MEASUREMENTS WITH A VERSATILE TEST BENCH FOR THE COMMISSIONING OF THE NEW GSI HIGH CURRENT LINAC

P. Forck, P. Strehl
Gesellschaft für Schwerionenforschung, Darmstadt, Germany

Abstract

For the commissioning of the new GSI pre-stripper a conventional slit-detector system and a single shot pepper-pot system has been installed on a mobile test bench to measure intensity distributions in the two transverse phase spaces. To determine intensity distributions in the longitudinal phase space, including beam energy capacitive pick-ups and newly developed diamond counters have been installed on the test bench. The set-up of the test bench provides also redundant information for beam current, beam profile and beam position. The most important features of all measuring systems including signal processing and data evaluation are reported. First results from the commissioning of the upgraded pre-stripper of the UNILAC at GSI are reported.

1 INTRODUCTION

The Wideröe pre-stripper part of the UNILAC has been removed at the beginning of 1999. The new pre-stripper [1] consists of an RFQ [2] with a final energy of 120 keV/u followed by two IH structures [3] with the final energies of 743 keV/u (IH1) and 1.4 MeV/u (IH2). The commissioning of the new accelerator structures including the injector has been started in March 1999 and will be performed step by step up to October 1999 using a transportable test bench.

2 GENERAL DESCRIPTION OF THE TEST BENCH

The type of beam diagnostic elements as well as their arrangement on the test bench depends on the expected relevant beam parameters and, therefore on the section under commissioning. The following systems have been provided for installation on the bench:

- An emittance measuring system consisting of a horizontal and a vertical slit - detector, using independently movable harps as detectors. Taking advantage of this feature the resolution in divergence can be improved by intermediate steps of the harp. Additionally, measurable maximum divergences can be extended by so-called off-set positions of the harp with respect to the slit position to cover misaligned beams, too. The system is controlled by a PC including appropriate evaluation of emittance data.
- A newly designed pepper-pot system provided especially for single shot emittance measurements at higher beam energies. The system has been described more detailed in [4] and the mathematical algorithms to extract emittance data are discussed in [5].
- One beam transformer for beam current measurement and monitoring of macro pulse shape.
- One residual gas ionization monitor for nondestructive beam profile measurements.
- One profile grid to compare profiles measured with the residual gas ionization monitor.
- Two segmented capacitive pick ups to determine beam energy and energy jitter by time-of-flight (TOF) measurements as well as nondestructive beam position determination.
- A large vacuum chamber equipped with a thin scattering foil and various detectors to measure parameters in the longitudinal phase space [6].
- To stop the high intense beam, a beam stopper provided for 1.5 MW pulse power can be mounted at the end of the test bench.
- To perform destructive beam profile measurements at full beam power, a movable slit designed also for high pulse power can be mounted in front of the beam stopper.

The test bench has an overall length of nearly 3 meters and is equipped with its own vacuum pump.

3 COMMISSIONING OF THE NEW INJECTOR

Due to the low energy of 2.2 keV/u the maximum pulse power in this section is always below 2.5 kW and therefore all destructive beam diagnostic elements can be used without restrictions. Since there are no prebunchers foreseen monitors provided for measurements in the longitudinal phase space are not needed. The test bench has been equipped as shown schematically in Fig. 1.

Since matching to the RFQ requires a double waist at the RFQ-input, which will be forced by a collimator in front of the RFQ (see Fig. 1) the movable horizontal and vertical slits have been installed just at the position of this waist.

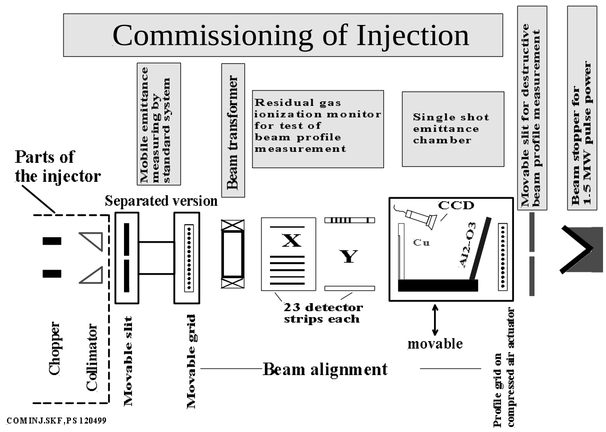

Figure 1: Scheme of the test bench for commissioning of the new injector section

To ensure focusing by the last quadruplet in front of the RFQ (not shown in Fig. 1) without restrictions, the collimator has been left out during commissioning. Figures 2 and 3 demonstrate the capability of the emittance measuring system. The theoretical settings of the beam transport elements in the injector section were confirmed. To

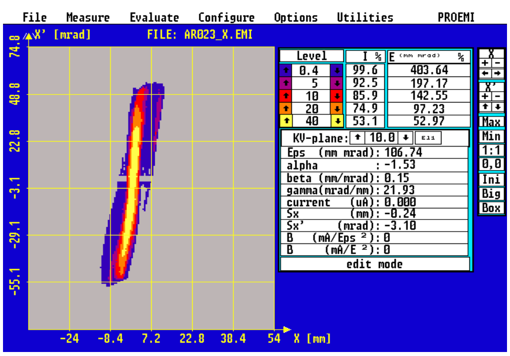

Figure 2: Measured emittance at the position of the RFQ-input. Horizontal phase plane, 10 mA Ar^{1+} with an energy of 2.2 kev/u

study the dependencies more than 30 emittance measurements have been performed in dependence of various settings of the ion source parameters, various settings of the beam transport elements and different ion beam intensities. Additionally, delay and width of the gate pulse have been varied for emittance measurements along the macropulse.

To test the pepper-pot system and especially the algorithms implemented to extract emittances in the two transversal phase planes from the measured intensity distribution in the 4-dimensional phase space, a Ni - beam from a MEVVA ion source has been analyzed with both systems. Figure 4 shows the measured horizontal emittance at the movable slit and Fig. 5 shows the picture observed on the screen of the pepper-pot system. Since the final version of software for the evaluation of emittances is yet under devel-

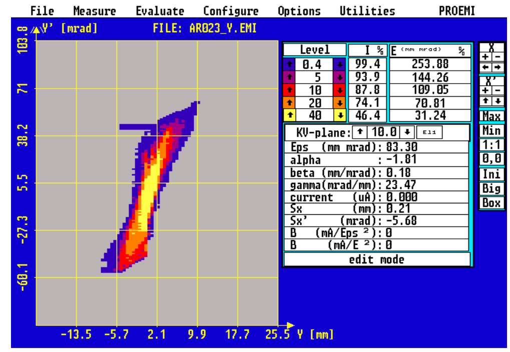

Figure 3: Measured emittance at the position of the RFQ-input. Vertical phase plane, 10 mA Ar^{1+} with an energy of 2.2 kev/u

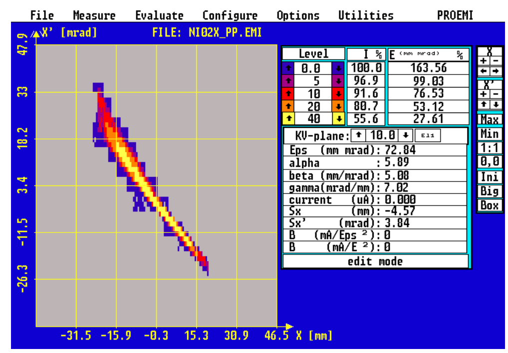

Figure 4: Convergent beam at the slit of the first emittance measuring system to test the pepper-pot-system. Ni^{1+} -ions, ca. 4 mA, MEVVA ion source.

opment, a practical, semi-manual algorithm which will be described detailed in [4], has been applied. Figure 6 shows the result. Taking into account the drift of about 1.5 m from the slit of the first emittance measurement to the pepper-pot we find good agreement concerning size and orientation. The measurement also confirms the theoretical set-

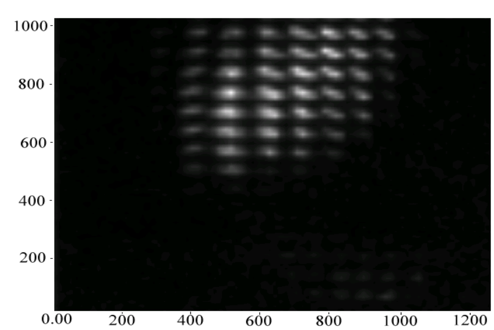

Figure 5: Observed spots on the viewing screen behind the pepper-pot plate. Ni^{1+} - ions, ca. 4 mA, MEVVA ion source. Values at the abscissa and ordinate give the pixel number of the CCD-camera.

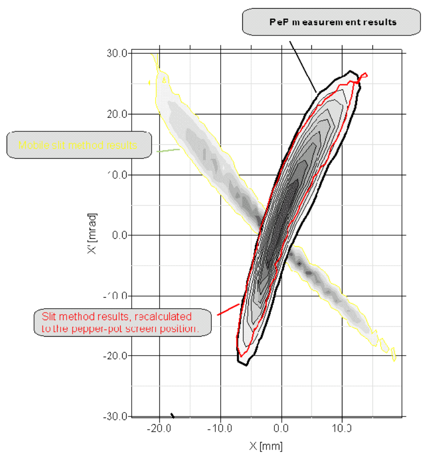

Figure 6: Evaluation of the spot pattern of Fig. 5. The Figure shows also the data of Fig. 4 and their transformation to the pepper-pot location.

ting of the quadruplet which has been adjusted to result in a waist in between both measuring systems. Furthermore, the transfer matrix of the quadruplet in front of the RFQ has been tested by measuring the profile width at the profile grid on the test bench in dependence of the quadrupole gradient. The calculated emittance has been transformed theoretically to the profile grid taking a set-value for this quadrupole corresponding to the observed waist at the profile grid. Figure 7 demonstrates the good agreement.

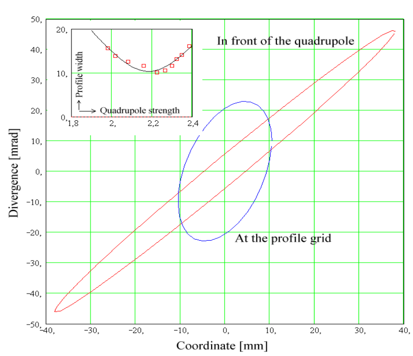

Figure 7: Emittance measurement by variation of the quadrupole gradient in front of the profile grid at the test bench.

Due to the higher beam power (217 kW pulse power behind RFQ, 730 kW behind IH1 and 1.37 kW behind IH2) profile grids cannot be used without restrictions concerning beam power and/or beam pulse length. Therefore, tests of the residual gas ionization monitor provided for non-destructive profile measurements at high intensities become essential. There are two important questions: which accuracy can be achieved in the calculation of the expected signal strength from known energy loss data taking into account different kinds of ions at various energies and has the space charge of non-compensated moving bunches an influence on the measured profiles. Due to missing bunches and the reasonable assumption of a nearly compensated beam in the injection section the second question is not relevant here and will be discussed later. To compare measured profiles with the calculated ones some measurements have been performed with the residual gas ionization monitor of the test bench. Figure 8 compares the measured profile with the calculated signal taking energy loss data from [7] and assuming a mean energy of 36 eV to produce an electron - ion pair. Furthermore, a mixture of 80% H_2 and 20% N_2 has been considered for the calculation of energy losses. Since the profile has been measured in the 50nA/V - range, the calculated data have been scaled to the same range. Considering all the uncertainties concerning pressure, gas-mixture, energy loss data, the agreement is excellent.

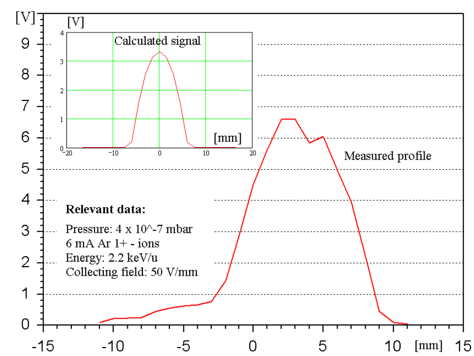

Figure 8: Comparison of measured and calculated signal strength for the residual gas ionization monitor.

4 COMMISSIONING OF THE RFQ

Commissioning of the RFQ is foreseen in two steps. First step is without the so-called superlens provided for matching the beam in all 3 phase planes for the input into the IH1-structure, while in the second step the superlens has to be included for the planned test measurements. At present only the first step has been started and, therefore it will be reported here about the measurements in the configuration shown in Fig. 9. Fig. 10 is a photo of the whole set-up. Of course, most interesting parameters commissioning a new type of accelerator are the output energy and bunch shape. The output energy of the RFQ has been measured in dependence of the rf-voltage by measuring the time of flight (TOF) between the two capacitive pick-ups. Due to the rather low output energy of 120 keV/u (design value) which corresponds to $\beta = v/c = 0.016$, the spacing between the bunches is only about 133 mm corresponding to an accelerating frequency of 36.136 MHz. Since the drift space between the two pick-ups is 3249 mm this corresponds to $N = 24$ bunches between the pick-ups which results at one hand in a very precise flight time determination but a rather

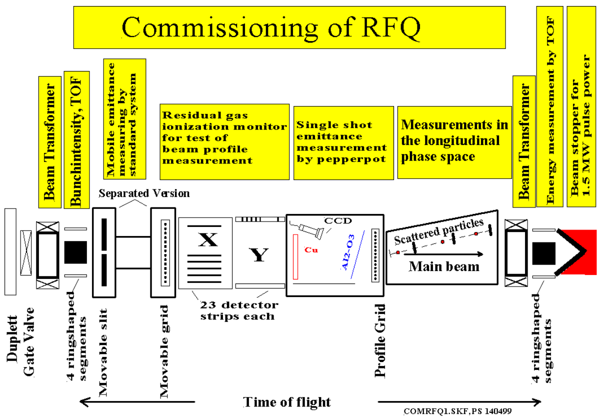

Figure 9: Scheme of the test bench for commssioning of the RFQ.

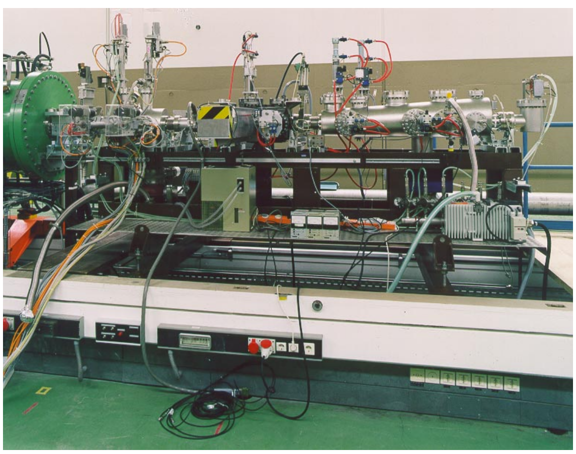

Figure 10: Picture of the test bench provided for commssioning of the new RFQ.

small separation of energies, belonging to $N \pm 1$. Figure 11 shows the result of the first energy determination. The

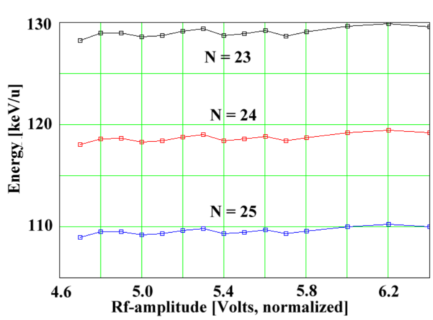

Figure 11: Energy determination by TOF-technique.

value of $N = 24$ has been confirmed using a third pick-up mounted directly behind the RFQ. To give an impression on the accuracy: an error in time of 100 ps leads to a change of 0.036 keV/u, while an error of 1mm in distance results in a change of 0.075 keV/u.

Due to the very low velocity of the ions the time structure of the bunches cannot be measured with capacitive pick-ups. But, assuming a width of 60 degrees of the rf-period, which results in a width (FWHM) of 2.5 ns the measured capacitive pick-up signal has been compared with the calculated signal. The result is shown in Figure 12. In the calculation losses in the cables (-2 dB for 20 m RG 214 and -6.2 dB for 160 m Flexwell) and losses in the electronics (-2.5 dB for pick-up selection by a multiplexer and - 1.9 dB for summing up the signals of two segments) as well as a gain of 32 dB has been taken into consideration.

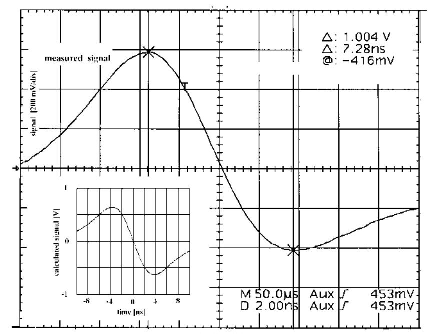

Figure 12: Comparison of measured signal from the first capacitive pick-up on the test bench with the calculated signal.

To measure the time structure of the bunches and longitudinal emittance a complex measuring system has been designed and installed into the large chamber at the end of the test bench. A very small number of particles is scattered out by Rutherford scattering on a very thin gold foil (120 $\mu g/cm^2$), passes a second thin carbon foil (5 $\mu g/cm^2$) and is analyzed by counting the particles rf-synchronously at the position of the carbon foil using a MCP. After a drift space of about 800 mm the particles are counted again, using a newly developed diamond counter [8], [6]. Figure 13 shows a bunch shape (rf-settings not optimized) from a first measurement with only one diamond counter. More results, their evaluation as well as the parameters of the system are discussed in [6].

After acceleration has been proved by the measurements in the longitudinal phase plane emittances have been measured again using the slit-detector system in comparison with the pepper-pot. Figure 14 shows a 3-dimensional display of the measured data. In this first measurement the beam current has been reduced to about 1 mA Ar^{1+} - ions for later comparison with a highly space charge dominated beam. The data obtained with the pepper-pot, shown in Fig. 15 compare very well.

During the commissioning of the RFQ profile measurements with the residual gas ionization monitor have been compared with the conventional profile grids, too. Figure 16 shows the measured profiles in both transverse direc-

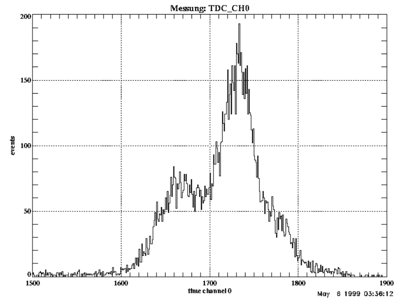

Figure 13: First time spectrum of bunches, measured with a diamond counter. Resolution 48 ps/channel, halfwidth of the main peak about 2.5 ns.

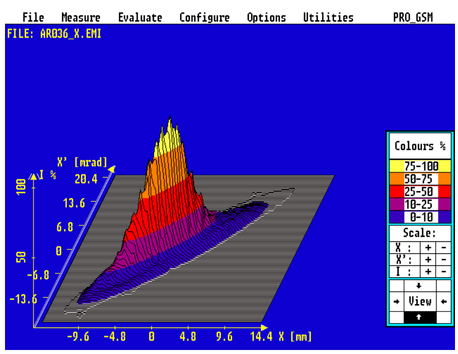

Figure 14: Measured emittance in the horizontal plane using the slit-detector system.

tions. The signal calculation taking energy loss data from [9] results in a maximum signal of about 1 Volt, again in a reasonable agreement with the measurement.

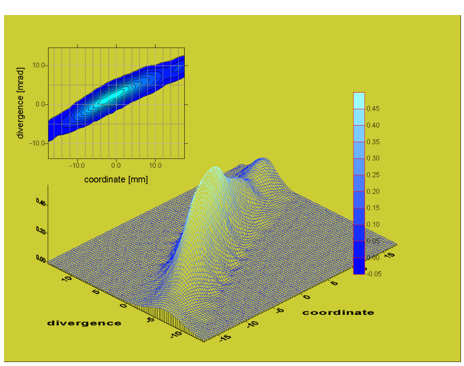

Figure 15: Emittance data in the horizontal phase plane from the pepper-pot.

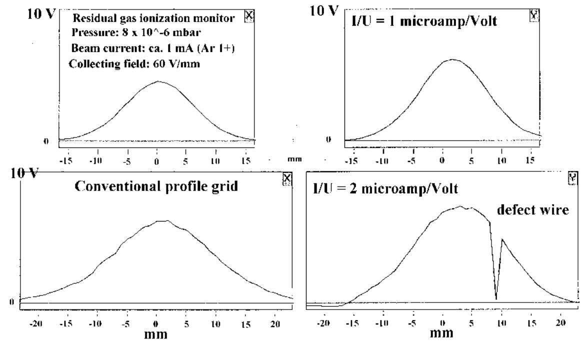

Figure 16: Comparison of transverse beam profiles.

5 ACKNOWLEDGMENTS

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