The new source of polarized ions for the JINR Accelerator Complex

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Abstract. The project assumes the design and construction of a universal high-intensity source of polarized deuterons (protons) using a charge-exchange plasma ionizer. The output \(\uparrow D^+ (\uparrow H^+)\) current of the source is expected to be at a level of 10 mA. The polarization will be up to 90\% of the maximal vector \((\pm 1)\) for \(\uparrow D^+ (\uparrow H^+)\) and tensor \((+1, -2)\) for \(\uparrow D^+\) polarization. Realization of the project is carried out in close cooperation with INR of RAS (Moscow). The equipment available from the CIPIOS ion source (IUCF, Bloomington, USA) is partially used for the Dubna device. The new source at the JINR NUCLOTRON accelerator facility will make it possible to increase the polarized deuteron beam intensity up to the level of \(10^{10}\) \(d/pulse\). Previous test runs on acceleration of polarized deuterons at the NUCLOTRON up to about 1 GeV/u and slow extraction of the beam to the beam transfer lines, have shown the absence of depolarization resonances. The first dangerous resonance is predicted at the beam energy of 5.6 GeV/u. The source could be transformed into a source of polarized negative ions if necessary.

1. Project motivation

Studies of the structure of light nuclei, including the deuteron, and features of strong interactions using beams of polarized deuterons accelerated at the Synchrophasotron - weak-focusing 10 GeV proton synchrotron, have been started at the Laboratory of High Energies (LHE, JINR) since the middle of the 80s [1]. The unique 4.5 GeV/c per nucleon polarized deuteron beams with the intensity of up to \(5 \times 10^9\) ppp attracted many collaborators from different countries. A lot of new experimental data, which could not be described with the existing popular theoretical models, were obtained at that time. Experiments with polarized deuteron beams resulted in the discovery of some effects, which had clearly demonstrated the necessity to revise the standard model of the nuclei as a set of nucleons, in the kinematical region where the distances between the nucleons were less than their sizes. Since 2003 these studies have been continued at the NUCLOTRON - a strong focusing superconducting 6AGeV heavy ion synchrotron that was put into operation in 1993 [2]. The accelerator can also provide the proton beam as well at maximum magnetic rigidity of about 50 T·m. The basic problem of the new machine in comparison with the Synchrophasotron is one-turn injection. The Nuclotron injection time is limited to about 8.36 \(\mu\)s whereas it was about 200 \(\mu\)s for the old accelerator. That’s why the construction of a new high-pulsed current polarized ion source is considered as a very important high priority task. The new flagship JINR project in the domain of high energy nuclear physics, NICA...
NUCLOTRON-based Ion Collider Facility), aimed at the study of phase transitions in strongly interacting nuclear matter at the highest possible baryon density, was started in 2006 [3]. Such conditions are obtained in heavy ion collisions in the energy range of $\sqrt{s_{NN}} \sim 4 - 11$ GeV. The NICA program consists of several subprojects. The first one is the project NUCLOTRON-M, where the new polarized ion source is included in. The realization of the project was started in 2008 and is supposed to be completed in 2011. Physics with polarized light ion beams is considered as an important part of the NICA collider program. It is supposed to realize collisions of different polarized particles ($p, d$) with different orientation of their spin and in the both modes: head-on and merging collisions. The expected luminosity is planned at the level of $(10^{30} - 10^{31})$ cm$^{-2}$s$^{-1}$. Some proposals for the NICA research program are collected in the "NICA White Book" [6].

The source of polarized deuterons used up to now (0.4 mA D$^+$ cryogenic source POLARIS [4, 5]) cannot provide some of the key parameters of the beams necessary for the NUCLOTRON/NICA facility. That is why the idea to use the Cooler Injector Polarized Ion Source (CIPIOS) developed at the Indiana University Cyclotron Facility (IUCF, USA) in cooperation with the Institute for Nuclear Research, Russian Academy of Sciences (INR, Moscow) in 1999 was strongly supported at the Laboratory.

The upgraded CIPIOS will provide high-quality polarized deuteron and proton beams at the NUCLOTRON-M. Installation of the new polarized source at the accelerator complex will allow us to continue soon the studies with polarized beams at much higher level. The goal of the first stage is to accelerate the 10 mA polarized D$^+$ beam to 5 GeV/u, i.e. to increase the beam intensity up to $10^{10}$ d/pulse.

2. Source of Polarized Ions

The project realization includes the following stages:
- development of the high-intensity source of polarized deuterons and protons using a charge-exchange plasma ionizer with the output current more than 10 mA of ↑D$^+$↑H$^+$; and it’s - complete tests;
- modification of the linac pre-accelerator high voltage platform and power station;
- adaptation of the existing remote control system (console of LU-20) of the polarized ion source to operate under the high voltage;
- assembling of the source and equipment at the pre-accelerator platform, test runs with polarized beams at linac LU-20 and polarization measurements at the linac output.

The Source of Polarized Ions (SPI) consists of an atomic beam section that uses sextupole magnets for focusing, and radio-frequency transition units to polarize the atoms before they are focused into the ionizer. SPI uses a set of permanent sextupoles ($B = 1.4$ T), a conventional electromagnet sextupole ($B = 0.9$ T) and radio-frequency units for nuclear polarization of the atomic beam. This allows one to get nuclear ±1 vector for ↑D$^+$↑H$^+$ and +1, −2 for ↑D$^+$ tensor polarization. The cryocooler is used for cooling the atomic beam. The resonant charge-exchange ionizer [7, 8] produces pulses of positive ion plasma inside the solenoid. The atomic beam pulse is focused through the extraction system into the solenoid where atoms are ionized by a highly efficient charge exchange reaction

Nearly resonant charge-exchange reactions to produce polarized protons and deuterons are as follows:

$$
\begin{align*}
H^0 \uparrow + D^+ & \Rightarrow H^+ \uparrow + D^0 \\
D^0 \uparrow + H^+ & \Rightarrow D^+ \uparrow + H^0 \\
\sigma & \sim 5 \times 10^{-15} \text{ cm}^2
\end{align*}
$$

Spin orientation of ↑D$^+$↑H$^+$ ions at the output of SPI is vertical. The ion beam is formed with a 25 kV extraction potential in a 100 μs wide pulse at a rate of 0.14 Hz. At the moment
the specificity of the NUCLOTRON is that single turn injection is used for it and this machine allows one to accelerate only positive ions.

Figure 1. Atomic Beam Source general view. A pulsed dissociator (INR-type), nozzle cooling to 70 K, set of permanent magnet sextupoles and one electromagnet sextupole (CIPIOS), WF and SF RF transitions units. Expected intensity of polarized deuteron beam is $1.5 \times 10^{17} \text{ sec}^{-1}$ (3 ms pulse), polarized hydrogen beam - $2 \times 10^{17} \text{ sec}^{-1}$.

The important fact is as follows depolarization resonances are absent in the total energy range of the NUCLOTRON but only for the deuteron beam.

Therefore as the first step of the offered project it is expedient to use a source of positive polarized deuterium ions. It is known that INR of RAS (Moscow) has developed a source of polarized protons with a charge-exchange plasma ionizer [9] and the polarized atom storage in the ionization volume [10, 11]. The intensity and polarization of the beam from the INR source are as high as 6 mA, 85 % [9] without polarized atom storage and 11 mA, 80 % [11] – with the storage. The ionizer with the storage of polarized atoms allows one not only to increase intensity of the polarized ion beam but also to reduce emittance of the polarized beam and reduce considerably $H_2^+$ ion current which is difficult to be separated from polarized deuterons due to the similar mass of the ions. The number of the polarized ions of the source at the intensity of the 10 mA beam and the 8 $\mu$s pulse duration is $5 \times 10^{11}$, that meets the requirements of the given project. The normalized emittance of the source beam is $1.2 \pi \text{ mm mrad}$ [12], that is much smaller than the acceptance of the linac.

Taking into account the above, we assume to convert the charge-exchange ionizer of CIPIOS
into the ionizer using a storage of polarized deuterium atoms and production of polarized deuterons by resonance recharging in the hydrogen plasma.

Within the frame of the project we suppose to develop the atomic beam source (ABS), see figure 1.

The RF-transition units will be checked and tuned with a sextupole electromagnet as an analyzing device. The purpose is to get the atomic D beam with the pulse density of $2.5 \times 10^{10}$ atoms/cm$^3$ at the distance of 150 cm from the cooling channel outlet and the most probable velocity of $1.5 \times 10^5$ cm/s.

The design and manufacture of ABS parts, optimization of the intensity of the atomic beams, and functional test of the cells of the nuclear polarization of deuterium (hydrogen) atoms will be performed on the agreement with INR. The beginning of tests of ABS is planned at the end of 2010.

The work to be carried out at LHEP JINR, includes the following:
- assembly and tests of the charge-exchange plasma ionizer, including the storage cell in the region of ionization and transportation of hydrogen plasma with the flow of unpolarized protons up to 100 mA through the storage cell;
- long-term tests with the storage cell in the ionizer.

It is necessary to develop electronic control system components for primary analysis and data acquisition.

3. Status of the project realization

Intensive work on preparation of the source for tests is carried out at INR. Special attention during the tests will be focussed at the problems of the atomic beam formation process and study of the RF - transitions efficiency under nuclear polarization of the atomic deuterium beam. Operation of the ionizer with a storage cell at the room temperature is planned at JINR for the fall of 2011.

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