Emittance Measurements of High Current Heavy Ion Beams Using a Single Shot Pepperpot System

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Abstract. The new 1.4 MeV/u high current injector for the Unilac succesfully commissioned in 1999 is now accelerating heavy ions close to the calculated intensities. For example an $^{40}Ar^{1+}$ beam with 8 emA allows to fill the GSI synchrotron to its inherent intensity limit. For emittance measurements of such intense beams a single shot pepperpot system has been developed. An overview of the hard- and software including mathematical algorithms is given. Results of emittance measurements at different intensities and energies are presented. The influence of stripping and related space charge effects on the emittance could be investigated.

INTRODUCTION

For commissioning purposes of the new prestripper section (1) of the UNILAC it was necessary to install an alternative method of emittance measurement. In the past the emittance of the transversal phase space was measured with the traditional slit/grid method which worked very well and for which devices are permanently installed at the Unilac injection section and at the GSI ion source department. With the development of the high current injector (2) using a 36 MHz RFQ with a final energy of 120 keV/u and two IH-DTL structures (743 keV/u, IH1 and 1.4 MeV/u, IH2) the thermic strain of material through high current heavy ion beams increased so that the conventional slit/grid hardware was destroyed although a cooling system was used. The destruction effects (Fig.1) did not lead to obvious misbehavior in the measurement process, so it is possible that undetected errors could have taken place.

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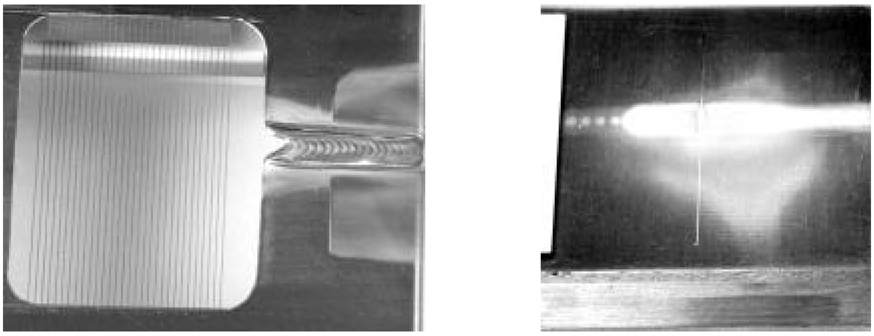

FIGURE 1. Grid (left) and slit (right) damaged during a measurement with an Ar^{1+} beam (about 5 mA and 5 Hz at 743 keV). The dotted line on the right picture was caused by macropulses while moving the detector into the beam. The large hole in the slit has a negative effect on the emittance calculation which is then difficult to detect. Some of the grid wires have been destroyed too, but have been replaced for re-use.

A pepperpot system using a Fast Shutter CCD camera was developed, with the main goal to measure transversal emittances of high current ion beams in a single shot. This led to short measuring times, and especially to a lower thermic stress on the used detector hardware.

Another advantages of the pepperpot system compared to the slit/grid method are the possibility to measure the emittance in coupled horizontal and vertical transverse phase planes and to examine pulse to pulse fluctuations.

HARDWARE SET-UP OF THE PEPPERPOT SYSTEM

The principle and the set-up (3) of the pepperpot system is shown in Fig.2. The used pepperpot plate, shown in Fig. 3 is made from copper. A regular grid pattern in an arrangement of 15x15 holes is drilled into the plate on an area of 45 x 45 mm^2.

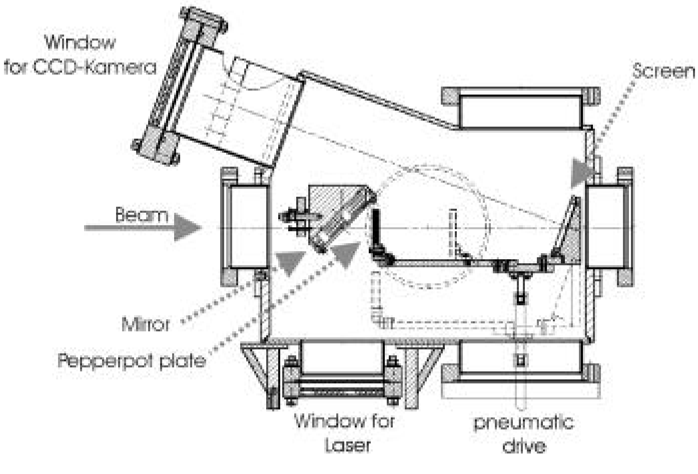

FIGURE 2. Schematic drawing showing the pepperpot system, which can be moved onto the beam axis by a pneumatic drive. A laser beam inflected by a mirror is used for calibration purposes.

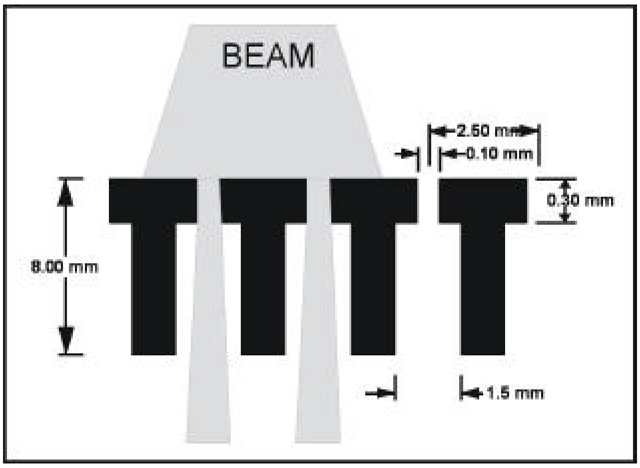

FIGURE 3. Scheme of the pepperpot plate in a cross sectional view and relevant dimensions.

For further development plans are to increase the angular resolution, in using a pepperpot plate, built up with a 0.1mm and 0.5mm thick tungsten or tantalum foil and holes of 0.1mm diameter. This foil is fixed between two copper plates for mechanical and thermal durability.

The scintillating fluorescent screen is made from Al_2O_3. The distance between the pepperpot plate and the screen can be varied between 150 and 250 mm to change the resolution in case of overlapping spots. To reduce errors caused by light refection, the interior of the chamber is totally blackened. Selection of materials and physical dimensions of all parts are based on the theoretical beam parameters given in Tab.1.

TABLE 1. Beam parameters of the new UNILAC prestripper section for U^{4+}

Parameter/Section	RFQ	IH 1	IH2
Energy (keV/u)	120	743	1396
? = v/c (%)	1.605	3.995	5.473
?-hor. (mm mrad, 90%, 4 x rms)	12.5	8.5	8.1
?-ver. (mm mrad, 90%, 4 x rms)	12.5	8.5	8.1
Bunch length (ns)	>2	1-2	<1
Beam current * (emA)	15	15	15
Beam power (kW, pulse)	114	708	1329
*Reference particle = U^{4+}			

A resolution of less than 0.5 mrad in divergence and 0.1 mm in the transverse coordinates can be achieved by using a PC controlled Fast Shutter CCD camera (4). Excerpts of the camera properties are listed in Tab.2.

TABLE 2. Main characteristics of the PCO CCD camera.

Sensor type	**CCD-Interline**
Resolution	1280(h) x 1024(v), SVGA
Pixel size	6.7µm x 6.7µm
Sensor format	2/3”
Scan area	8.6mm x 6.9mm
Response	280 ...1000nm
Trigger	external TTL, Software
Exposure time setting	Fast Shutter
Exposure step width	100ns
Exposure times	100ns – 10ms
Multiple exposure	max. 10 x 10ms = 100ms
Control	PC, fiber optic link

SOFTWARE FOR DEVICE CONTROL, DATA ACQUISITION AND EVALUATION

It is planned to implement the pepperpot emittance measurement system into the regular GSI control system. Access to the pepperpot systems in an agreeable way for the operating staff had to be developed. The software is based on Windows NT and programmed in C++. Full hardware access including GSI interlock system for single shot mode is provided for expert and commissioning user. The expected standard operation mode is reduced to a minimum of working steps and is mostly automatic.

The software provides the following functions:

- Hardware control
- Graphical user interface
- Setup
- Image acquisition
- Calculation
- Presentation

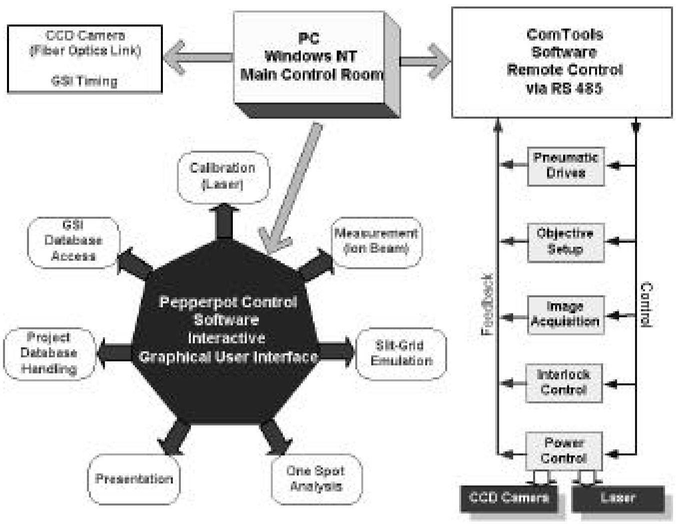

FIGURE 4. Scheme of pepperpot software

More detailed information about the evaluation algorithms is given in (5).

MEASUREMENTS

Calibration process

For the calibration process, a parallel laser beam is used to correlate the pixels of the obtained image with the real physical coordinates of the pepperpot holes. A regular rectangular grid has to be fitted with its nodes on the centre of each displayed spot. This step is shown in Fig. 5. For later calculation of the angle deviation the set of data is stored in the local database.

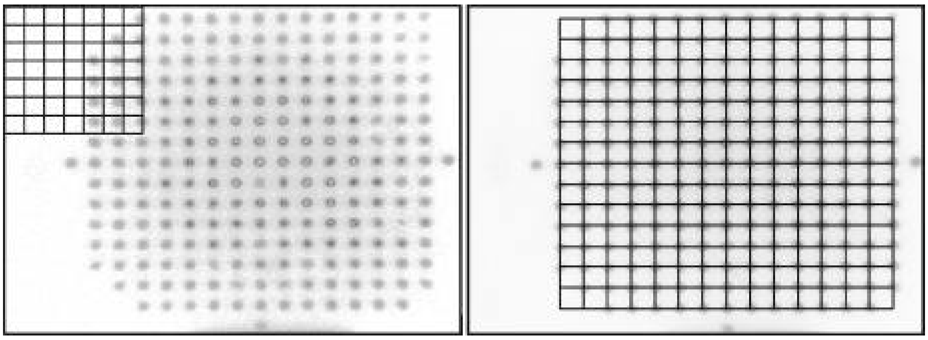

FIGURE 5. CCD images of the screen illuminated through the pepperpot by laser light (reverse display).

Emittance calculation

On the obtained ion image the stored grid from the calibration process has to be fitted on the spots again. This information is used as a starting point for a search algorithm to scan the hole spot intensity distribution.

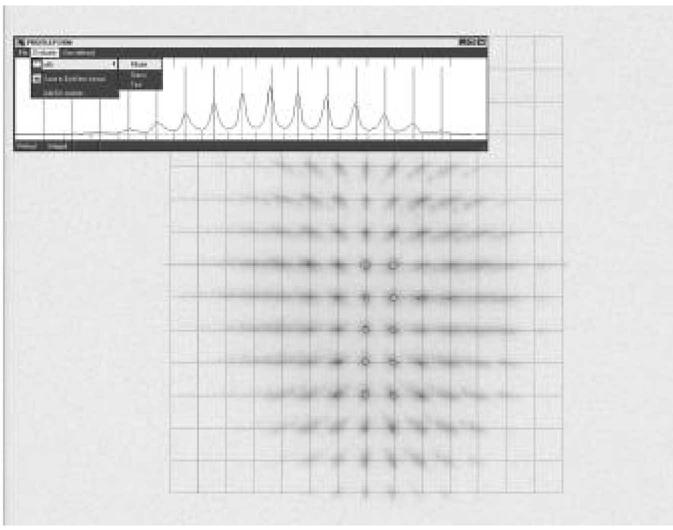

FIGURE 6. Fit of calibration data on real ion beam image.

The use of a profile window displayed in Fig. 6 is similar to the conventional slit-grid technique. The grid lines on the maxima of the profile can be moved manually for each spot to ensure correct separation of all spots and to create the dependence to its corresponding pepperpot hole. It is possible to use one line of spots for evaluation or the integral of all spot lines. The analysis is separated in horizontal and vertical data output. The development of a more sophisticated algorithm which leads to emittance calculations in coupled transverse phase planes is in progess (5).

RESULTS

Fig. 7 shows the new GSI gas stripper section with the charge analyzing spectrometer and the two pepperpot devices. With this set-up it is possible to examine stripping and space charge effects and their influence on the emittance.

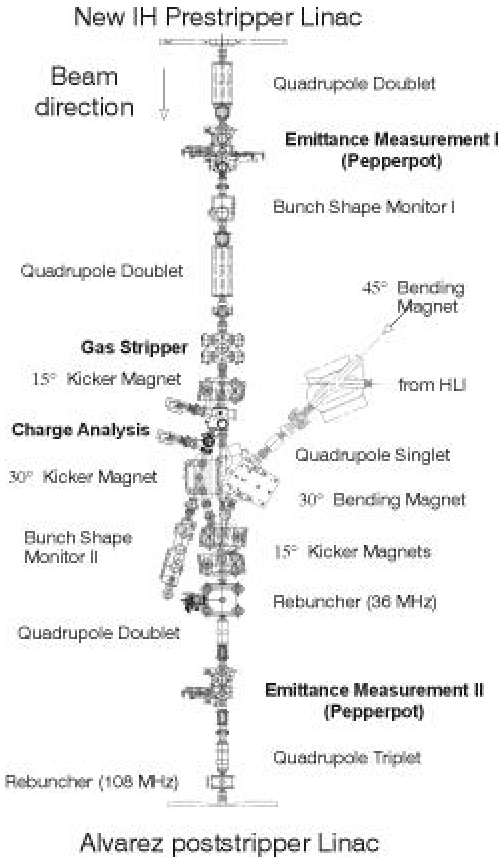

FIGURE 7. New Unilac gas stripper section.

Stripping an $^{40}Ar^{1+}$ beam of 7.5 emA results in an 18 emA current of $^{40}Ar^{10+}$. This is three times the current (resp. 6 emA $^{40}Ar^{10+}$) the beam transport system can handle without space charge compensation due to electrons from the gas stripper. The charge density directly behind the stripper is the highest within the whole Unilac.

Partial beam neutralization prevents a stronger emittance growth and leads to improved transmission for the highest currents. Fig. 8 shows the intensity distribution in 2D-phase space for different current levels behind the stripper of $^{40}Ar^{10+}$. The intensity was varied with slits in the low energy beam transport in front of the RFQ. No signifcant changes due to intensity variations are examined for the emittance in the prestripper section. Behind the stripper the emittance in the vertical plane shows a strong current dependence. Effects on the horizontal emittance were not observed. This is due to the elliptic beam profile which allowed higher space charge forces in the horizontal plane.

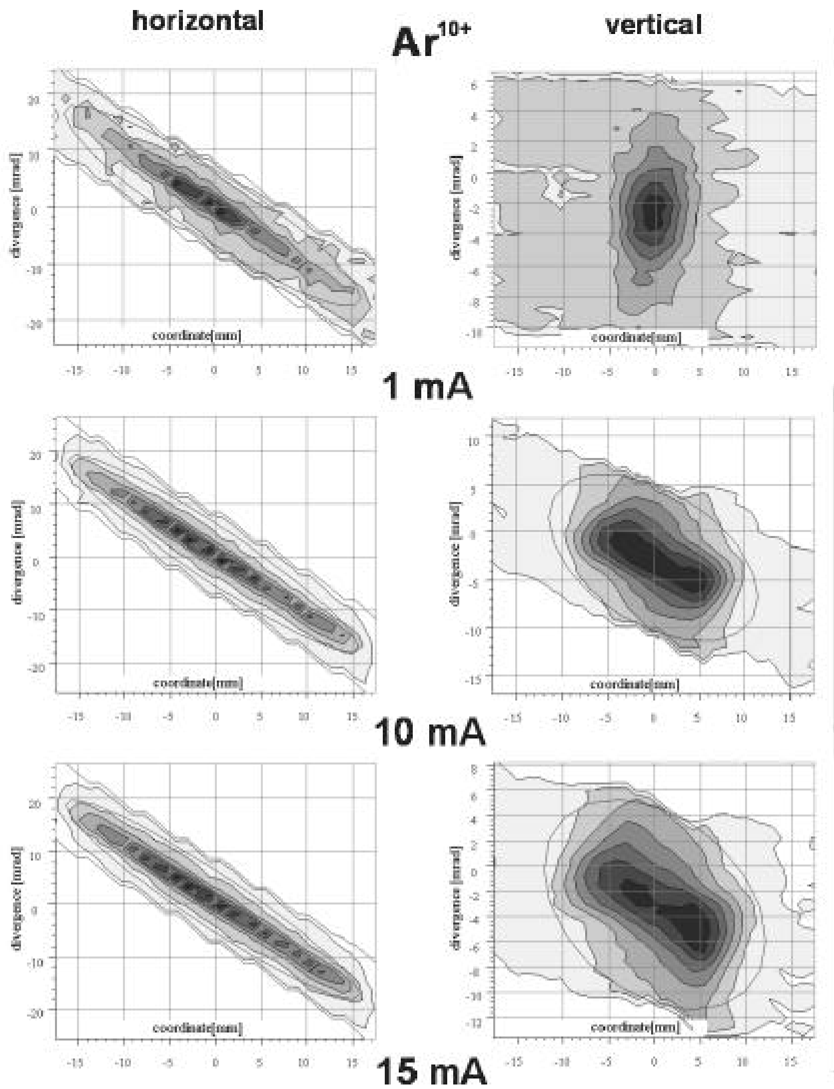

FIGURE 8. Intensity contour plots of the measured beam distribution.

Another indication of space charge compensation could be seen comparing signals from a capacitive pick-up which is directly placed behind the gas-stripper with the pulse current measured with a beam transformer which is installed directly in front of the stripper.

Since the mean charge of the Ar-ions rises from 1+ to 10+ by passing the stripper and charge separation has not yet taken place at the position of the capacitive pick-up, the effect of neutralization is observable on the signal amplitude of the pick-up. The non-linear run of the curve in Fig. 9 can be interpreted as a result of charge compensation. More information on space charge effects, beam neutralization and charge state spectra of the new prestripper linac and stripper section is given in (6).

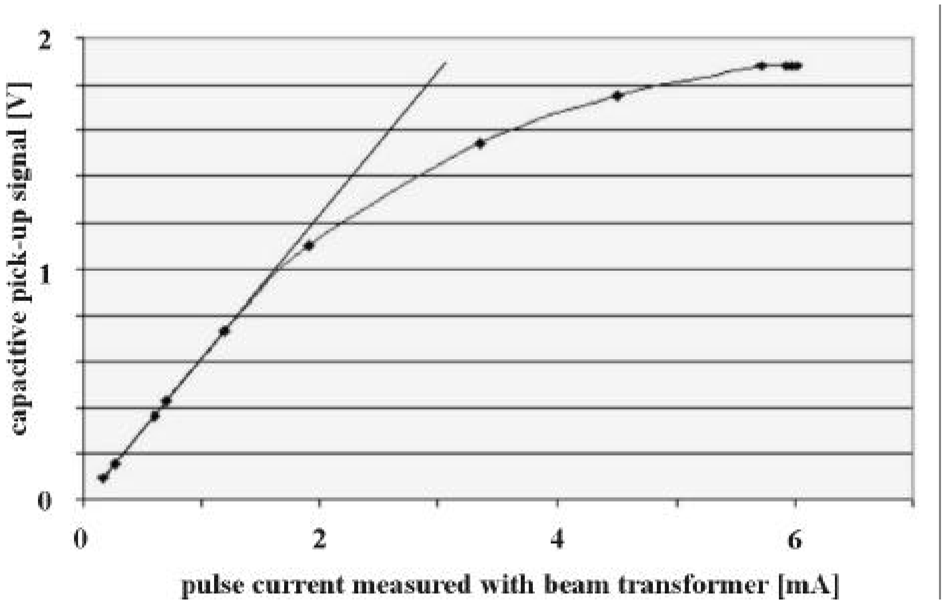

FIGURE 9. Effect of bunch neutralization observed with a capacitive pick-up

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