COMMISSIONING OF THE HITRAP DECELERATOR USING A SINGLE-SHOT PEPPER POT EMITTANCE METER*

J. Pfister†, R. Nörenberg, U. Ratzinger
Institut für Angewandte Physik, Goethe-Universität Frankfurt, Frankfurt am Main, Germany
W. Barth, L. Dahl, P. Forck, F. Herfurth, O. Kester, T. Stöhlker
GSI, Darmstadt, Germany

Abstract

The Heavy Ion TRAP (HITRAP) project at GSI is in the commissioning phase. Highly charged ions up to U^{92+} provided by the GSI accelerator facility will be decelerated and subsequently injected into a large Penning trap for cooling to the meV/u energy level. A combination of an IH- and an RFQ-structure decelerates the ions from 4MeV/u down to 6keV/u. In front of the decelerator a double drift-buncher-system is provided for phase focusing and a final de-buncher integrated in the RFQ-tank reduces the energy spread in order to improve the efficiency for beam capture in the cooler trap. This contribution concentrates on the beam dynamics simulations and corresponding measurements in the commissioning beam times up to the position of the entrance to the RFQ. Single-shot emittance measurements at higher energies using the GSI pepper pot device and construction of a new device using Micro Channel Plate technology for low energies as well as profile measurements are presented.

HITRAP FACILITY AT GSI

The highly charged ions are accelerated in the heavy ion synchrotron to typically 400MeV/u, almost completely stripped and injected into the experimental storage ring (ESR). Here, they are first treated by stochastic cooling and decelerated to an intermediate energy level of 30 MeV/u. Then they are electron-cooled and further decelerated to 4 MeV/u. After another electron cooling cycle the ions are ejected from the ESR as a bunch of about $10^5 - 10^7$ ions depending on the element and a pulse length of 1-2 µs. Then they enter the linear decelerator of HITRAP. The final goal is the reduction of a deceleration cycle (filling the ESR, cooling, deceleration and ejection) down to 10-20s. Before the ion bunch enters the drift tube structure, the ion pulse is micro bunched by the double-drift buncher (DDB). After deceleration in the IH-structure as well as the RFQ, the ions enter the Cooler (Penning) trap with only 6 keV/u, where they can be confined by a combination of electrostatic and magnetic fields. By sympathetic cooling with cold electrons the trapped highly charged ions will reach a thermal energy corresponding to ~4K. The cold ions are then transported, with kinetic energies of only a few keV*q, to the different setups installed on top of the re-injection channel as a high-quality, low emittance, highly charged ion beam [1].

LINAC COMMISSIONING

After deceleration and cooling of the ions down to 4MeV/u in the ESR, they were ejected via the transport line towards the HITRAP linac (see Fig. 1). The DDB is the first component of the HITRAP linac and is used for phase focussing. It was commissioned during two beam times in 2007 with an uncooled beam of the lighter ion species $^{64}Ni^{28+}$ and $^{20}Ne^{10+}$. The next structure is the IH-structure that decelerates the ions down to 500keV/u. Its initial commissioning took place in August 2008 with a partially cooled heavy $^{197}Au^{79+}$ beam and will be continued in October of this year [2]. For beam diagnostic measurements there are phase probes as well as beam diagnostic stations installed in the beamline. They house Faraday cups, grids and YAG-scintillation targets. Furthermore there were a single-shot pepper pot emittance meter and a diamond detector installed for transversal and longitudinal emittance measurements.

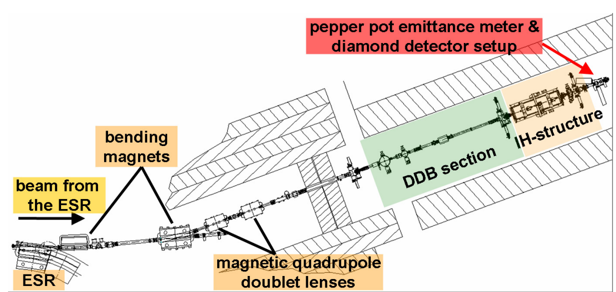


Figure 1: Overview of the transport beam line from ESR towards the position of the pepper pot emittance meter (later: position of the RFQ entrance).

Single-shot Emittance Measurements

Since the HITRAP linac gets a bunch of ions only every 35-60 seconds from the ESR during commissioning the single-shot pepper pot emittance meter is the ideal choice for this task. The GSI pepper pot device has been adapted to the special needs at HITRAP and a new evaluation software has been developed [3].

In 2007 emittance measurements were done at the position of the entrance of the IH-structure whereas in August 2008

* work supported by BMBF under contract 06FY160I
† jpfister@gsi.de

the device was placed at the RFQ injection point. Measuring in front of or behind the IH-structure makes a big difference for evaluation, since the measurement behind the IH is much more influenced by noise mainly produced by secondary electrons and small angle scattering as it can be seen in Fig. 2.

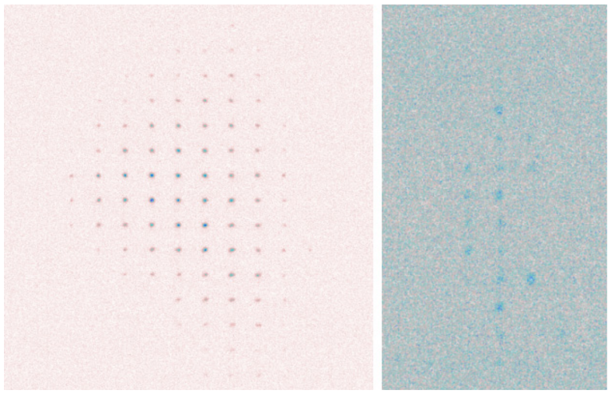


Figure 2: Typical pictures taken from the phosphor screen for emittance evaluation with Ne-beam in front of the IH (left) and Au-beam behind the IH-structure (right).

The emittance data has been evaluated with a new program written in MATLAB and ProEMI-PEDISP software as well as in profile measurements (2007 beam times only) using the "non-destructive" emittance evaluation method [4]. The evaluation data from MATLAB and ProEMI are in good agreement. Since the profile method is only a rough estimation of the emittance this value differs a little bit, but is still within the uncertainty limits. The emittance values are bigger than expected from prior calculations but this is due to the fact that cooling of the beam after deceleration in the ESR was not possible because of a limited beam lifetime. The emittance values and TWISS parameters calculated from the measurements were then used for the beam dynamics calculations backwards from the entrance of the IH-structure to the ESR.

Table 1: Comparison of emittances measured with uncooled Ne-beam and calculated with different software

	$\varepsilon_{\text{rms,hor}}$ $[mm \cdot mrad]$	$\varepsilon_{\text{rms,vert}}$ $[mm \cdot mrad]$
MATLAB	1.7	2.0
ProEMI	1.9	2.2
profiles	2.4	1.7

The evaluation of the $^{197}Au^{79+}$ data was done with MATLAB only. The quality of the pictures was not satisfying (see Fig. 2). The signal-to-noise ratio was approx. 1.7. In Fig. 3 a detailed evaluation screen is shown for one of the examples that was possible to evaluate. Evaluation of the complete set of measurements still has to be done. The data, which were evaluated so far show a horizontal rms-emittance of 0.6(3)mm·mrad and a vertical of 1.7(5)mm·mrad.

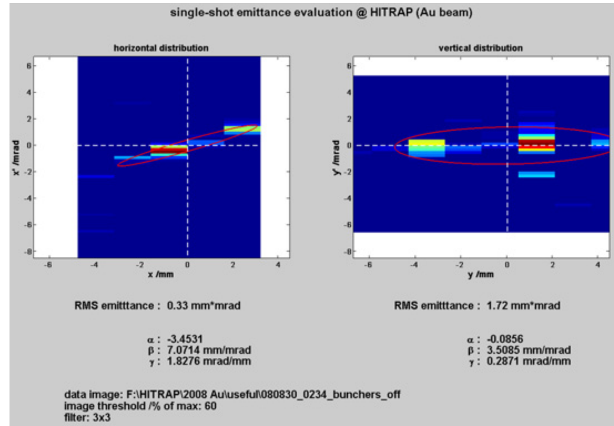


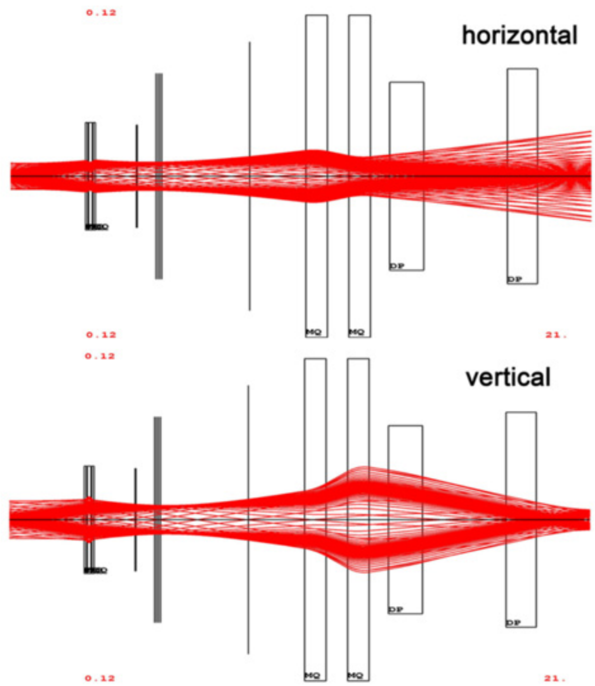
Figure 3: Data taken from the Au beam time with 60% noise cut.

BEAM DYNAMICS CALCULATIONS

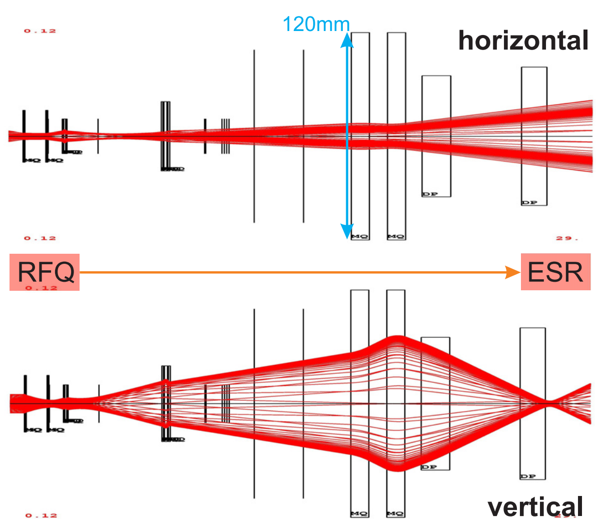
The lens settings, measured emittance values and TWISS parameters at the entrances of the IH-structure and RFQ were used to perform beam dynamics studies tracing the beam back from the point of measurement to the ejection point of the ESR. It was found that for the $^{20}Ne^{10+}$ beam the diameter in the dispersive plane of the bending magnets at the ESR is 40mm and 5mm in the lateral plane. But in the DDB cavities a beam with an approximately circular beam shape and a small divergence is required in order to avoid emittance growth. The corresponding envelopes of the beam calculated with COSY INFINITY [5] for both beam times are shown in Fig. 4. The beam size at the ESR exit corresponds approximately to the expected values due to the restricted aperture, but the divergence is larger due to the lack of cooling at 4MeV/u in the ESR during the 2007 run. However, the beam line tune reveals good beam transport properties with high transmission of 90%.

LOW ENERGY PEPPER POT EMITTANCE METER

For measurements in the low energy section of HITRAP as well as in other applications it is advantageous to measure the emittance in one single shot at energies in the low keV-range. We proved that this is not possible with pure scintillator screens at low intensities [6]. The measured emittance value strongly depends on the used scintillator material. Therefore a Micro Channel Plate (MCP) with an amplification factor of about 10^4 is placed in between the aperture plate and the scintillation screen. The resolution of the MCP (approx. 12 µm) is better than the resolution of the CCD camera, which is 1392×1040 pixels (1:1 transformation). Distributed to the size of the active area of the MCP the device will get an effective spacial resolution of 35 µm. Using a fixed focus lens no degradation of image quality is anticipated.



(a) 2007 Ne beam dynamics



(b) 2008 Au beam dynamics

Figure 4: Envelopes of Ne and Au beam calculations using the beam optics settings and measured emittance values as input data.

With this new device the user will have all benefits like intensified images, online evaluation and phase space illustration of the measured beam. The device partly looks similar like the beam diagnostic monitors that were designed at KVI Groningen and are used for beam profile and current measurements in the low energy beam transport line of HITRAP. The system was upgraded and suited for its main purpose. It is equipped with the emittance meter and a Faraday cup. Determination of beam current and emittance can be done within seconds, nevertheless still two shots of ions are needed. The online readout of physical data within the scintillation effect on the phosphor screen that is the anode of the MCP takes place from a dedicated PC with special image acquisition software. The setup (see Fig. 5) with its fixed flange is mounted to a linear translator to move either the emittance meter or Faraday cup on beam axis or to remove it from the beam completely.

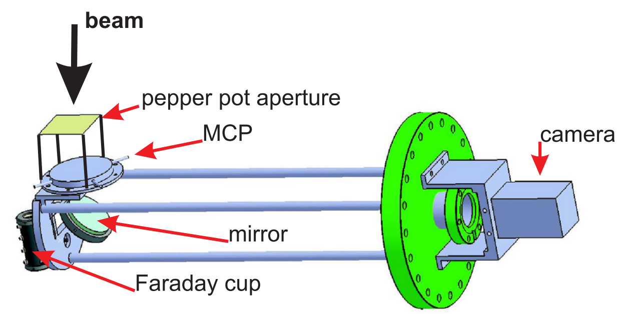


Figure 5: Design drawing of the new pepper pot emittance meter for low energies incorporating the device itself and a Faraday cup. Everything is mounted on a moveable CF-160 flange.

OUTLOOK

Two more commissioning beam times are scheduled in October 2008 and beginning of 2009. The first beam time is forseen for final commissioning of the IH-structure and the re-buncher. After successful tuning the structure for deceleration down to 0.5MeV/u, emittance measurements are foreseen. The 2009 beam time is dedicated to the commissioning of the RFQ.

The new pepper pot device is almost completely designed and will be built this winter using a MCP instead of pure scintillators for emittance measurements. Using such a device, beam quality resp. emittance measurements in the low energy beam section of HITRAP will become possible.

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