A DECELERATOR FOR HEAVY HIGHLY CHARGED IONS AT HITRAP*

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Abstract

The Heavy Highly Charged Ion Trap (HITRAP) project at GSI is in the commissioning phase. In 2007 the first part of the linac, namely the double-drift buncher section, was commissioned successfully. Measurements included transverse emittance, the longitudinal bunch structure and phase and amplitude tuning of the structures. Since the HITRAP linac gets every minute a macro-bunch from the GSI experimental storage ring only, it is not reasonable to use a slit-scanning method for emittance measurements. Therefore the GSI single-shot pepper pot device was used for these measurements. This contribution concentrates on the emittance measurements in the first two beam times and corresponding beam dynamics simulations. .

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 electron-cooled as well as decelerated and a single bunch is created by bunch-merging. At an energy of 4MeV/u, the ions are ejected from the ESR as a bunch of about $10^5 - 10^7$ ions depending on the element, with a pulse length of 1-2μs. 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 linac structures, 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 a few keV/u. By cooling the trapped highly charged ions will reach a thermal energy corresponding to slightly more than 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 reinjection channel as a high-quality, low emittance, highly charged ion beam [1].

LINAC COMMISSIONING

The double-drift buncher is the first component of the HITRAP linac and is used for phase focussing. It was commissioned during two beam times in May and August 2007. After deceleration and cooling (only during first beam time) of the ions down to 4MeV/u in the ESR, they were ejected via the transport line towards the HITRAP linac (see fig. 1). For the first run a $^{64}Ni^{28+}$ beam was used in May 2007. In August the ion species was $^{20}Ne^{10+}$. 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. These boxes were used for the "non-destructive" emittance evaluation method. Furthermore there were a single-shot pepper pot emittance meter and a diamond detector installed for transversal and longitudinal emittance measurements.

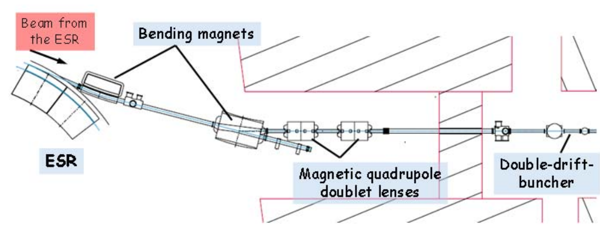

Figure 1: Overview of the transport beam line from ESR towards the DDB.

Single-shot Emittance Measurements

Since the HITRAP linac gets a bunch of ions from the ESR every 50-60 seconds during commissioning the slit-scanning method for emittance measurements is not reasonable. Therefore a single-shot pepper pot emittance meter is used for the measurements, which was built at GSI at the beginning of this decade [2]. This device takes 10-bit bitmap pictures of ions scintillating on a phosphor screen after passing through an aperture plate with a defined matrix of 15x15 holes. Projecting the intensity distributions to both x and y axes one gets the same kind of data as with a slit-scanning measurement and one can evaluate the emittance in both, horizontal and vertical direction from one single picture using the well known definition of the RMS-emittance:

$$\varepsilon_{rms} = \sqrt{< x^2 > \cdot < x'^2 > - < x \cdot x' >^2} \quad (1)$$

The properties of the pepper pot aperture need to be chosen to fit the existing beam parameters. The hole diameter on the tantalum foil was chosen to be 100μm with a thickness of 300μm. The distance between two holes was 1.6mm and the drift distance between aperture and screen 150mm. A typical picture of a neon beam impinging on the screen is shown in fig. 2.

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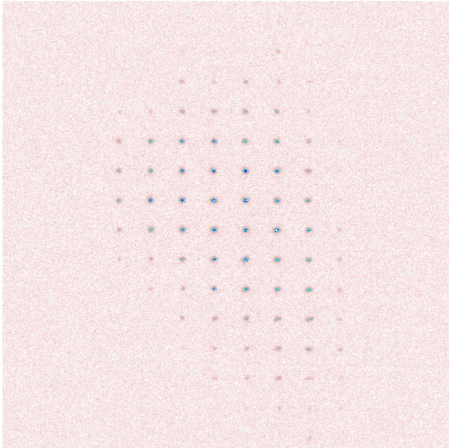

Figure 2: Typical photo taken from the phosphor screen for emittance evaluation.

The bitmap data have been evaluated with a new program written in MATLAB®. Since there is up to 55% background noise, background cuts and filtering (averaging) were investigated prior to the evaluation procedure. Different filter sizes were tested. Since the data in the picture has a circular shape the filter should have a similar one! Averaging filters with 3x3, 5x5 and 7x7 pixels filter size were used. Not all filters reduce the emittance value. The main reason is the intensity accumulation in areas without signal, where noise is amplified by large area filters. A comparison for different filter sizes is shown in fig. 3. All parameters are fixed except the filter size. The systematic increase of the emittance value with increasing filter size is obvious.

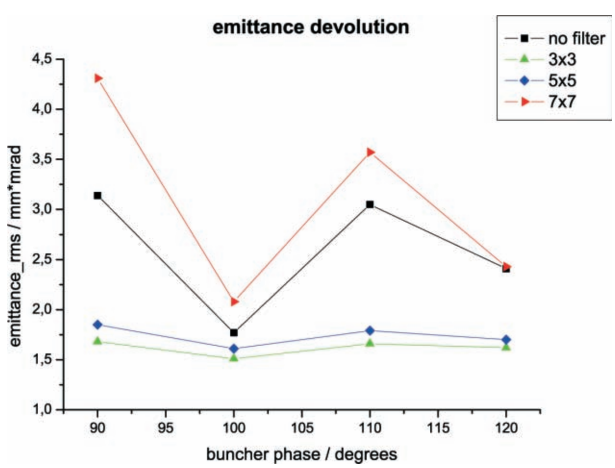

Figure 3: Comparison of different filter sizes.

To determine the right level for cutting the background, an emittance evaluation in dependence on the level cut was performed. An example is shown in fig. 4. The graphic shows that the emittance of the beam core can be evaluated by fitting a line to linear section of the corresponding curve and using the value, where the fit-line crosses the y-axis. This is the lowest value one can assume! We expect the emittance to be slightly bigger than that. A Gauss fitting algorithm is in preparation.

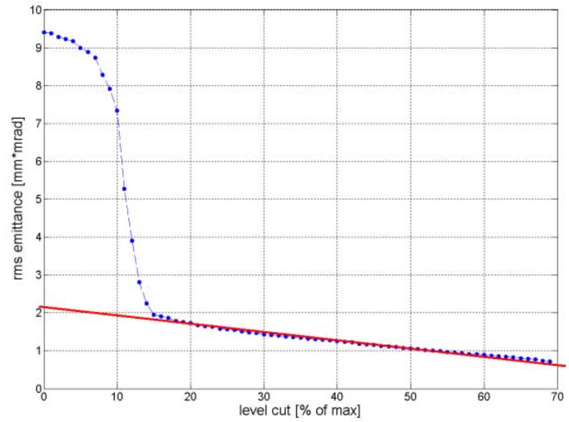

Figure 4: Dependence of the RMS-emittance on background level cuts.

The phase settings of the bunchers were changed and emittance measurements were carried out to find the optimal phase focussing for later injection into the IH-structure (see table 1). Due to a non-cooled ion beam from ESR, emittances are about 4-5 times larger than those values of previous measured cooled beams from the ESR.

Table 1: Measured RMS-emittances at HITRAP (normalized) in dependence on buncher phases with non-cooled beam from ESR (horizontal (x)-direction).

DDB phase [degrees]	$\varepsilon_{rms,norm}$ **[mm·mrad]**
90	0.291
100	0.164
110	0.283
120	0.224

Another emittance evaluation program available at GSI was used to verify the emittance values of the same data. Therewith the accuracy of the MATLAB program could be determined and calibrated. The calculated data were approved by the ProEMI-PEDISP software. On the measurements done in 2007 the angular resolution was 0.3mrad. This is related to the pixel size and the zoom factor of the lens. For upcoming measurements it is envisaged to get an angular resolution of about 0.15 to 0.2mrad in order to get even more accurate results.

Profile Measurements

Emittance evaluation was also done using the "non-destructive" emittance evaluation method. It uses beam profile measurements in dependence on the focussing strength of a lens in front of a profile monitor. In the HITRAP commissioning beam times, we used the YAG scintillator screens. With the knowledge of the beam transfer matrix of the lens-drift system for different settings and corresponding profile measurements one can evaluate the beam emittance as well as TWISS parameters by a best fit [3]. This emittance determination has been done for double-checking the emittance values generated from the pepper pot measurements.

We used seven different lens settings for a good fit of the emittances and TWISS parameters. Using this method the emittance was calculated to be 9.7mm·mrad KV-emittance in x and 6.7mm·mrad in vertical (y) direction. This value is comparable to the measurements done with the pepper pot method. An example of the picture evaluation software is shown in fig. 5.

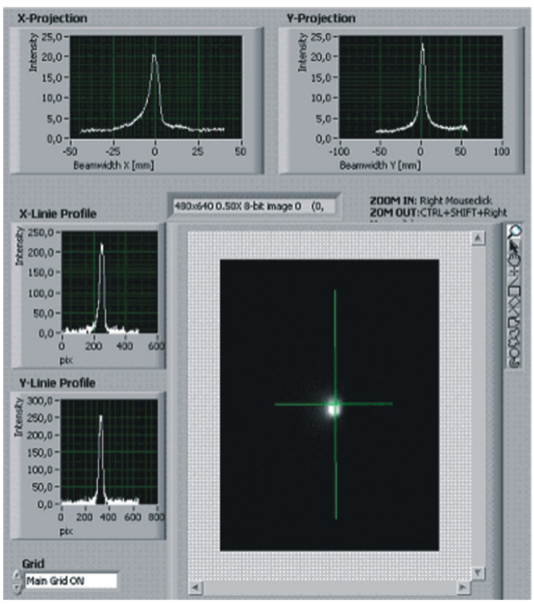

Figure 5: Tool for readout of scintillation images for "non-destructive" emittance evaluation method. The projections are used for further calculation.

BEAM DYNAMICS CALCULATIONS

The beam from the ESR has approximately 40 mm in diameter in the dispersive plane of the bending magnets and is 5 mm wide in the lateral plane. In the DDB cavities a beam with an approximately circular beam shape and a small divergence is required in order to avoid emittance growth. A corresponding beam tune has been adjusted and emittances have been measured with the pepper pot device. The lens settings, measured emittance values and TWISS parameters have been used for backtracing of the beam from the IH-structure towards the ESR. The corresponding envelopes of the beam calculated with COSY INFINITY [4] are shown in fig. 6. 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 4 MeV/u in the ESR. However, the beam line tune reveals good beam transport properties with high transmission of 90%.

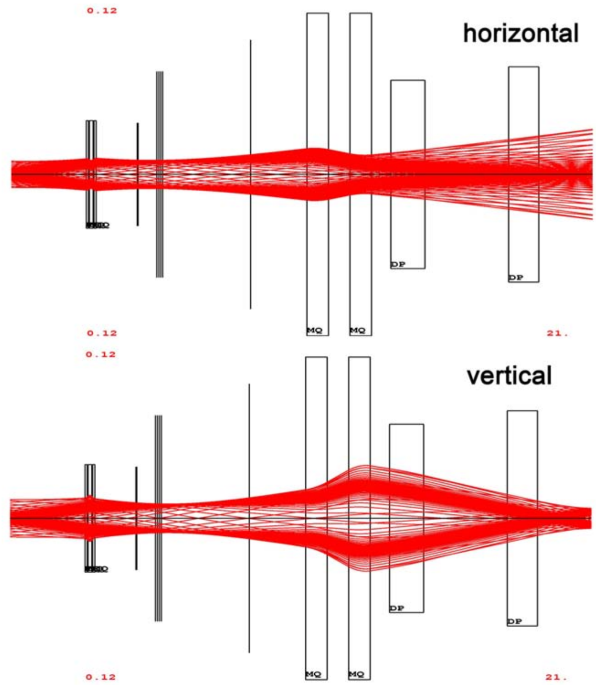

Figure 6: Envelope of the beam calculation using the beam optics settings and measured emittance values as input data.

OUTLOOK

There are two more commissioning beam times scheduled in 2008. The first beam time is forseen to commission the IH-structure with $^{197}Au^{97+}$. Here, emittance measurements are foreseen with a beam at 4 MeV/u energy, drifting through the IH-structure and a decelerated beam of 0.5 MeV/u. During the second run using $^{64}Ni^{28+}$ the RFQ is tested and the first shot into the cooler Penning trap is planned as well as a first experiment behind the cooler trap. A new pepper pot device is being designed and will be built until end of 2008 using MCPs instead of pure scintilators for emittance measurements. Using such a device, emittance measurements in the low beam energy section of HITRAP will become possible.

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