POLARIZED DEUTERONS AT THE JINR ACCELERATOR NUCLOTRON

Yu.K. Pilipenko, S.V. Afanasiev, L.S. Azhgirey, A.Yu. Isupov, V.P. Ershov, V.V. Fimushkin, L.V. Kutuzova, V.F. Peresedov, V.P. Vadeev, V.N. Zmirov, L.S. Zolin and A.S. Belov[a]

Joint Institute for Nuclear Research, Dubna,
(a) *Institute for Nuclear Research RAN, Troitsk.*
† *E-mail: pilipen@sunhe.jinr.ru*

Abstract

The spin physics program is an important part of the LHE JINR scientific program. An intensive study of polarization phenomena was carried out at the Dubna 4.5 Gev/nucl. synchrophasotron, using cryogenic source of polarized deuterons ($\uparrow D^+$) POLARIS and some polarimeters. The commissioning of the new superconducting accelerator Nuclotron supposes to continue the spin physics program. There is a project to make an intensive polarized deuteron beam in the new accelerator. The Nuclotron has a short one-turn injection (8 μs) of positive ions at present. To increase the intensity of the accelerated polarized beam up to 0.7-1*$10^{10}\uparrow$d/pulse the source POLARIS is reconstructed into the $\uparrow D^-$ source and multyturn charge exchange injection of negative ions (20-30 turns) will be applied. Simulation shows that depolarizating resonances are absent under polarized deuteron acceleration almost at all energy range of the machine. A test run has been done at the Nuclotron using the existing $\uparrow D^+$ source POLARIS to check the polarization of low and high energy beams. The vector polarization of the deuteron beam behind the 10 MeV linac, inside accelerator ring and after beam extraction are conformed. The source design, setup parameters and results of the polarization measurements are presented.

1. $\uparrow D^+$ source POLARIS

An intensive study of polarization phenomena in high energy spin physics was carried out at the Dubna 10 GeV synchrophasotron using the cryogenic polarized deuteron source POLARIS [1,2,3]. It is the cryogenic atomic beam source with two tapered sextupole superconducting magnets, SC solenoid, internal 4.2 K cryopanels for gas pumping. The source POLARIS consists of two LHe cryostats: a pulsed atomic beam stage and the Penning plasma ionizer. A new pprmanent sextupole magnet (inside bore - 30 mm, l- 60mm) is planned to install behind the SC sextupoles for additional focussing of the atomic beam. The energy of the deuteron beam at the output of the source is about 3 keV,the current: 0.3-0.4 mA. The vector and tensor polarizations are: P_z=±0.54; P_{zz}=±0.76.
The commissioning of the new superconducting accelerator Nuclotron supposes to continue the spin physics program. Simulation shows that depolarizating resonances are absent under polarized deuteron acceleration almost at all energy range of that accelerator [4]. There is a project to produce a polarized deuteron beam. In this project it is

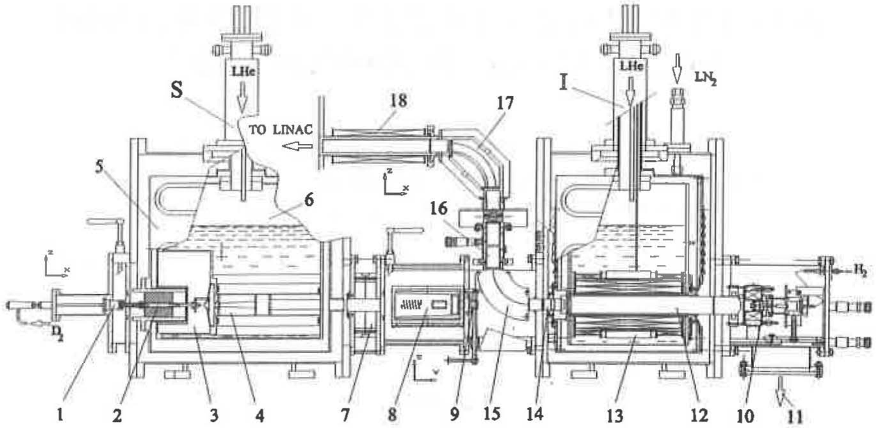

Figure 1: Schematic view of the polarized deuteron source POLARIS. S - polarized atomic source, I - charge exchange ionizer. 1- pulsed D_2 valve, 2- dissociator, 3- nozzle chamber, 4- SC sextupole magnets, 5- nitrogen shield, 6- helium cryostat, 7- permanent sextupole, 8- RF cell, 9- vacuum gate, 10- H^- plasma generator, 11- two 500 l/s turbopumps, 12- HV charge exchange space, 13- SC solenoid, 14- extraction electrodes, 15- 90^0 bending magnet, 16- ion optics, 17- electrostatic mirror, 18- solenoid of spin-precessor.

supposed to realize the following:
- to upgrade the atomic stage of the source POLARIS,
- to modify the existing $\uparrow D^+$ charge exchange ionizer into the $\uparrow D^-$ ionizer,
- to realize multyturn charge exchange injection in the Nuclotron ring.

2. Charge Exchange Ionizer

The new machine Nuclotron has a short one turn injection (8 μs) of positive ions (factor 50 less compared to the old one). So to get a large intensity of the accelerator a new plasma charge exchange ionizer has been developed [5,6,7] (Fig.1). It has similar the Penning ionizer LHe cryostat with the 60 mm cold bore SC solenoid. A short pulse (300 μs) H^+ arc plasma generator is installed at the solenoid entrance. The potentials of the plasma source and the HV shield are +12 kV. A nuclear polarized deuterium atomic beam is injected into the solenoid space towards the plasma beam. The charge exchange reaction between polarized deuterium atoms and hydrogen plasma ions $\uparrow D^0 + H^+ = \uparrow D^+ + H^0$ takes place inside the HV shield.
Using POLARIS atomic beam stage, the 0.8 mA polarized D^+ beam, accompanying the 9 mA background H_2^+ plasma current have been measured behind a 90^0 bending magnet output of the charge exchange ionizer. An efficiency of the new ionizer was 3-5% instead of 1-2% for the our old Penning ionizer.
Vacuum in the ionizer is provided by cryopumping. Hydrogen vapor pressure at 4.2 K cryostat is 2-4*10^-6 mbar. Two 500 l/s turbopumps are installed at the plasma generator region to reduce hydrogen gas load to the cryostat.

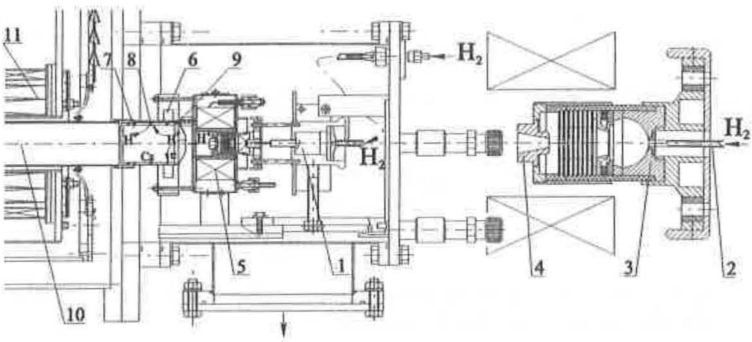

Figure 2: H^- plasma generator. 1- pulsed H_2 valve, 2- H_2 tube and ignition electrode, 3- Cu cathode, 4- anode, 5- magnetic coil, 6- traverse magnetic filter, 7- molybdenum converter, 8- heater, 9- Ti-Cs pellet volume, 10- HV charge exchange shield, 11- SC solenoid.

To reach the accelerated polarized beam intensities up to 0.7-1*10^{10} $\uparrow$d/pulse a multyturn charge exchange injection (20-30 turns) should be applied. It is realized by injection into the Nuclotron ring of $\uparrow D^-$ ions and stripping them inside the ring. A polarized $\uparrow D^-$ beam from the source is required.
The existing D^+ plasma charge exchange ionizer has been modified into $\uparrow D^-$ ionizer using an external converter-emitter [7,8,9]. At output of the H^+ plasma generator, a molybdenum surface converter is placed to produce H^- ions (Fig.2). Titanium-cesium chromate pellets are loaded into an O-ring groove of the converter and heated up to 300-500^{0}C. Cesiated molybdenum surfaces of the converter are exposed to an intense flux of superheated hydrogen atoms, positive ions and effectively generate H^- ions.
Fast plasma electrons, accompanying H^+ plasma beam, are removed by a 150 Gs transverse magnetic field of a permanent magnet, to avoid of H^- ion destruction. H^- ions, generated inside the converter, space charge compensated by residual H^+ ions, are entered axial region and fill up a charge exchange volume of the HV shield (-20 kV). The reaction $\uparrow D^0 + H^- = \uparrow D^- + H^0$ takes place. Polarized negative deuterium ions, confined in the radial direction by magnetic field of the solenoid, drift to the extracting grid. The 90^0 bending magnet separates accelerated H^- plasma and polarized $\uparrow D^-$ ions.
Reconstruction of the ionizer cryostat is finished, cryogenic tests were started. A study of the surface conversion technology H^+ to H^- ions takes place simultaneously. Some configurations of the H^+ generator and molybdenum converter have been tested. A test bench ionizer with a sectioned conventional solenoid was used to exclude cryogenic and to have mobile runs. In time of the plasma generator tests were modified:

- converter diameter (32-45 mm), cone shape ($60^0, 180^0, 120^0$), length (50-90 mm),
- plasma source magnetic coil length (23-44 mm),
- arc discharge configuration space (cathode, divider plates, preanode volume),
- filter magnetic field (150-250 Gs),
- extraction electrode configuration,
- arc discharge feeding scheme (inductive pulse or direct capacitor discharge).

About 0.1 cm^3 H_2 gas at pressure 0.5-1.2 bar is injected into a hollow cathode space by a

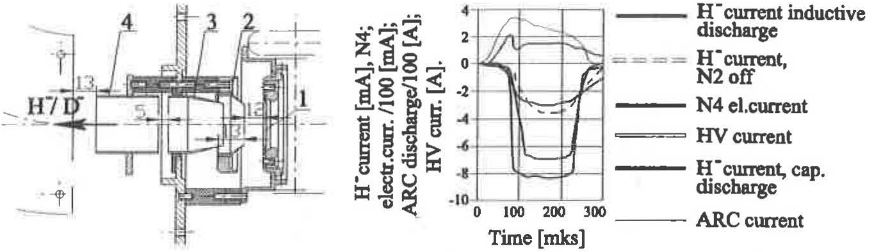

Figure 3: Scheme of test bench extraction electrodes and H^- current pulses behind bending magnet. 1- HV plasma wire mesh, 2,3,4- electrodes.

fast thyristor triggered valve. High current arc discharge and H^+ plasma beam are started in the 0.9 ms due to ignition pulse. High voltage power supply sends acceleration pulse to the charge exchange shield, plasma generator, converter and H_2 valve simultaneously. The coils of the solenoid, bending magnet and plasma generator have been pulse too.

A scheme of the extraction electrodes is shown on Fig.3. Extraction of positive and negative ions from the charge exchange space are different for the same acceleration voltage (U_{acc}=12-17 kV). An extraction grid length of positive ions is short (two fine wire mesh, with gap 4-6 mm) and required strong electrical field gradient (3-4 kV/mm). Extraction electrodes (N2,N3) for negative ions have a cone shape. The first electrode gap is 12-15 mm and optimal gradient is about 0.5 kV/mm. A changing of the N2 electrode potential from 0 to -9 kV is heighten H^- current double from 4 to 8 mA. H^- current pulse is raised if two middle sections of the solenoid magnetic coils are tuned. A capacitor discharge scheme of the arc feeding is preferable. Duration of the plasma current pulse is about 200 μs in that case. It is correspond to 25 turns of the injected beam. H^- currents at the output of 90^0 bending magnet, electron current of the N2 electrode and total current of the HV power supply are shown on Fig.3.

A conditioning of the converter surfaces and theirs covering by Cs are very important. There is small H^- current (0.2-0.5 mA) accompanying large quantity of plasma electrons first time after installation. The current is slowly raised with time. It is depend on arc voltage, pulse frequency, clean vacuum, converter temperature, Cs covering. Quantity of the injected gas strongly influences on the negative current value. Surface activation process takes place in a pulse time while an adsorption of residual gas molecules occur between pulses.

The 10 mA H^- current was observed at the frequency 0.3 pulse/s. It is expected to get the larger current in real ionizer configuration, using cryostat with SC solenoid and cryopumping. Estimation shows, 0.3-0.5 mA $\uparrow D^-$ polarized beam should be got, using POLARIS atomic stage.

The plasma charge exchange ionizer of the polarized source has another important feature. It can be used as the intensive source of unpolarized proton or deuteron beams (10-20 mA). In that case the bending separation magnet is adjusted not for polarized but for the plasma beam.

Development of the ionizer will be continued.

3. Test run at the Nuclotron

Simulation shows that depolarizating resonances are absent under polarized deuteron acceleration almost at all energy range of the machine [4]. A special test run have been done at the Nuclotron using the existing $\uparrow D^+$ source POLARIS with Penning ionizer to check the polarization of low and high energy beams during acceleration.

The results of measurements are:

		Pz (1-4)	Pz (3-6)
1. Beam polarization measured behind the linac		- 0.56+/-0.07	0.62+/-0.07
2. Internal target measurements	at 3.5 GeV/c	-0.58+/-0.04	0.59+/-0.04
	at 5.0 GeV/c	-0.56+/-0.03	0.60+/-0.03
3. Polarization of the extracted beam			
	at 3.5 GeV/c	-0.54+/-0.02	0.56+/-0.02
	at 5.0 GeV/c	-0.66+/-0.02	0.60+/-0.02

The vector polarization of the deuteron beam is saved during an acceleration and conformed by all polarimeters.

As expected, the intensity of the polarized deuteron beam in one turn injection mode is observed as $1.3*10^8$ $\uparrow$d/pulse. The charge exchange multyturn injection is required.

Acknowledgments:

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