POLARIZED DEUTERONS AT THE NUCLOTRON [1]

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.Zhmyrov, L.S.Zolin

Joint Institute for Nuclear Research, Dubna
† *E-mail: pilipen@sunhe.jinr.ru*

Abstract

The first acceleration of polarized deuterons was done at the accelerator nuclotron since the old machine synchrophasotron has been shutdown. Simulation shows that depolarization resonances are absent under polarized deuteron acceleration almost at all energy range of the machine. The $\uparrow D^+$ source POLARIS was used. The polarization of the beam was measured by some polarimeters: at the exit of the 10 MeV linac, inside the accelerator ring and after the beam extraction. The high vector polarization value of the deuteron beam during acceleration conformed by all polarimeters. Its measured Pz as: - 0.56 and + 0.62. The intensity of the polarized deuteron beam in a short one turn injection mode (8 μs) is observed as $1.3{*}10^8\uparrow$d/pulse. To increase the intensity of the accelerated polarized beam up to $0.7\text{-}1{*}10^{10}\uparrow$d/pulse a multyturn charge exchange injection of negative ions (20-30 turns) should be applied. The polarized $\uparrow D^-$ ion source is required. The existing $\uparrow D^+$ source POLARIS is reconstructed into the $\uparrow D^-$ source. New plasma $\uparrow D^-$ charge exchange ionizer developed and tested. The source design and first results of the beam 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 during last 20 years. In fall of 2002 last polarized beam run has passed before that historical machine was shutdown. All that time cryogenic source POLARIS was used to produce polarized deuteron beam [1,2,3]. It was design at the end of 1970-ies, when turbopump oilfree technology hasn't been developed yet. The source atomic beam forming process is required to pump a large mass of injected gas. It was decided insted of conventional pumping to apply cryocondensation of deuterium molecules on cooled surfaces. POLARIS is compact atomic beam source with internal 4.2 K surfaces for effective gas cryopumping, cold nozzle, superconducting magnets. It is consists of two LHe cryostats:

- a pulsed atomic beam stage with two superconducting sextupole magnets,
- the Penning plasma ionizer with high field SC solenoid.

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.

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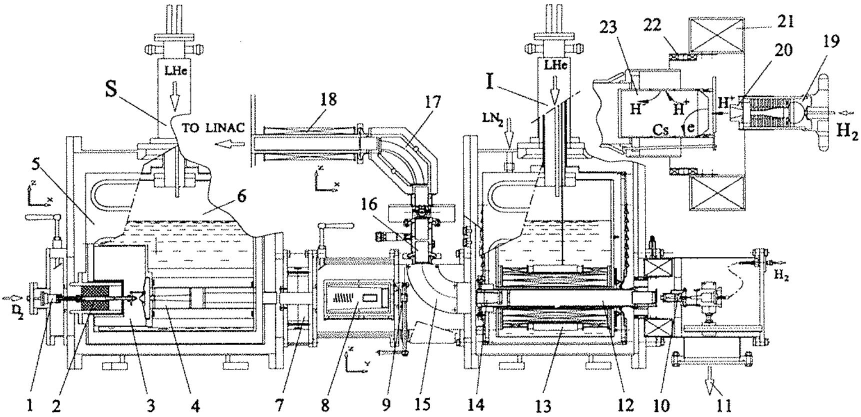

Figure 1: Schematic view of the polarized deuteron source POLARIS. S - polarized atomic source, I - charge exchange ionizer. 1- pulsed D_2 valve, 2- dissociator, 3- nozzle chamber, 4- SC sextupole magnets, 5- nitrogen shield, 6- helium cryostat, 7- permanent sextupole, 8- RF cell, 9- vacuum gate, 10- 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, 19- Cu cathode, 20- anode, 21- magnetic coil, 22- transverse magnetic filter, 23- molybdenum converter

The commissioning of the new superconducting accelerator nuclotron supposes to continue the spin physics program. A first test polarized run at the new machine took place since the synchrophasotron has been shutdown. Simulation shows that depolarizating resonances are absent under polarized deuteron acceleration almost at all energy range of the nucloron [4]. There is a project to produce a polarized deuteron beam. It is supposed to modify $\uparrow D^+$ source POLARIS into the $\uparrow D^-$ one and 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 synchrophasotron). To get a large beam current 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. 0.05-0.1 cm^3 H_2 gas at pressure 0.5-1.2 bar is injected into a hollow cathode space of the plasma generator by a fast thyristor triggered valve. High current arc discharge and H^+ plasma beam are started due to ignition pulse in 0.9 ms. An acceleration potentials of the plasma generator and the HV charge exchange pipe are +(13-17) 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 space. $\uparrow D^+, H^+, H_2^+$ three component plasma is extracted by extraction grids to separation magnet.

Using POLARIS atomic beam stage, about 1 mA polarized D^+ (mass 2) current accompanied by 9 mA H_2^+ (mass 2) background from the plasma generator, has been measured output of the charge exchange ionizer behind the 90^0 bending magnet. To get proper vertical orientation of spin the polarized beam should be passed through electrostatic mirror and spin rotator. A beam space charge limit of the mirror is around 10-12 mA. An efficiency of the new ionizer is 3-5% instead of 1-2% for the our old Penning ionizer. It is clear the $\uparrow D^+$ charge exchange ionizer can't sufficiently rise intensity accelerated beam in one turn injection mode.

To reach the accelerated polarized beam intensities up to $0.7\text{-}1{*}10^{10}$ ↑d/pulse a multyturn charge exchange injection (20-30 turns) could be 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 $\uparrow D^-$ one 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 $300\text{-}500^0$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 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 pipe -(17-20) 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 grids. The 90^0 bending magnet separates accelerated H^- plasma and polarized $\uparrow D^-$ ions.

Vacuum in the ionizer is provided by cryopumping and by some turbopumps. Hydrogen vapor pressure at 4.2 K cryostat is 1-2*10¯6 mbar. Reconstruction of the ionizer cryostat is finished, cryogenic tests have done. A study of the surface conversion technology H^+ to H^- ions took place simultaneously. Some configurations of the H^+ generator and molybdenum converter have been modified and tested:

- converter diameter, cone shape, length,
- plasma source magnetic coil length,
- arc discharge configuration space,
- filter magnetic field,
- extraction electrode configuration,
- arc discharge feeding scheme.

A scheme of the extraction electrodes is shown on Fig.2. Extraction of positive and negative ions from the charge exchange space are different for the same acceleration volt-

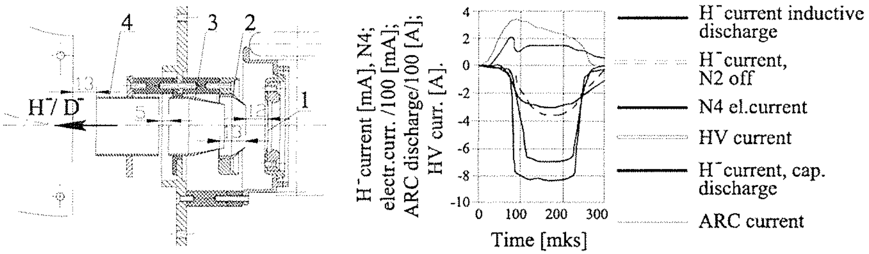

Figure 2: Scheme of test bench extraction electrodes and H^- current pulses behind bending magnet. 1- HV plasma wire mesh, 2,3,4- electrodes

age range (U_{acc}=12-17 kV). An extraction grid length of positive ions consist of two fine wire mesh, with gap 10-15 mm. Extraction electrodes N2, N3 for negative ions have a cone shape. 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 direct 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.2.

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 (10-15 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

A test run has been done at the nuclotron using the existing $\uparrow D^+$ source POLARIS with Penning ionizer.

The polarizations of low and high energy beams during acceleration were measured:

- low energy polarimetrs with He^3, He^4 targets behind the 10 MeV linac,
- internal target polarimeter during an acceleration,
- two-arm relative polarimeter with polyethylene target.

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	-0.55+/-0.03	0.53+/-0.03
at 5.0 GeV/c	-0.58+/-0.02	0.63+/-0.02

The vector polarization of the deuteron beam is retained 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 $1.3*10^8$ ↑d/pulse. The charge exchange multyturn injection is required.

Acknowledgments

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