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NONDESTRUCTIVE DIAGNOSTICS OF ACCELERATED ION BEAMS WITH MCP-BASED DETECTORS AT THE ACCELERATOR COMPLEX NICA. EXPERIMENTAL RESULTS AND PROSPECTS

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Abstract

Non-destructive ion beam detectors based on microchannel plates are presented. The design of two-coordinate profilometer situated in the high vacuum volume of the Booster ring is discussed. Experimental data on registration of circulating beam of the Booster in the second run (September 2021) are presented. The possibility of adjustment of the electron cooling system with the help of this detector based on the obtained experimental data is discussed.

INTRODUCTION

Obviously, development of nondestructive diagnostic systems for both circulating and extracted beams is one of the most important tasks at the acceleration complex NICA [1]. One can speak of nondestructive systems of two types: the first one registers electromagnetic radiation, and the second one registers interaction of beam ions with molecules of residual gas in the vacuum chamber of the accelerator.

This paper considers some first results of operation of the nondestructive diagnostic system implemented at the Booster put in operation at the end of 2020. This diagnostic system provides registration of the space-time beam structure directly inside the Booster vacuum chamber at the input point from HILAC.

A similar system is situated in the Nuclotron ring and at the extracted beam line of Nuclotron (see Fig. 1) [2, 3, 4, 5].

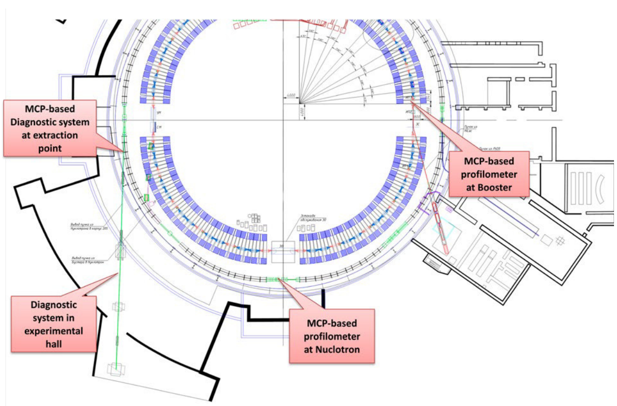

Figure 1: Schematic diagram of diagnostic system locations at the Booster and Nuclotron.

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NUMERICAL STUDY OF MCP-BASED DETECTOR

The drawing of the MCP-based profilometers mounted inside the chamber is shown in Fig. 2.

This detector geometry implemented in the Booster chamber was used in the software CST for simulation of the detector operation.

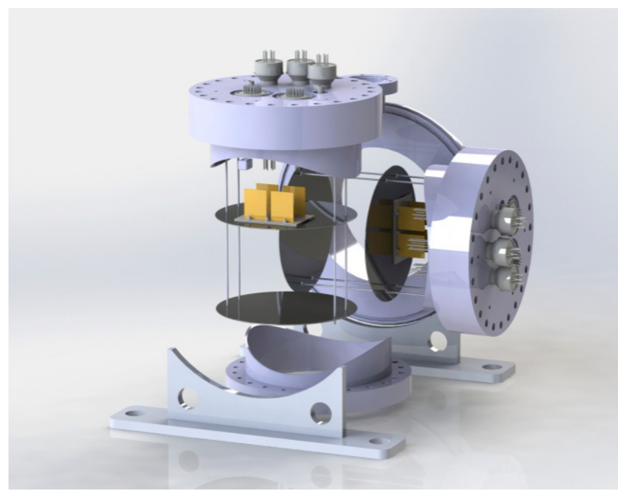

Figure 2: Assembly drawing of MCP-based profilometers mounted on vacuum flanges.

CST is designated for simulation of a wide range of electromagnetic interactions, including construction of electrostatic models and charged particle tracking in simulated fields. The study presented here used the solvers "E-Static" and "Particle Tracking" of the module "Statics and low frequency" CST. The real geometry of the existing detectors was input in the simulation.

The physics of the simulated processes is as follows. accelerated charged particles, passing the ion beam line, ionize residual gas. The number of ions produced in unit volume is proportional to the beam intensity, residual gas pressure, and squared ion charge. These ions are accelerated by electrostatic field toward the chevron assembly of the MCP detector and are registered by the detector to give the space-time parameters of the beam.

In the simulation, ionized particles were distributed uniformly over the whole detector volume and their trajectories were traced in the electrostatic system of the detector. It was found out that the electrostatic systems of the X and Y profilometers distort the electrostatic field and, as a consequence, ion trajectories inside the vacuum

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chamber. The shape of electrodes was specially adjusted numerically in order to reduce this distortion. The repulsive electrode was bent with a radius of 180 mm from the center at an angle of 45° to the beam axis; the cuts for plate fastening and detectors were shifted by 20 mm along the beam from the center of the unit. Also, the special absorbers in the form of rectangular plates along the beam axis were added to the electrostatic system of detector. These absorbers cut off ions produced beyond the working region of the detector; the working voltage at the absorbers was 2.2 kV. The detectors used at the Booster were manufactured according to this numerically found optimal shape.

The detector resolution was also determined in the simulation as the root mean square deviation of the coordinate calculated for all tracks. The resolution in both X and Y directions was found to be not worse than 0.3 mm.

MEASUREMENTS OF BEAM SPATIAL DISTRIBUTION WITH MCP-BASED DETECTOR

The photo of the MCP-based detectors used at the Booster is shown in Fig. 3.

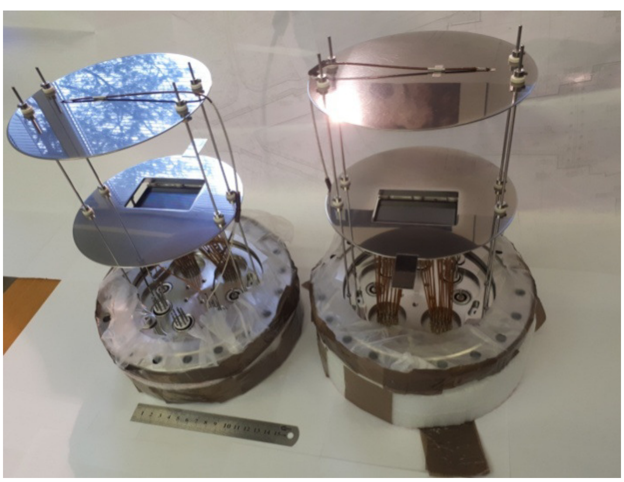
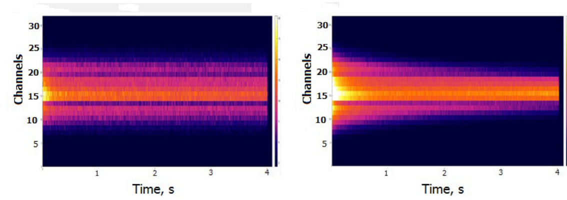


Figure 3: Photo of the two MCP-based detectors installed at the Booster for X and Y profile measurement.

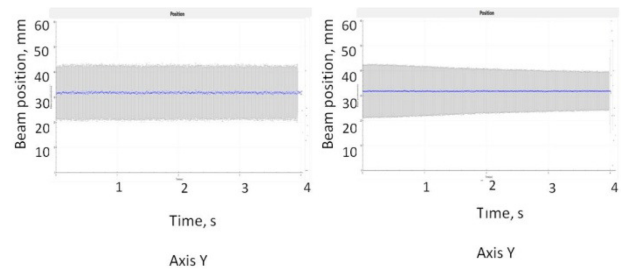
The electron cooling system of the Booster beam was tested in run 2 (September, 2021). The MCP-based detectors shown above were installed at the Booster and used in this run for beam diagnostics. The detector system provided measurement of the beam profile in the X and Y directions. The electron cooling system was tested in the course of injection with $^{14+}$Fe beam. The electron velocity corresponding to the velocity of beam ions was about 1.85 keV.

The plots below: Fig. 4, Fig. 5, and Fig. 6 show the dynamic profile of the beam with and without the electron cooling system. It can be seen that the electron cooling has a noticeable beam narrowing effect.



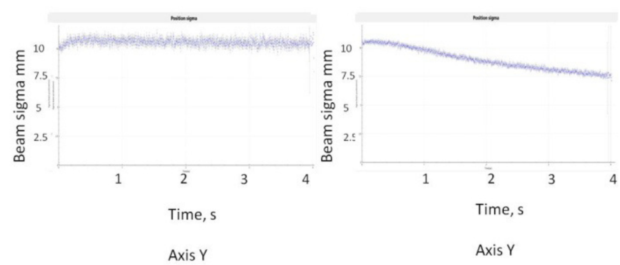
(a) (b)

Figure 4: Y profile of 14+Fe beam as a function of time: (a) without electron cooling; (b) with electron cooling. The working electron cooling voltage is 1.83 keV.



(a) (b)

Figure 5: Y position of $^{14+}$Fe beam as a function of time: (a) without electron cooling; (b) with electron cooling. The working electron cooling voltage is 1.83 keV.



(a) (b)

Figure 6: Dispersion of $^{14+}$Fe beam as a function of time: (a) without electron cooling; (b) with electron cooling. The working electron cooling voltage is 1.83 keV.

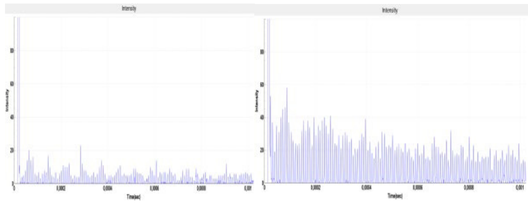
Similar results were obtained for both X and Y directions at different electron beam energies and currents.

MEASUREMENTS OF TIME RESOLUTION WITH MCP-BASED DETECTOR

It was already shown earlier [6] that the MCP-based detector is capable of measuring first turns and even the beam structure within one beam revolution.

Figure 7 shows the beam dynamics for the first 125 turns of the beam after injection measured in run 2 of the Booster, which corresponds to a time slice of 1 µs.

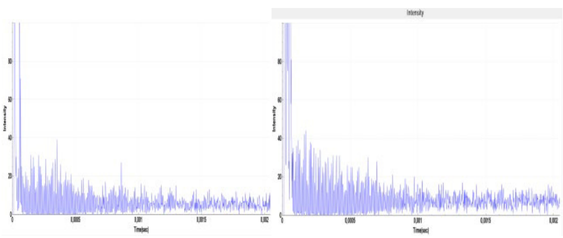
Regular beam oscillations in the transverse direction with a frequency of about 12 kHz can be clearly observed.



(a) (b)

Figure 7: $^{14+}$Fe beam intensity as a function of time immediately after injection in run 2 of the Booster: (a) along X (horizontal); (b) along Y (vertical).

Figure 8 shows the beam dynamics for the first 250 turns of the beam after injection measured in run 2 of the Booster. It can be clearly seen that the above mentioned oscillations die out after the first hundred of turns.



(a) (b)

Figure 8: $^{14+}$Fe beam intensity as a function of time immediately after injection in run 2 of the Booster: (a) along X (horizontal); (b) along Y (vertical).

This illustrates the potential of application of this detector for adjustment of injection and optimization of the beam capture in acceleration cycle at the initial stage of acceleration.

The data acquisition system for these detectors is based on the electronic module TIC-64 developed by our team. This module represents a counter with buffer memory based on FPGA. This module, with a synchro-pulse from the accelerator, remotely sets the time delay for measurements and records pulse counts in 64 channels with given time intervals from hundreds ns to seconds.

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