Beam Diagnostics for the HITRAP Decelerator

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Overview

In the six HITRAP beamtimes between May 2007 and April 2009 several diagnostic devices were used for the detection of low energy and intensity beams. The aim of the experiments was to extract the ions from the ESR into the HITRAP beam-line, and to guide it from the IH-structure to the third diagnostics chamber in front of the RFQ. The beam line from the RFQ to the Cooler TRAP and experimental area is currently still under construction [1].

The HITRAP poses three challenges:

- a single beam pulse with length of 3 µs
- a low beam intensity (in the µA region / 1E6 particles per pulse)
- a low repetition rate (1 pulse every 60 to 70 seconds),

due to which it is necessary to work with different beam diagnostic devices like Faraday-Cups (FC), scintillation screens, harp systems (SEM-profile grids) and capacitive pick-ups in different locations at the HITRAP beamline [2]. Beam current transformers are not used, because their resolution (in the µA range) is not high enough.

Hardware Setup for Faraday-Cups

The HITRAP beamline from ESR to the RFQ is currently equipped with 3 FCs in each diagnostic chamber. Current-amplifiers DHPCA-100 (FEMTO Messtechnik GmbH, Berlin) are used, offering sufficient bandwidth for the given time structure of the extracted pulse. The gain range setting is controlled by a LabVIEW application (National Instruments Co.) and a Remote-Desktop-PC at the GSI control room (CR). The analogue signals are monitored by a LeCroy 6030A oscilloscope. This oscilloscope is controlled also by the Remote-Desktop PC at the CR. The pressure drives of FCs are controlled by the standard console-program via the GSI control system.

Measurement-Results with FCs

In spite of the low HITRAP beam current, all FC-systems could detect and display adequate beam signals with a time resolution down to 100 ns depending of the gain setting of the current-amplifier . The blue trace in Fig. 1 shows the FC signal of a 1.5 µA Ne^{10+} beam pulse.

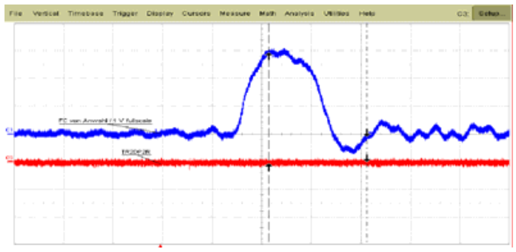

Fig. 1: FC signal (blue) recorded with 1 µs/Div and 0.5 µA/Div.; Ne^{10+}, ~1.8*10^6 particles

Hardware Setup for Scintillation Screens

To monitor beam positions and profiles, YAG scintillation screens with a diameter of 70mm are installed in the same locations as the FCs. The YAG material offers a good light yield at low energy. The screens are observed by CCD digital cameras (Marlin F033B, Allied Vision Technology) equipped with an IEEE1394 (Fire Wire) interface. The data acquisition was programmed in LabVIEW, while the Graphical User Interface is done in C++ using Qt libraries [3]. The software provides a raw image of the screen with an overlaid grid, as well as projections of the beam in horizontal and vertical direction for each camera. Fig. 2 shows an image of the scintillation screen with a beam spot, and the calculated profiles in x-/y direction. The image of the screen can be changed to B/W and false-colour display, where the latter shows more details from the YAG screen.

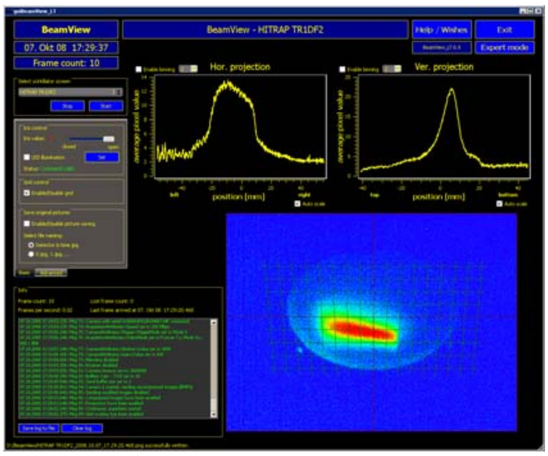

Fig. 2: Scintillation screen software – "BeamView"

A precise triggering of the digital camera allows using fast scintillation materials and the detection of short beam pulses with low repetition rate.
The pressure drives of scintillation screens are operated by standard software at the HITRAP-PC-console (CR).

Measurement-Results with Scintillation Screens

The optical system and the YAG-screens are sensitive enough to acquire reasonable images for each individual shot. The beam profile data in dependence of the quadrupole lens settings have been used to estimate the beam emittance in the HITRAP DDB section, resulting in $3 \cdot 10^{-6}$ mm mrad at 4 MeV/u, approximately.
After the decelerating IH-structure and the following dipole magnet (steerer), different energies produced in the IH-structure were detected. Fig. 3 shows two separated spots on the YAG-screen as caused by the varying energetic composition of the beam and the separation by a dipole magnet. These spots are not detectable with harp systems, or capacitive pick ups. The harps are limited in resolution because of the wire spacing. Pick-ups will not work correctly if the beam has different energies. So the scintillation screens are very important for HITRAP operating, and they were used extensively during the last beamtimes.

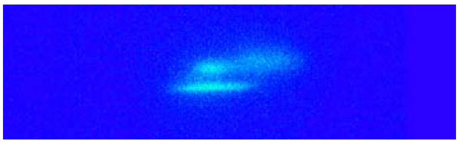

Fig. 3: Image for a scintillation screen behind the IH-structure and dipole magnet. The image shows two beam spots with 2.3 MeV/u (top) and 4 MeV/u (below); Ion species was Ne^{28+}.

Hardware Setup for Harp Systems

In addition, three secondary electron emission harp systems (SEM-grids) are installed in the same three diagnostic chambers as the FCs and the scintillation screens.
The harp systems are operated via the GSI control system and standard software. One big advantage of the harps is that they offers a transmission of about 93% as given by the wire spacing of 1.5 mm and the wire thickness of 0.1 mm, Therefore, it is possible to do measurements at different locations at the same time.

Measurement-Results with Harp Systems

Fig. 4 shows a measurement with all harps at HITRAP at the same time. Harp 1 is on the top of this Figure and in the first diagnostic chamber of the HITRAP beamline.

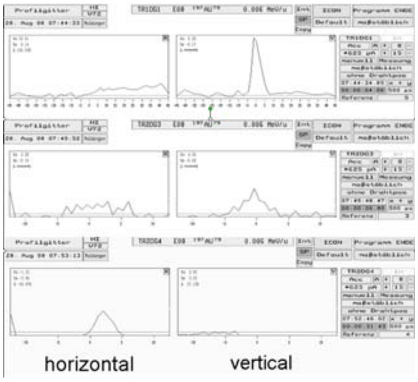

Fig. 4: Beam profiles, measured in August 2008 (Au^{79+}), taken in the lowest range (625pA, "Soft"-zoom)

Harp 2 is in the middle. Harp 3 is after the IH-structure and here in the bottom part of this Figure. The beam passes the first harp (number 1, top) and then through the second harp (middle) and the third harp (number 3, below). The result shows that the measurement with harps is not very practical in the HITRAP lattice. The intensities were too low, and the operating was heavily affected and therefore the screens, which shows sufficient signal strength are used in most cases.

Hardware Setup for Tubular Pick-up

A capacitive "tubular" pick-up is used in front of the first buncher, for monitoring the time structure of the extracted beam from the ESR.
The signal cable is routed directly to a high impedance amplifier (1MOhm, 150 MHz bandwidth, HVA-S, FEMTO). The amplifier's output is displayed on a single oscilloscope channel. This oscilloscope is as well controlled via remote desktop connection from the CR.

Measurement-Results with Tubular Pick Up

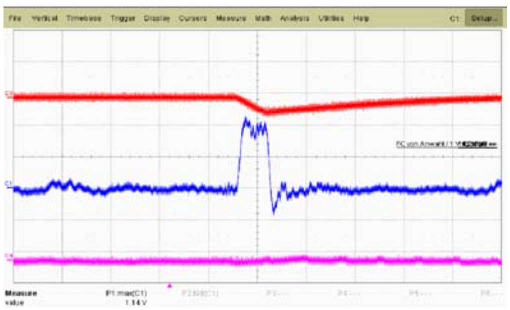

Fig. 5: Tubular pick up signal (red trace), with FC-signal (blue trace); the beam grazed the pickup's electrode.

Usually, the tubular pick up shows an output signal similar to a FC, but Figure 5 shows that this did not happen. The reason is, that the ring plate was hit directly by secondary electrons.

Hardware Setup for Ring Pick Ups

After bunching the macro-pulse passes a first "time of flight" (TOF) measurement section, consisting of two successive capacitive pick-ups with 50 Ω termination, suited for the 108 MHz bunch frequency. The second TOF measurement section is located behind the decelerating IH-structure. Signals from bunchers and pick-ups are displayed simultaneously and time-correlated by a LeCroy 6100A oscilloscope.

Measurement-Results with Ring Pick Ups

The operating was affected by the insufficient characteristics of the pick up system. In the beamtime of Oct. 2008 the TOF measurements were possible, but it was necessary to activate the averaging mode of the oscilloscope. Figure 6 shows an image of the oscilloscope screen with typical output signals from two pick-ups.

The signal could only be detected by averaging of 6 measurements, resulting in a waiting time of about 7 minutes. For an effective operating this is not useful.

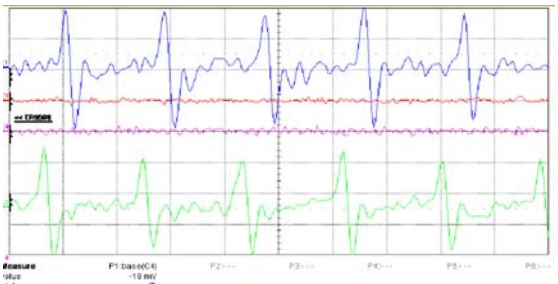

Fig. 6: Pick-up signals after averaging of 6 measurements at a time; the time scale was 5 ns/div and 20 mV/div, the beam current was ~1.5 µA.

Unfortunately, in most of the cases measurements were not possible with the ring pick-ups. Two typical and noisy signals of the pick-ups are shown in Figure 7. Several different attempts to achieve a signal like in Figure 6 were not successful. It is assumed that the signal/noise ratio was too low due to cable losses and mixture of different energies and non-uniform beam delivery.

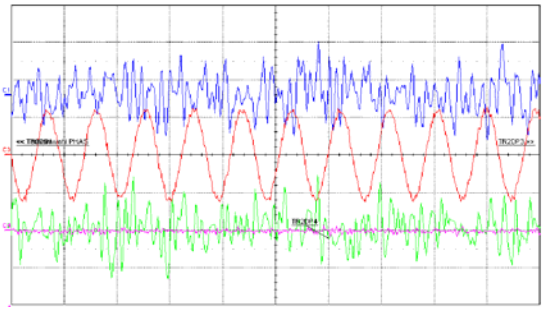

Fig. 7: Pick-up signals (blue and green trace). The red trace is the RF-reference. The time scale was 10 ns/div and 20 mV/div,

Summary and Outlook

Low energy and intensities were measured successfully with the FCs. A calculation of the particle transmission and time-resolved measurements were possible.

In addition, the scintillation screens were very helpful, and essential for operating. The detection of beam position was possible down to 300nA beam current and short (< 2us) beam pulses.

The TOF-measurements are very important for operating, but the sensitivity of these devices is presently not high enough.

In March 2010 the next beamtime will be launched.

At the moment the beam diagnostic department works on some upgrades of the different pick-up devices. One suggestion is to reduce the length of the tubular pick-up.

For the 50 Ω impedance pick-ups low noise pre-amplifiers between devices and transmission lines are foreseen, which will improve the signal/noise-ratio by 6dB.

References

[1] O. Kester et al., GSI-Scientific Report 2007.

[2] Beam Diagnostic for HITRAP, GSI-Scientific Report 2007; C Andre, et al.; Page 106

[3] R. Haseitl et al., Proc. DIPAC 2009, Basel p. 134 (2009).