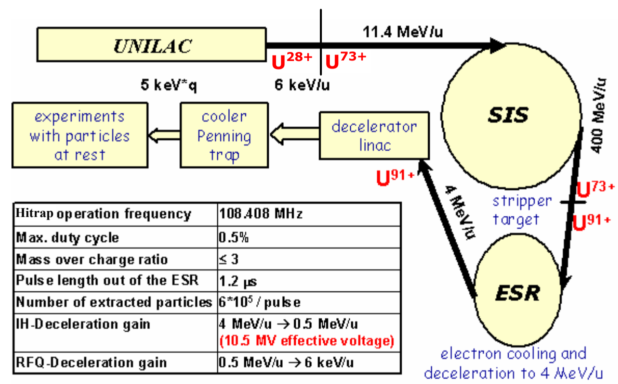

Figure 1: Scheme of the GSI accelerator facility and production process of U^{92+}.

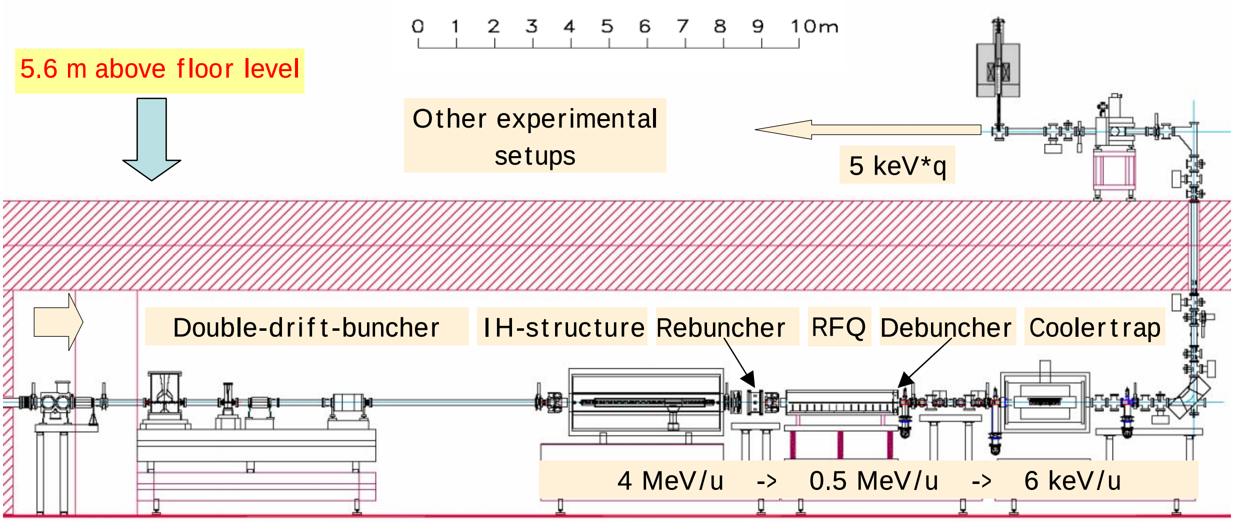

Figure 2: Overview of the HITRAP-decelerator in the reinjection channel.

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HITRAP LINEAR DECELERATOR

The HITRAP-facility [2,3] (Fig. 2) decelerates on basis of 108 MHz linear rf structures the heavy highly-charged ions with a mass to charge ratio of up to 3 from 4 MeV/u down to 6 keV/u. After extraction of the ion beam from the ESR, the beam is rebunched by a λ/4-resonator and a second harmonic λ/4-resonator (harmonic double-drift-buncher, DDB). A subsequent IH-type structure decelerates the beam to 0.5 MeV/u. Another rebuncher tank of spiral-type prepares the beam longitudinally for the second deceleration down to 6 keV/u by an RFQ-structure. The overall particle transmission is expected to be 50%. A debuncher section integrated in the RFQ tank at the low energy end provides low energy spread for maximum capture of the ions in a cylindrical Penning trap. The ions will be cooled further by electron and resistive cooling to cryogenic temperatures. The cold ions can be extracted again and transported to the subsequent experiments. Due to the ESR repetition rate of 0.1 Hz and pulse lengths of 1.2 µs, the rf duty cycle of the decelerator is below 0.5%.

Double-Drift-Buncher

The DDB concept was chosen to ensure a capture efficiency of 67 % within the limited phase acceptance of the IH-structure. The DDB consists of a 108 MHz (4 gaps) shown in Fig. 3 and a 216 MHz (2 gaps) coaxial quarter wave resonator with shunt impedances of 65 MΩ/m and 42 MΩ/m. Solid state amplifiers with 2 kW peak power are sufficient to drive the cavities. The electromagnetic properties are calculated by the MWS® code.

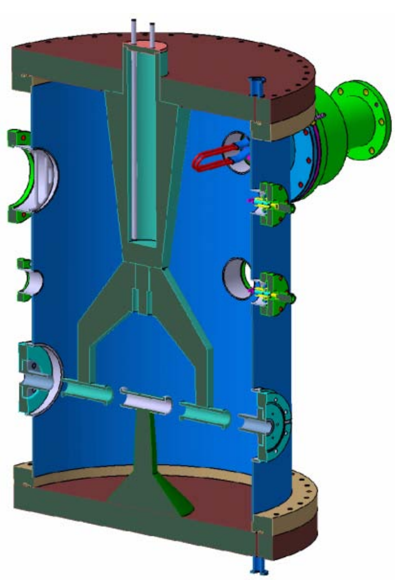

Figure 3: Cross-sectional view of the 4-gap 108 MHz λ/4-resonator buncher cavity.

The bunchers are ordered and are nearly ready for rf measurements prior to copper plating at GSI.

IH-Structure

The IH structure [4] (Fig. 4) holds 25 gaps to generate 10.5 MV effective acceleration voltage, one inner tank magnetic triplet lens with maximum field gradients of 64 T/m and an aperture of 20 mm, and a steering magnet. The gap field maxima are designed to stay within a range of 10%. The expected Q-value is 25,810 and the shunt impedance is 285 MΩ/m. Thus, an available amplifier from GSI stock with 200 kW rf-peak power enables to drive the cavity.

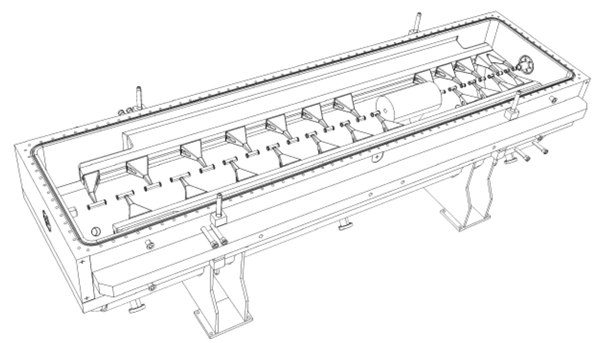

Figure 4: Sketch of the IH-structure.

The beam dynamics within the IH structure starts with a debunching section of 4 gaps at 145^0, followed by a deceleration section of 11 gaps at 180^0, and a 3 gap rebunching section at -145^0 directly behind the triplet. Finally 7 gaps at 180^0 decelerate the beam down to 0.5 MeV/u. The calculated growth of the normalized transverse emittance is 20%.

The inner tank triplet is already ordered and will be delivered end of 2006. The IH structure is designed. It consists of a solid middle frame carrying the drift tubes and two shells. Call for tender is placed.

Rebunching Section

The 20° phase width of the ion bunches extracted from the IH-structure needs to be matched to the RFQ acceptance of 45°. Thus, an existing two gap 108 MHz spiral rebuncher was modified by IAP Frankfurt to meet the HITRAP beam specifications and is ready for installation in the matching section. It is driven by a 2 kW solid state amplifier.

RFQ-Structure and Debuncher

The design of the HITRAP 4-rod-RFQ [5] follows the 108 MHz structure of the GSI-HLI linac. The low A/q ratio allows a short tank of 143 cells and 1.9 m length. The maximum inter-rod voltage is limited to 75 kV. At the low energy end a separated single harmonic spiral debuncher is integrated (Fig. 5). Both loads are fed by one 200 kW peak power amplifier, also taken from GSI stock. The power of only several Watts for the debuncher is branched off the RFQ power line by a directional coupler. Thus, the energy spread of the ion beam injected into the cooler trap will be reduced from 14 % to only 8 %

(Fig. 6) and improves the particles capture efficiency into the Penning trap.

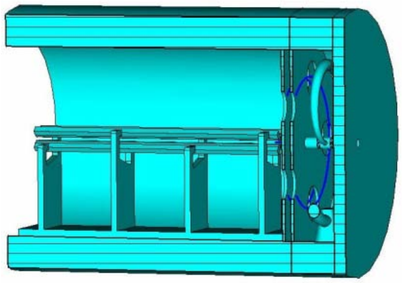

Figure 5: Cross-sectional view showing the low energy end of the RFQ with the integrated debuncher section.

The RFQ-tank is already manufactured and copper plated at GSI. The rods are in the production process.

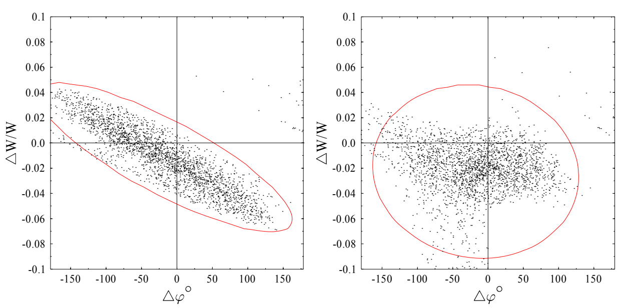

Figure 6: Longitudinal particle distribution at the HITRAP low energy end without (left) and with debunching (right).

BEAM DIAGNOSTICS

At the extraction of the ESR the beam intensity will be measured by a Faraday cup, a low bandwidth pick up monitors the beam length. In front of the IH-structure two SEM-grids allow for transverse position control and two capacitive phase probes for TOF measurement. The matching section is equipped with a SEM-grid, a Faraday cup, a screening target, and another couple of phase probes to control the RFQ input beam energy. The small transverse emittance of the beam requires SEM-grids with 32 wires with only 0.8mm distance. Due to the low beam intensity of some 10^5 particles per macro pulse additional scintillating screens based on single YAG-crystals and read out by a digital CCD-camera will complete the diagnostically instrumentation at different positions.

All beam diagnostic instruments are already in house or ordered for delivering this year.

TIME SCHEDULE AND COMMISSIONING

The request of 105 shifts within 5-7 runs for HITRAP commissioning with U^{91+}-beam have been applied for and are partially approved by the external scientific committee of GSI. The goals and objectives of commissioning are the optimization of the beam transfer from the ESR to the decelerator, to measure and optimize the beam quality behind each cavity section, to optimize the injection efficiency into the cooler trap, and to establish the settings for all components for later routine operation.

In fall 2006 the complete DDB-section will be assembled and commissioned with beam. A specific beam diagnostics set-up containing bunch shape measurement by transverse scanning of low energy secondary electrons [6], a pepper pot emittance meter, a capacitive pick up, and a Faraday cup will be installed to review the expected beam parameters for injection into the IH-tank. This setup will also be used for commissioning of the IH-decelerator, the matching section, the RFQ, and the LEBT.

Timing controls for rf-amplifiers and beam diagnostics are derived from the ESR-cycle. A preparation event signalizes the approached extraction of the beam by a kicking magnet and interrupts an independent continuous 5 Hz rf-amplifier pulsing for tank warming. The preparation event triggers a sequence of further events servicing rf-equipment, beam diagnostics, and the cooler trap. All magnets will be driven in DC-operation. Controls and operations of the HITRAP-decelerator will be fully integrated into the GSI accelerator control system.

In spring 2007 the installation of the IH-tank will take place. The installation of the rf equipment on a new local gallery platform is already going on. This enables a brisk progress in commissioning of the subsequent components. Finally the injection of the ion beam into the cooler trap and the test of the cooler scheme and extraction are planned for fall 2007.

OUTLOOK

After successful operation of the decelerator behind the ESR, the HITRAP set-up will be an integral part of the GSI future facility FAIR [7] at a new location behind the NESR (New Experimental Storage Ring). The major areas of investigations with HITRAP will be extended to antiprotons and radioactive ions.

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