BEAM DIAGNOSTICS FOR THE UPGRADED UNILAC AT GSI

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Abstract

For the envisaged stepwise commissioning of the new LINAC (RFQ and IH) the design of a portable test bench, equipped with all needed beam diagnostic devices is in progress. Due to the very intense beam and the expected fluctuation of the new high current ion sources, all relevant parameters have to be determined in one macro pulse. An overview of improved diagnostic devices are given. The pepper-pot emittance equipped with a modern CCD camera and a designed bunch-shape monitor is discussed more in detail.

1 DEMANDS FOR BEAM DIAGNOSTICS

The upgrading of the prestripper part of the UNILAC within the GSI high intensity program [1] is scheduled for spring 1999. The present Wideroe will be replaced by a 36 MHz 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 maximum specified macro pulse current of 16.5 emA for the reference particle U^{4+} of the high intensity project results in about $7{\cdot}10^8$ charges within a bunch. This corresponds to an increase in intensity of about a factor 1000 for the heavy isotopes compared to the present status. Development of new diagnostics for such high currents became essential. But there are also requirements for currents even below 100 nA for rare isotopes, which have to be monitored with the upgraded diagnostic systems.

The commissioning of the new accelerator structures including new developed ion sources [4] will be performed step by step using a transportable test bench. The beam parameters which are relevant for the performance tests are beam current, beam position, beam profiles as well as emittances in the transverse planes, beam energy, energy spread and time structure of the bunches. After the performance tests are finished most of the diagnostic elements will be installed permanently in the stripper area. Due to the high maximum beam power (217 kW pulse power for the reference particle U^{4+} behind RFQ, 730 kW behind IH1 and 1.37 MW behind IH2) and the very small penetration depth of the slow heavy ions ($\leq$ 10 μm in the prestripper area) thermal aspects of the intercepting diagnostic devices become essential [5]. Fig. 1 is a schematic drawing showing all the beam diagnostic devices and their arrangement on the test bench. In the following the improved systems will be described briefly, while the bunch shape monitor (first element at the test bench) and the single shot emittance measuring device will be discussed more in detail.

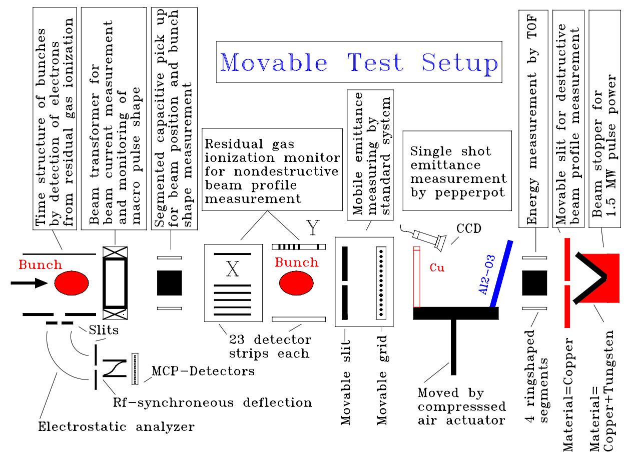

Figure 1: Schematic drawing of the transportable test bench.

2 IMPROVEMENTS OF PRESENTLY USED DIAGNOSTICS

The existing pick up system [6, 7] will be replaced by a newly designed one. Each pick up consists of 4 ring-shaped segments in well defined broadband geometry allowing measurement of position, energy and energy spread. More than 30 devices will be installed along the UNILAC beam lines. To perform position measurements the required number of charges within one bunch is about 10^7 to obtain a signal to noise ratio of S:N=1, assuming a displacement of 1 mm. With a spacing of 2 m between the two pick-ups of the test bench for determination of energy, energy spread and jitter an accuracy better than 0.2 % can be achieved.

About 30 newly developed beam transformers [6, 8] will be installed along the UNILAC. These devices cover a macro pulse current range between 400 nA and 25 mA. Besides current and pulse shape monitoring, the transformer system is provided for a fast interlock to avoid damage of accelerator components. In addition about 6 high beam power Faraday cups [5] are provided to stop the beam at well defined locations and measure currents even below 100 nA up to the maximum.

The residual gas monitor ionization for non-destructive profile measurement installed at the test bench is described in [6].

3 TRANSVERSE EMITTANCE

There will be two different emittance measuring devices at the test bench (see Fig. 1), where the slit-grid system is the transportable standard device as used at GSI since some years to test ion sources and beam transport systems. Con-

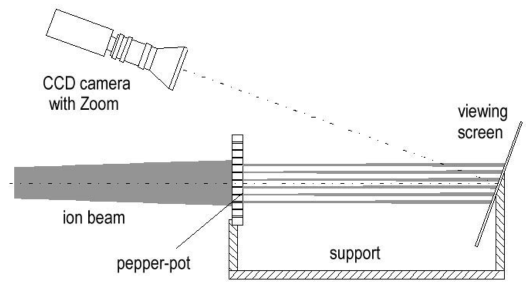

Figure 2: Schematic sketch of the pepper-pot emittance device.

sidering thermal aspects this system can be used only in the new injection area or at lower intensities, while the newly developed pepper-pot system is provided for test of the new accelerating structures up to the maximum ratings. The principle of a pepper-pot emittance-meter can be considered as an extension of the pinhole camera [9]. A schematic plot is presented in Fig. 2. There are several reasons to decide on a single shot pepper-pot system:

- For a single shot system only thermal aspects of the pulse power have to be considered.
- Any moving of apertures or detectors through the beam will result in unacceptable long measuring times. Furthermore in this case water cooling becomes necessary [5].
- Fluctuations of beam intensity and, possibly, beam emittances from pulse to pulse have to be observed to asses the performance of new types of ion sources.
- Space charge effects behind the pepper-pot plate will be smaller in comparison to a multiple-slit-detector-system.
- Depending on the accuracy which can be achieved in the determination of the 4-dimensional phase space distribution and the implemented mathematical procedures more information (e.g.coupling effects in the two transverse phase spaces) can be obtained from the data.

Based on thermal calculations [10] copper has been selected as the material of the pepper-pot plate. Due to the unknown response of the viewing screen material for heavy ions concerning light intensity, spectral distribution and decay time four different plates with hole diameters of 0.1, 0.15, 0.20 and 0.25 mm can be mounted in front of the viewing screen. Since the beam spot size has to be enlarged covering an area of about 1000-1200 mm^2 to avoid melting of the material within one pulse [5] we expect maximum divergences of about 5 mrad from emittance calculations [2, 3]. Due to geometrical limitations concerning the insertion length and to minimize space charge effects a distance of 250 mm between the pepper-pot plate and the viewing screen has been chosen. To measure divergences up to 10 mrad we decided to arrange 15 x 15 holes in a symmetric grid pattern of 2.5 mm spacing which, for a distance of 250 mm, is just the limit to avoid overlapping of the light spots. In case of larger emittances it will be possible to mount the viewing screen in a distance of 150 mm. Calibration and alignment of the system will be performed in the following steps:

- In a first step an 1.5 mW HeNe-laser ($\lambda = 543$ nm), will be installed in front of the pepper-pot housing chamber to align the pepper-pot plate and the viewing screen to the chamber axis (=beam axis) taking advantage of the small laser-spot-size of 0.8 mm.
- Then the laser beam is enlarged to a parallel beam of about 50 mm in diameter using a telescope lens system. The light spot pattern of the laser on the screen will be observed by a PC-controlled CCD-camera and stored in the PC.
- In the next step the laser has to be installed on a port perpendicular to the beam axis, a mirror looking onto the viewing screen is moved in and adjusted to respond with the same image pattern as the stored one.
- After the chamber has been installed in the final position and adjusted to the beam line. This alignment can be checked remotely each time.

To achieve a resolution of less than 0.5 mrad in divergence and 0.1 mm in the transverse coordinates a PC-controlled CCD-camera (PCO SensiCam) has been provided. The scan area of the camera is 8.6 mm x 6.9 mm which corresponds to a pixel size of 6.7 μm x 6.7 μm and 1280(H) x 1024(V) pixels. The exposure times can be varied from 100 ns-100 ms in steps of 100 ns. The focal length of the appropriate zoom lens can be varied from 15 to 150 mm. Control of the camera is performed via a 200 m long high speed serial fiber optic link.

The implementation of the application software to evaluate the pepper-pot light spot patterns which represents the 4-dimensional phase space is in progress. Clearly, each light spot will consist of a determined number of pixels depending on a given threshold for the intensity. The mathematical algorithms to extract data like the intensity distribution in the two transverse phase spaces, the rms-values of the emittance patterns as well as beam profiles and angular distributions are based on the evaluation of each pixel. Obviously, the location of each pixel on the PC-screen is related to the transverse coordinates x and y, while the position of a pixel measured relative to the location of the corresponding hole in the pepper-pot plate gives the divergences x' and y'. An appropriate software has been delivered together with the camera system to determine the intensity for each pixel. Therefore, determination of the 4-dimensional intensity distribution $I(x, y, x', y')$, which is the base to extract all the data mentioned above will be straightforward.

4 BUNCH-SHAPE MEASUREMENT

With an accelerating frequency of 36 MHz and a typical phase spread of 15^o [3] the bunch length in time will be 1.2 ns FWHM. Because of the low velocity between $\beta = 1.6\%$ (RFQ) and 5.5% (IH2) a bunch structure with at least 100

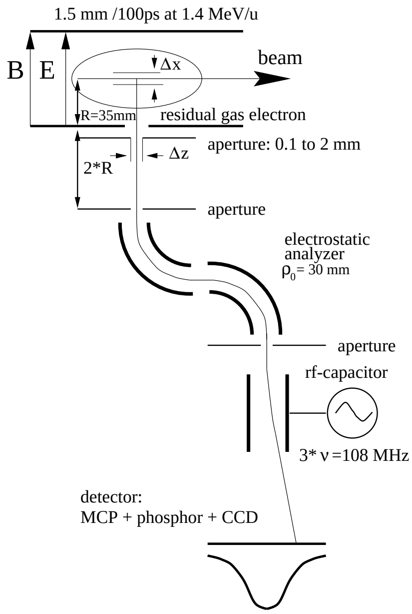

Figure 3: Schematic sketch of the designed device for the bunch length measurement.

ps time resolution cannot be measured by capacitive pick-ups. Since several years devices are available, which transform the time information of secondary electrons ejected from a small intercepting wire to spatial differences using a rf-deflector [11]. Due to the fact that a wire will not withstand the high intensity of the slow ions, a system is under development, which adapts this principle, but using secondary electrons freed from the residual gas, see Fig. 3. The secondary electrons are accelerated by a homogeneous electrical field of about 500 V/mm perpendicular to the ion beam direction, as in a residual gas monitor. To shorten the interaction length and the divergence in the direction of the ion beam, two apertures are used. The width of them can be varied by dc-motors between 0.1 and 2 mm. To restrict the detection volume of the secondary electrons in their flight direction, a cylindrical electrostatic energy analyzer with variable entrance- and exit-slits will be used with a bending radius of $\rho_0 = 30$ mm. Two similar devices are foreseen to place the electron detector perpendicular to the beam pipe. After the analyzer the time information is transferred into spatial differences by a rf-deflector running at the third harmonics. This $\lambda/4$-resonator will be manufactured at the Institute for Nuclear Research in Moscow [11]. About 50 cm downstream a 70 mm diameter MCP with a phosphor screen will be installed as the electron detector. The data will be acquired with a similar type of CCD camera used for the pepper-pot emittance.

One has to take great care for the signal distortions due to the space charge field, which can be up to 100 V/mm. To prevent the acceleration of the secondary electrons towards the center of the bunch, we will use a magnetic field parallel to the electric field; this technique is well known for residual gas monitors [12]. To get a magnetic induction of about 100 mT inside the detection volume, but a very low field outside, we use a design with rare earth permanent magnets (VACODYM 383HR from Siemens VAC). The setup uses shims at the side of the main field-creating magnets and guiding magnets rectangular to it at the soft-iron yoke. According to numerical calculations we can achieve a peak value of 96 mT with a inhomogeneity of 5 % inside the full bunch volume using only 3 to 5 mm thick permanent magnets.

We performed Monte Carlo simulations using realistic δ-electron cross sections and included the space charge effect as well as the magnetic field to simulate the resolution of the device. For a proper setting of the apertures a resolution of ± 20 ps is expected, mainly caused by the starting velocities of the electrons. But in addition there is a remaining shift of maximal 30 ps of the center of mass of the electron distribution, which depends only on the space charge. This effect is due to a deceleration of the electrons by the bunch field towards the apertures, which can not be annulled by the magnetic field. We can conclude, that time resolution (50 ps with full space charge field) is about a factor of 5 worse than the devices build by Ostroumov et al. [11], but still sufficient for our application. In addition this device is designed for high current where intercepting devices cannot be used and space charge effects have to be taken into account.

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