EMITTANCE MEASUREMENTS OF POLARIZED ION BEAMS USING A PEPPER-POT EMITTANCE METER

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Abstract

A Source of Polarized Ions (SPI), developed at JINR, produces pulsed beams of polarized protons and deuterons for NUCLOTRON accelerator. The accelerated polarized ion beams will be injected into future NICA collider. In order to reconcile requirements of a RFQ fore-injector of the Alvarez type linear accelerator LU-20, it is necessary to measure a transverse emittance of the ion beams produced by the SPI. The emittance of beams of polarized deuterons and polarized protons was measured by the pepper-pot method. The results of measurements of the emittance and profile of the polarized ion beams are presented.

INTRODUCTION

The NICA (Nuclotron-based Ion Collider fAcility) is accelerator facility, which is now under construction at Joint Institute for Nuclear Research (JINR, Dubna) [1]. A study of spin physics with extracted and colliding beams of polarized deuterons and protons at the energies up to 12.6 GeV (for protons) is foreseen with the NICA facility. A proposed program allows to search for possible signs of the nuclear matter phase transitions and critical phenomena as well as to shed light on the problem of nucleon spin structure [2].

Initially, it was intended to use the Alvarez-type linac LU-20 as an injector for light ions, polarized protons and deuterons for NUCLOTRON and NICA accelerator complex. Now a possibility of LU-20 replacement by a new linac of 30 MeV energy for protons and ≥7.5 MeV/nucleon for deuterium beam is discussed. SPI has been developed at JINR as a source of polarized protons and deuterons for the LU-20 injector. The maximum permissible emittances of the beam at the input to the RFQ-based for-injector, are 4 π mm mrad for q/A= 1 and 2 π mm mrad for q/A= 0.5 [3]. To match the output beam from the SPI source with the injector acceptance, it is necessary to measure the emittance of the source.

Source of Polarized Ions

The SPI is an atomic beam-type polarized ion source with nearly resonant charge-exchange plasma ionizer and storage cell in the charge-exchange region [4]. Schematic diagram of the SPI is shown in Fig. 1.

The main parts of the source are the atomic beam section (on the left in Fig. 1), the plasma ionizer (on the right in Fig. 1) and the spin rotator [5]. The atomic beam section includes a pulsed RF discharge dissociator of molecular hydrogen or deuterium, sextupole separating magnets and RF transition units to get the nuclear polarized hydrogen or deuterium atomic beam.

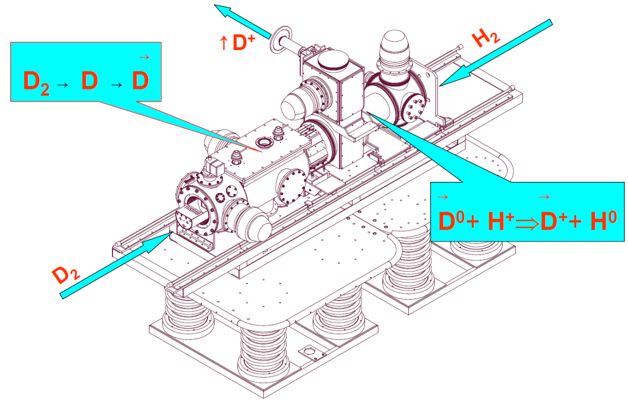

Figure 1: SPI source.

Polarized deuterons or polarized protons are produced in the source via nearly resonant charge-exchange in plasma between polarized atoms and unpolarized ions of the isotope relatively the polarized atoms:

$$H^0 \uparrow + D^+ \to H^+ \uparrow + D^0,$$
$$D^0 \uparrow + H \to D^+ \uparrow + H^0.$$

The polarized ions then accelerated to the energy of 25 keV together with unpolarized plasma ions. Spin rotator extraction system include: 90^0 bending magnet, electrostatic Einzel lens, 90^0 electrostatic deflector and output spin precessor solenoid. In the spin rotator extraction system polarized ions change the spin orientation from horizontal to vertical, separate from unpolarized plasma ions and are extracted from the source by turning first in a vertical direction by magnet and later deflecting in the horizontal plane by an electrostatic deflector.

The source worked in pulsed mode with repetition rate of 0.2 Hz and pulse duration of ~100 μs.

EXPERIMENTAL SETUP

The emittance meter was mounted on the output flange of the SPI source (see Fig. 1, near $\uparrow D^+$ row). The emittance meter is a pepper-pot meter device [6]. Its main parts are a copper mask with a pattern of holes, and a scintillator behind it. Both the mask and the scintillator are

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mounted together within a vacuum chamber (Fig. 2) on a rod of linear vacuum feedthrough.

The copper mask receives an input ion beam from the source, and the holes in the mask break the beam on the set of beamlets, which hit the scintillator and produce a flash of light from it.

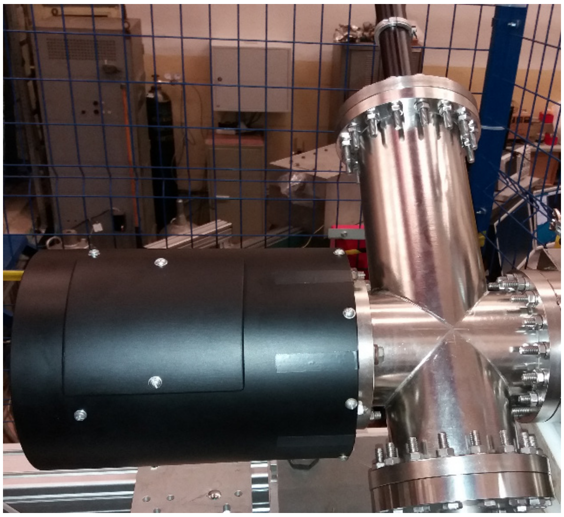

Figure 2: Emittance Meter.

The scintillation pattern consists mainly of a set of spots, and it is recorded by the VCD camera through a glass window on the opposite side of the vacuum chamber. The VCD camera, which registers light from the scintillator, is mounted inside the external light shield on the beam axis, outside the vacuum chamber. Due to the fact that the output flange of the SPI source does not completely coincide with the input flange of the emittance meter, the emittance meter is rotated 11° counterclockwise.

Common parameters of the emittance meter, the measurement procedure and the emittance calculation sequence are presented in [6]. Notable emittance meter parameters, specific for this series of measurements and not listed in [6], are: distance between a copper mask and a scintillator is 16 mm; the distance from the output flange of SPI to the plane of the mask is 90 mm; VCD camera parameters: exposition is 7-10 ms, gain is 500.

MEASUREMENT MODES AND RESULTS

Measurements were made for two types of polarized ions: deuterons and protons. For each case, measurements were first made for background unpolarized ions, and then for polarized ions together with background ions.

For polarized deuterium ions $\uparrow D^+$, non-polarized ions of molecular hydrogen H_2^+ from a plasma ionizer were background. The mass of molecular hydrogen ions (2 protons + electron) differs from the mass of the polarized deuterium ions (proton + neutron) by only 0.04%, so they can't be separated by the bending magnet, and are present in the output beam together with polarized deuterium ions $\uparrow D^+$.

In the case of polarized protons $\uparrow H^+$, the bending magnet can separate the polarized beam from the unpolarized H_2^+ ions and unpolarized deuterium ions D^+. The background ones in this case are unpolarized protons H^+, which are extracted from the deuterium plasma of the ionizer and arise, for example, due to ionization of water vapor and other hydrogen-containing molecules of the residual gas.

Table 1 shows typical values of the ion pulsed current for that 4 measurement modes.

Table 1: Typical Values of the Ion Pulsed Current

Beam composition	H_2^+	$H_2^+ + \uparrow D^+$	H^+	$H^+ + \uparrow H^+$
Output Beam Current (pulse peak value), mA	3.6	6.5	1.0	3.3

$\uparrow D^+$ *Measurements*

Beam profiles for background molecular hydrogen ions and polarized deuterium ions are shown in Fig. 3.

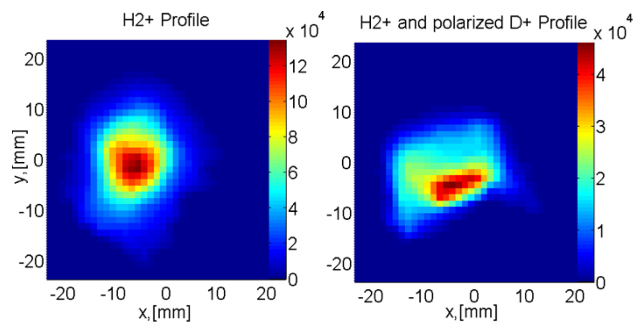

Figure 3: Background and polarized ions profiles.

For each ion type, the profiles were plotted from images on a scintillator averaged over a number of measurements. The images of the profiles in the coordinate system orthogonal to the Earth's surface are recalculated due to the rotation of the emittance meter by 11^0. Note that the intensity of the scintillator radiation from the background beam consisting only of molecular hydrogen (with a current of 3.6 mA) is higher than the intensity of the scintillator radiation from the beam with both types of ions: polarized deuterium and molecular hydrogen (with a total current of 6.5 mA), with equal parameters of the emittance meter. A higher radiation intensity for lighter nuclei is a typical case for a given scintillator material.

Figure 4 shows images of beams of background and polarized ions in x-x' phase space.

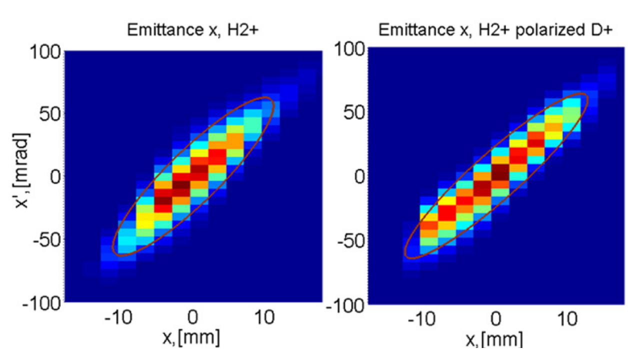

Figure 4: Background and polarized ions emittances.

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In each series of measurements, it was found that the beam occupies one of two stable positions on the screen of the scintillator. Each of the positions was fixed for several pulses in a row, an average of 15 pulses for one of the stable positions and 3 pulses for the other. Figure 4 shows single-shot images of beams in phase space, taken from series with a larger number of pulses.

$\uparrow H^+$ *Measurements*

The beam profiles for polarized protons and background unpolarized protons are shown on Fig. 5.

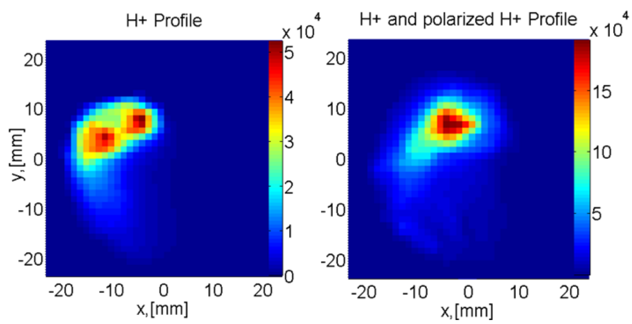

Figure 5: Background and polarized protons profiles.

Note that for identical types of ions, the total beam has a higher radiation intensity than the background one.

Figure 6 shows the images of polarized protons and background unpolarized protons on the x-x' phase space.

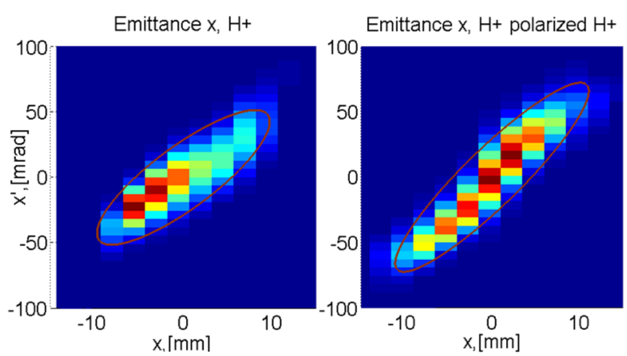

Figure 6: Background and polarized protons emittances.

CONCLUSION

Table 2 summarizes the measurement results.

Table 2: Results of Emittance Measurements

Measurement type	H_2^+	$H_2^+ + \uparrow D^+$	H^+	$H^+ + \uparrow H^+$
Emit_x norm, 4rms, π mm mrad	1.68	1.63	2.12	2.48
Emit_y norm, 4rms, π mm mrad	1.89	1.53	2.86	3.12
Twiss params: α_x	-1.98	-2.57	-1.58	-2.26
Twiss params: β_x, mm/mrad	0.39	0.56	0.35	0.38
Twiss params: α_y	-2.57	-2.23	-2.73	-3.62
Twiss params: β_y, mm/mrad	0.50	0.29	0.46	0.67
Beam size σ_x, mm	7.56	10.26	8.18	8.06
Beam size σ_y, mm	7.47	6.83	5.11	9.74
x beam position, mm	-6.88	-6.56	-10.2	-5.60
y beam position, mm	0.19	1.50	-3.74	0.36

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