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Injection of Polarized Protons and Light Ions in the Nuclotron Superconducting Synchrotron

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Abstract—A source of polarized deuterons and protons (SPI) has been created as part of the experimental program on accelerated polarized beams at the Nuclotron superconducting synchrotron. The electrostatic accelerating tube has been replaced by an accelerator with spatially homogeneous quadrupole focusing (RFQ linac), and the power-supply system of the ion sources has been also replaced to work with the source of polarized ions on the preinjector of the LU-20 linear accelerator. This article presents the results of 52–54 experiments on the acceleration of polarized protons and light ions in the Nuclotron.

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INTRODUCTION

The NICA (Nucleotron-based Ion Collider Facility) accelerator complex [1], which will deliver beams of charged particles to the external targets and detectors of the Collider, is being constructed in JINR (Dubna). The program of experiments on the existing Nuclotron accelerator complex, as well as the planned works on NICA, includes experiments on polarized ion beams. For this purpose, a new source of polarized ions SPI (Source of Polarized Ions) was developed in cooperation with the INR RAS (Troitsk) [2].

The preinjector of the LU-20 linear accelerator was upgraded for the commissioning of this source, since the system that was used earlier to power the sources on the high-voltage platform was designed for power up to 5 kW, while the power that is consumed by the new source is 25 kW.

MODERNIZATION OF PREINJECTOR

In the course of modernizing the preinjector, the electrostatic accelerating tube was replaced by RFQ linac [3], whose parameters are given in Table 1. This made it possible to reduce the potential on the high-voltage platform from 600 to 100 kV and use a 160-kV to 35-kVA isolating transformer to supply power to the sources. The development of RFQ linac was performed by a collaboration of the Joint Institute for Nuclear Research (JINR), the Moscow Engineering Physics Institute (MEPhI) (Moscow), and the Institute for Theoretical and Experimental Physics (ITEP) (Moscow). Modeling of beam dynamics, the modeling and development of the accelerator resonator, and the development and manufacture of the RF power

Table 1. RFQ linac parameters

Ratio of charge to mass Z/A	1.0	0.5	0.3
Injection energy, keV	31.0	61.8	103
Maximum current, mA	10	20	10
Energy at the output, keV/n		156	
Operating frequency, MHz		145.2	

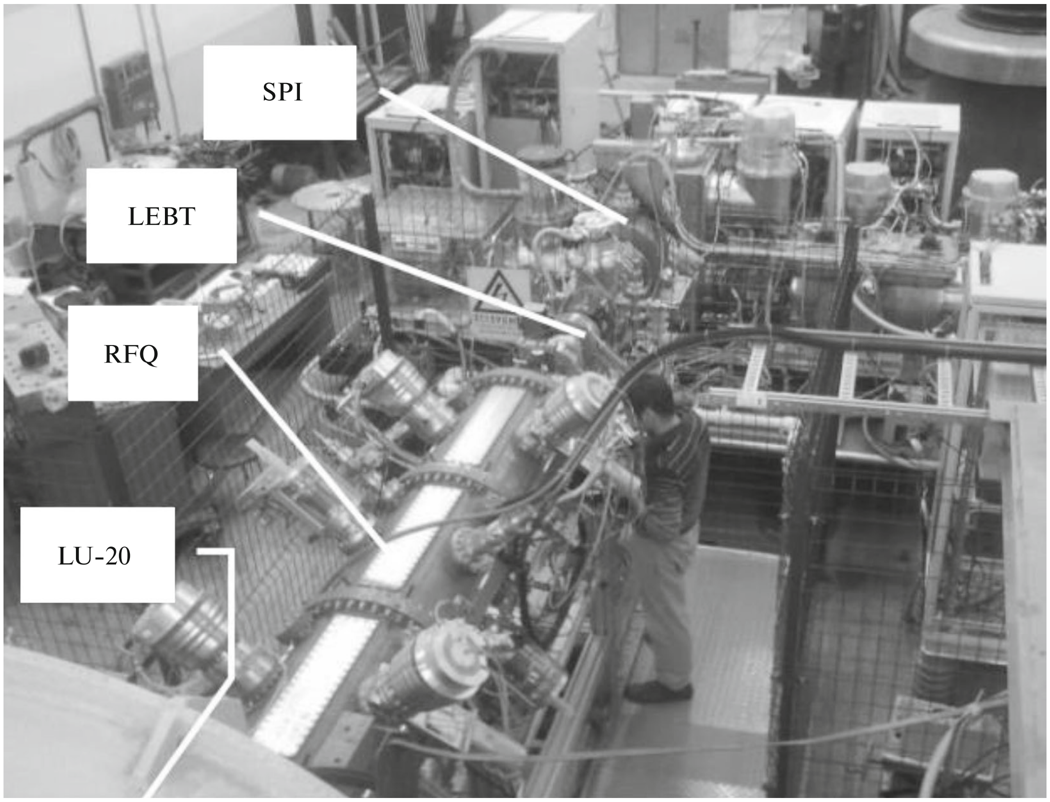

Fig. 1. LU-20 preinjector. SPI is the source of polarized ions, LEBT is the transport channel from the source to the accelerator with RFQ linac, and the preaccelerator is the accelerator with RFQ linac.

supply system were carried out in 2011–2013. The resonator of RFQ linac was manufactured at Zababakhin VNIITF (Snezhinsk).

Channels for transporting low-energy beams from the ion source output to the input of the section with RFQ linac and from the RFQ linac output to the LU-20 input were developed and installed. The linear accelerator with Lu-20 drift tubes is the injector of the Nuclotron synchrotron and is currently used to accelerate ions with a charge-to-mass ratio ≥1/3 at the second multiplicity of the RF field up to energy of 5 MeV/n [4]. The ion beam is transported by two short-focus magnetic lenses and a double corrector from the ion source to the input of the accelerating electrostatic tube by two electrodes, and after acceleration to the input of the section with RFQ linac. The transport channel between the RFQ linac and LU-20 consists of a debuncher, two triplets of quadrupole lenses, and a dipole corrector. The channel of beam transportation in the Nuclotron includes a debuncher, two dipole magnets, twelve quadrupole lenses, and two dipole correctors. The diagnostics of the beam was carried out from the source to injection into the Nuclotron by four Faraday cylinders: at the input of the section with RFQ linac, at the LU-20 input and output, and at the Nuclotron input.

NUCLOTRON ACCELERATOR SESSIONS

The SPI source was installed on the high voltage platform of the new preinjector in May 2016 (Fig. 1). In June 2016, the first technological session of the Nuclotron with a deuteron beam, which was obtained using a new source and preinjector, was held. As a result, all major systems of the ion source and injector confirmed their working capacity and were put into operation.

The session, which was mainly devoted to experimental studies in the field of spin physics (with polarized deuterons), began on October 26, 2016, and its total duration was more than 1500 h. The average intensity of the polarized deuteron beam was 5–7 × 10^8 particles/cycle, and it was increased to 2 × 10^9 particles/cycle during the next acceleration session, which was held in February–March 2017, (Fig. 2). During this session, a beam of polarized protons was obtained at the accelerator complex for the first time in the history of the LHE/LHEP. The study of the collisions of polarized protons in order to obtain new experimental data to determine the quark-parton structure functions of the proton is the main task of the program of polarization studies at the SPD installation of the NICA complex. The achievement of the result was preceded and facilitated by hard work on transferring the SPI source to the mode of the genera-

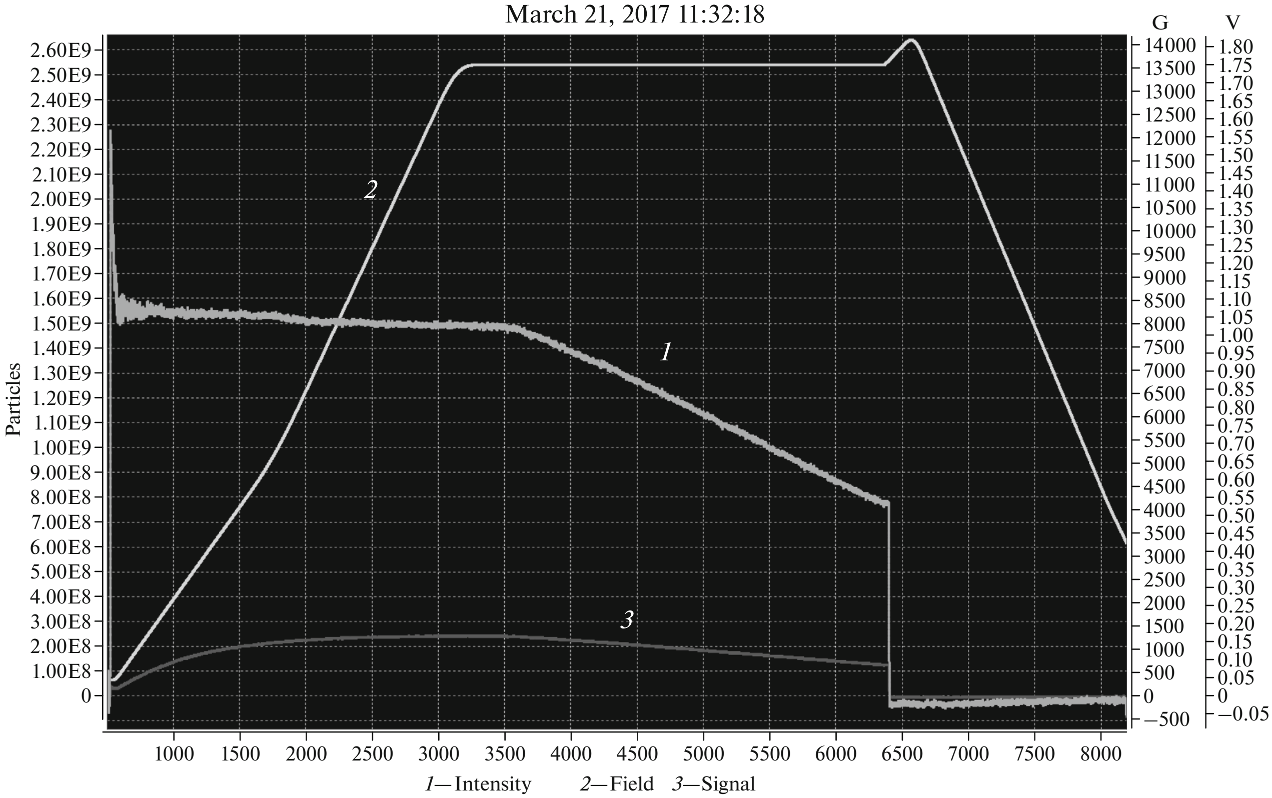

Fig. 2. Cyclic diagram of a polarized deuteron beam during acceleration and slow extraction from the Nuclotron. Intensity is shown by line *1* and the main magnetic field is shown by line *2*.

tion of polarized protons, ensuring the transportation and acceleration of the beam of polarized protons in the RFQ linac section, a preaccelerator, in the LU-20 and further injecting into the Nuclotron ring, providing the mode of stable circulation, capturing into the acceleration mode, and further accelerating and outputting of the accelerated beam and recording of the polarization level. The most problematic issue in terms of the dynamics of the proton beam was the adjustment of the mode of circulation and capture of a proton beam with an energy of 5 MeV in connection with the need to reduce the amplitude of the injection magnetic field from 300 G (in the case of deuterons) to 150 G. Ensuring the capture of the proton beam at low injection energy at the acceleration mode was also a problem. All these problems were successfully solved and an accelerated proton beam was obtained from the SPI in the Nuclotron and in the output channel where the polarimeter was located. The measurements of the polarization of the circulating and output beams at a beam energy of 1 and 2 GeV were carried out. The operational modes of the SPI source on polarized protons, polarimeters, capturing system, processing, and representation of the data on polarization have been tested and tuned at the operating modes at the acceleration complex.

The average weighted values of the polarization of the proton beam were found to be 0.017 ± 0.021 and 0.354 ± 0.022 for the nonpolarized and polarized beam, respectively [5]. The polarization at the SPI output was -0.90 ± 0.06 according to the calculations of spin transfer, taking into account the current magnetic conditions in the Nuclotron injection line. The vertical component of the polarization of the proton beam in the inner target can be increased to this value by installing two solenoids at the SPI output and in the Nuclotron injection line [5].

THE INSTALLATION OF THE DEBUNCHER

In June 2017, the debuncher, which was developed by JINR and ITEP, was put into operation. It is installed under the LU-20 vacuum casing on the section between the output of the accelerator and the Lou-20 input and is designed to coordinate the longitudinal beam emittance at the RFQ linac output with the LU-20 acceptance. Tests have shown that the debuncher increases the beam current at the LU-20 output 1.5 times for a deuteron beam (Fig. 3). The current increased 2.5 times during the experiment with the C^{5+} and Li^{3+} beams.

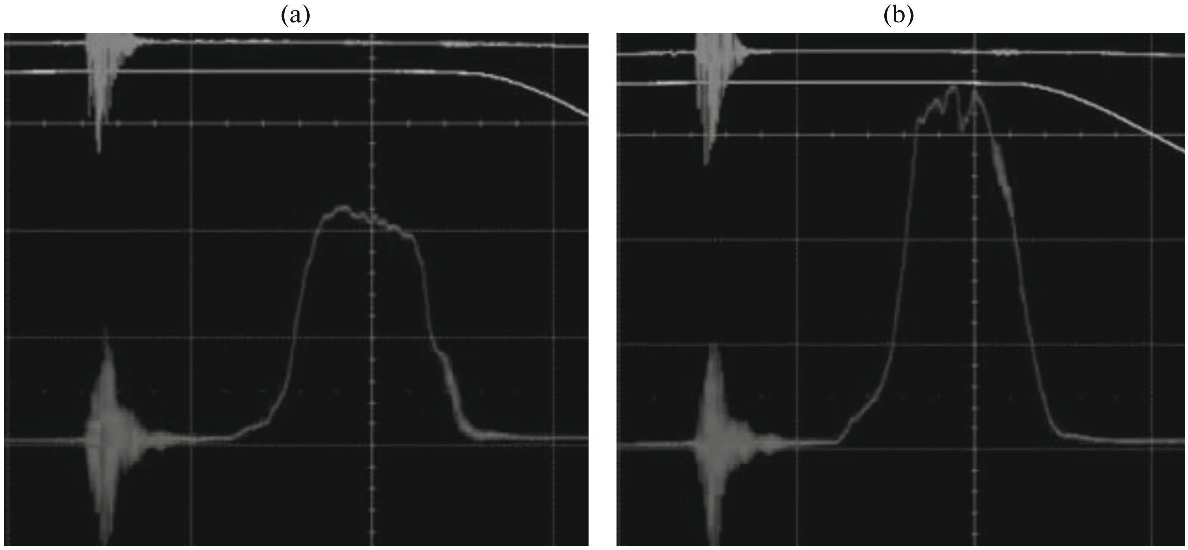

Fig. 3. (a) Deuteron-beam current at the switched-off debaucher at the LU-20 output; (b) current of the deuteron beam at the switched-on debuncher at the LU-20 output.

CONCLUSIONS

The beams of polarized deuterons and protons from the SPI source were injected and accelerated in synchrotron during 52–54 sessions of the Nuclotron. The upgraded preinjection provided the injection of polarized deuterons and protons from the new SPI source and the beams of light ions from a laser source into the LU-20. For the first time, protons were accelerated at the linear accelerator LU-20 at the second multiplicity of the accelerating RF field. The beams of polarized deuterons and protons with an intensity of 2.0×10^9 and 1.8×10^8, respectively, were accelerated at the Nuclotron and extracted to physical installations. The debuncher for the LU-20, which was put into operation, will be tested during the upcoming accelerator sessions and will make it possible to increase the intensity of the particles in the Nuclotron.

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