Status of the Source of Polarized Ions project for the JINR accelerator complex

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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.

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.

The feature of this machine in comparison with the Synchrophasotron is one-turn injection. The NUCLOTRON injection time is limited to about 8.36 μs whereas it was about 200 μs for the old accelerator. That's why the development of a new high intensity polarized ion source is considered as a very important high priority task.
The new flagship JINR project in 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 put forward in 2006.

The NICA program consists of several subprojects. The one of them is the project NUCLOTRON-M, where the new polarized ion source is included in, because the existing 0.4 mA ↑D⁺ cryogenic source POLARIS cannot provide some of the key parameters necessary for the new facility. Physics with polarized light ion beams is considered as an important part of the NICA collider program also. The expected luminosity is planned at the level of \((10^{30} - 10^{31}) \text{ cm}^2 \cdot \text{s}^{-1}\).
Further development of the polarization program at NUCLOTRON/NICA facility supposes the substantial increasing of pulsed intensity of source of the polarized light nuclei.

The new project: Source of Polarized Ions project (SPI-project) assumes the design and production of the universal high-intensity source of polarized deuterons & protons.

- As the first step the increase of intensity of the accelerated polarized D\(^+\) beam is supposed.
- The important fact is depolarization resonances are absent in the total energy range of the NUCLOTRON-M but only for the deuteron beam.

The main purpose of the SPI-project is to increase the intensity of the accelerated polarized beams at the JINR Accelerator Complex up to \(10^{10}\) d/pulse.
The **SPI-project** assumes the development of the source using charge-exchange ionizer

Nearly resonant charge-exchange reactions for production of polarized protons & deuterons are:

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

- The design output current of the **SPI** is up to **10 mA** for \( \uparrow D^+ (\uparrow H^+) \)

- The \( D^+ \) polarization will be up to 90% of the maximal vector \((\pm 1)\) & tensor \((+1,-2)\) polarization
The **SPI-project** is based on the equipment which was supplied within the framework of the Agreement between JINR & IUCF (Bloomington, USA)

*Cooler Injector Polarized Ion Source (CIPIOS) has been developed in IUCF & INR RAS collaboration and produced polarized and unpolarized $H^+$ and $D^-$ ions with current up to 2 mA and polarization of up to 85% for $H^+$ and up to 90% for $D^-$ ions.*

The polarization program at IUCF has been stopped in 2002 and some parts of the CIPIOS have been transported to JINR

*The SPI-project is realized in close cooperation with INR of RAS (Moscow, Russia)*
The SPI-project includes the following stages:

- development of the high-intensity Source of Polarized Ions
- complete tests of the SPI
- modification of the linac pre-accelerator platform & power station
- adaptation of the existing remote control system (console of linac) of the SPI under the high voltage
- SPI & Linac runs with polarized beam and polarization measurements at the linac output
NEW SOURCE OF POLARIZED IONS (DEUTERONS)

\[ \text{D}_2 \rightarrow \text{D} \rightarrow \text{D} \]

\[ \text{D}^0 + \text{H}^+ \rightleftharpoons \text{D}^+ + \text{H}^0 \]
The basic equipment for the **Source of Polarized Ions** is:

- Pump, Turbo-V 3K-T, 2300 l/s H2, 2400 l/s He  - 2 items
- Pump, Turbo-V 2K-G, 1600 l/s N2  - 2 items
- Fore pump Dry scroll pump type TriScroll 600 Inverter, 30m³/h  - 2 items

Cryocooler, Single Stage Cryodyne Refrigeration System, Model 350 will provide 40 watts of heat lift at 77K

Pressure measurement system, MaxiGauge TPG256A controller for 6 gauges

### ABS Sextupole
- Power supply Sorensen SGI40X375C-1CAA (40V, 375A, 15kW) - ABS sextupole
- Power supply Sorensen DCS 8-350E (8V, 350A, 3 kW)
- Power supply Sorensen DCS 12-250E (12V, 250A, 3 kW)
- Power supply Sorensen XG 8-200 (8V, 200A, 1.6 kW)
- Power supply Sorensen DCS20-150E (20V, 150A, 3 kW) - ionizer solenoid
- Power supply Sorensen XG 40-42 (40V, 42A, 1680 W) - ABS arc source

### ABS & IONIZER Equipment
- Signal Generator SMB100A with option SMB-B102 9kHz – 2.2 GHz - 1 item
- High Frequency Generator HG1462C 100kHz-400MHz - 2 items
- Power amplifier FLG-15CA, 0.7GHz-3GHz - 1 item
- Power amplifier FLH-20B, 20MHz-1000MHz - 2 items
- Power Supply ZUP-10-20, 0-10V, 0-20A - 4 items
- High voltage power supply HCP350-35000 0-30 kV, 0-10 mA, positive - 1 item
- High voltage power supply HCP350-35000 0-30 kV, 0-10 mA, negative - 2 items

### RF - Units
- Power amplifier FLHG20B, 20MHz-1000MHz - 1 item
- High voltage power supply HCP350-35000 0-30 kV, 0-10 mA, positive - 1 item
- High voltage power supply HCP350-35000 0-30 kV, 0-10 mA, negative - 2 items

The equipment is already purchased.
High-voltage isolation transformer 35kVA 160kVDC

**Stewart** isolation transformer
Electrostatically shielded
50.52 amps/35 kva- 160 kvdc isolation between input and output

Device is intended to SPI power supply located on a high-voltage terminal at linac
The **NUCLOTRON** feature is that the injection is possible only for positive ions.

Therefore it is expedient to use the source of positive polarized deuterium ions.

**Note:** The highest intensity of the beam is reached for positive polarized ion sources with charge-exchange plasma ionizer and the storage cell.

- **SPI-source** assumes to convert the charge-exchange ionizer of **CIPIOS** into the ionizer using storage of polarized deuterium atoms and production of **positive polarized deuterons** by resonance charge-exchange in the hydrogen plasma.
The ionizer with storage of polarized atoms for the SPI allows
- increase intensity of the polarized $D^+$ beam,
- reduce emittance of the polarized beam
- considerably reduce $H_2^+$ ion current which is difficult to be separated from polarized $D^+$ due to similar mass of the ions.
INR RAS polarized ion source

- atomic beam-type source with resonant charge-exchange plasma ionizer and with a storage cell in the charge-exchange region

(Belov et. al. INR RAS, 1986, 1999)

$$H^0 \uparrow + D^+ \rightarrow H^+ \uparrow + D^0$$

11 mA of $H^+ \uparrow$ 80% polarization has been obtained from the INR source.
The designing and manufacture of ABS parts, optimization of the intensity of the atomic beam, and functional tests of the RF cells of the nuclear polarization of deuterium (hydrogen) atoms were performed at INR of RAS.

The purpose is to get atomic D beam with the pulse density of \(2.5 \cdot 10^{10}\) at/cm\(^3\) at the distance of 150 cm from the cooling channel outlet and the most probable velocity of \(1.5 \cdot 10^5\) cm/s.
Source POLARIS (JINR)

<table>
<thead>
<tr>
<th>Transition</th>
<th>I</th>
<th>$P_z$</th>
<th>$P_z^2I$</th>
<th>$P_{zz}$</th>
<th>$P_{zz}^2I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (1 → 4)</td>
<td>1/2</td>
<td>-2/3</td>
<td>2/9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M (3 → 6)</td>
<td>1/2</td>
<td>2/3</td>
<td>2/9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M (2 → 6)</td>
<td>1/2</td>
<td>1/3</td>
<td>1/18</td>
<td>1</td>
<td>1/2</td>
</tr>
<tr>
<td>M (3 → 5)</td>
<td>1/2</td>
<td>1/3</td>
<td>1/18</td>
<td>-1</td>
<td>1/2</td>
</tr>
</tbody>
</table>

SPI (JINR)

<table>
<thead>
<tr>
<th>Transition</th>
<th>I</th>
<th>$P_z$</th>
<th>$P_z^2I$</th>
<th>$P_{zz}$</th>
<th>$P_{zz}^2I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (1 → 4)</td>
<td>1/3</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>4/3</td>
</tr>
<tr>
<td>M (3 → 5)</td>
<td>1/3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1/3</td>
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<tr>
<td>M (1 → 4)</td>
<td>1/3</td>
<td>-1</td>
<td>1/3</td>
<td>1</td>
<td>1/3</td>
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<tr>
<td>M (3 → 5)</td>
<td>1/3</td>
<td>1</td>
<td>1/3</td>
<td>1</td>
<td>1/3</td>
</tr>
</tbody>
</table>

The **RF-transition units** will be checked and tuned with a sextupole electromagnet as an analyzing device.
Atomic Beam Source general view (INR test bench)

Pulsed dissociator (INR-type), nozzle cooling to 70 K, set of permanent magnet sextupoles and electromagnet sextupole, MFT, WFT and SFT (CIPIOS)
Atomic Beam Source setup general view
(INR test bench)
Signals of the TOF MS with the sextupole electromagnet “ON” and “OFF”

Peak intensity obtained: \( D^0 \uparrow - 1.0 \cdot 10^{17} \text{sec}^{-1}, H^0 \uparrow - 1.5 \cdot 10^{17} \text{sec}^{-1} \)
Status of the ABS development

At this moment the Atomic Beam Source (ABS) of the SPI has been assembled and tested at INR RAS

✓ The pulse density of atomic D beam at the distance of 150 cm from the cooling nozzle outlet is $2.5 \cdot 10^{10}$ at/cm$^3$ at the most probable velocity of $1.5 \cdot 10^5$ cm/s

✓ Functional tests of WFT&MFT of the RF cells of the nuclear polarization of deuterium (hydrogen) atoms were performed
RFT scheme and deuteron polarization

<table>
<thead>
<tr>
<th>HFT between 6poles</th>
<th>HFT after 6poles</th>
<th>Final D hfs</th>
<th>$P_Z$</th>
<th>$P_{ZZ}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFT 3 $\rightarrow$ 4</td>
<td>WFT 1 $\rightarrow$ 4, 2 $\rightarrow$ 3</td>
<td>3,4</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>MFT 3 $\rightarrow$ 4</td>
<td>SFT 2 $\rightarrow$ 6</td>
<td>1,6</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>MFT 1 $\rightarrow$ 4</td>
<td>SFT 3 $\rightarrow$ 5</td>
<td>2,5</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td>MFT 1 $\rightarrow$ 4</td>
<td>SFT 2 $\rightarrow$ 6</td>
<td>3,6</td>
<td>0</td>
<td>+1</td>
</tr>
</tbody>
</table>
Tests of the WFT

Deuterium atoms

Hydrogen atoms

D atoms WFT efficiency – 0.95

H atoms WFT efficiency – 0.90
Tests of the MFT

Deuterium atoms

3 → 4 mode

1 → 4 mode
The work which is carried out at JINR includes

- assembly and tests of the charge-exchange plasma ionizer, including the storage cell in the ionization volume
- optimization of the ion-optical system up to 25 keV and transport of the high-current deuteron beam
- long-term tests of the SPI with the storage cell in the ionizer
- polarimetry of the accelerated beam at the output of linac

It is necessary to develop control system components for primary analysis & data acquisition and for fiber optic system of data transmission
Assembly of the charge-exchange plasma ionizer (JINR responsibility)
view from the ABC

TMP

ABS support bearing stand

Bending magnet
General view of SPI (September 2012)

ABS

Charge-exchange plasma ionizer
SPI view from the dissociator chamber
Summary & Outlook

• Intensive work was carried out at INR of RAS (Moscow) and testing of the ABS systems was finished in July 2012.

• In August 2012, the ABS was transported from the INR of RAS (Moscow) and assembled at JINR.

• All-inclusive SPI-testing will be carried out in 2012-2013 at JINR.
Thank you