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DEVELOPMENT OF HIGH-VOLTAGE NEGATIVE ION BASED NEUTRAL BEAM INJECTOR FOR FUSION DEVICES

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A prototype of powerful high-voltage neutral beam injector (HV-NBI), based on acceleration of negative hydrogen ions and their neutralization is under development at the Budker Institute of Nuclear Physics (BINP) [1]. The design of BINP high-voltage injector includes several innovative components, important for injector operation stability and an overall efficiency: 1) multi-aperture long-pulsed surface-plasma negative ion source, 2) wide-aperture low-energy beam transport section (LEBT), 4) high-energy beam transport channel (HEBT), 5) plasma target for negative ions neutralization, 6) energy recuperators of non-neutralized accelerated ions. The several test stand facilities were constructed at BINP for injector components study. The works on RF surface-plasma H- source prototype with production of H- beam and it transport through the LEBT were carried out at the test stand, schematically shown in Fig.1.

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Fig.1. The principal scheme of the RF ion source and LEBT. At the right –H- beam profile.

The essential features of the BINP ion source are: negative ions are produced on the plasma grid surface covered by cesium, temperature of the ion-optical system electrodes (heating/cooling) is actively controlled, magnetic field lines in the gaps between the grids are made convex so as to increase the high-voltage holding, and cesium is directly deposit to the plasma grid. The prototype source delivers 0.8 A, 100 keV, 10 s H- beams. Up to 1,3 A, 117 keV, 2 s H- beam were regularly produced as well [2]. About 0.5 g of cesium seed provided the long-term operation during 2 month period.
In order to remove impurities and secondary particles from the negative ion beam before entering the accelerator tube, the wide-aperture LEBT section was used. It is equipped with two wide-aperture magnets, providing parallel shift of the beam from the source axis before entering the acceleration tube. Thereby the ion source is protected from back-streaming positive ions, and the accelerator - from the fluxes of undesirable neutral and charged particles, as well cesium vapor, escaping from the ion source. Additional coils are used to correct the beam trajectory. An intense pumping by two 105 l/s cryopumps reduces the residual hydrogen pressure in the LEBT and accelerating tube. It decreases multiplying and avalanching of secondary particles in the accelerator. The NI beam intensity and profile was recorded by the movable water-cooled Faraday cup (FC) with the direct electrical measurements of the beam at the 1.6 m distance from the source, and by the sectioned calorimeter at the LEBT exit (at 3.5 m from the ion source). The typical profile of transported H- beam is shown at the right side of Fig.1. The groups of fast neutral atoms produced due to NI stripping in the LEBT were measured by calorimeter with the magnetic scan and H- beam deflection. The fast indirect control of NI beam intensity is done by subtracting of currents in IOS power supplies and in IOS electrodes circuits. At the operational LEBT vacuum of 3•10-3 Pa up to ~ 80% of 93 кeV H- beam, outgoing the source were transported to calorimeter plane [3].
The main injector test bench, included the 1.5 A, 120 keV negative ion source, LEBT with powerful cryopumps, one-aperture accelerator with an 0.5 - 0.9 MeV acceleration energy and HEBT is erected in the X-ray shielded hall (Fig. 2). The H- source with its components (RF and IOS power supplies, gas, hydrogen and thermostabilization systems) and the LEBT tank with cryopumps and magnets were installed on the High Voltage platform. The 0,9 MV acceleration voltage is supplied by 0.3 MV rectifiers, connected in series with the help of HV bushings. The beam transport line is equipped with beam position detectors, installed before and after acceleration tube. The beam, transported through the HEBT is measured by the section calorimeter. In 2019, the injector has been commissioned. The first experiments on H- beam production and transport through the LEBT, acceleration tube and HEBT have started in 2020. A negative ion beam with of up to 1 A and an energy of 80 keV was obtained and transmitted through LEBT to the input of the accelerator tube. At the moment, experiments are carried out to further accelerate the beam in acceleration tube and to transmit it through a bending magnet into the energy recuperator. The first results on the accelerator test bench physical launch and on 1A, 90 keV, 20 sec negative ion beam production and acceleration will be presented.
The report will describe the other work carried out at the Institute in the framework of the high-voltage injector program: the development of the full-scale 9 A negative ion source, of high-efficiency plasma neutralizer for the negative ion beam, studies of the possible implementation of a photon beam neutralizer.

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Fig.2. Test bench with HV platform, 0.88 MV accelerator and HEBT.
The full-scale RF H- source with projected parameters 9A, 120 KeV, 100 sec and it main components were produced at BINP machine shop. The source includes four RF-type plasma drivers, attached to the Ø 700 mm x 170mm plasma confinement box, and the 4-electrodes IOS, forming the beam with 142 beamlets. The IOS electrodes shape provides the ballistic beam focusing. The H- beam emission current density of 25 mA/cm2 in the IOS openings is projected. The details of full-scale source will be discussed.
The prototype of plasma neutralizer (PPN) was constructed, and it experimental study was performed at the separate test bench (Fig.3). The complex magnetic field configuration of the PPN is produced by an array of circular permanent magnets. This configuration (multicusp at the walls, longitudinal in the plasma volume, and the inversed end mirrors) provides the plasma confinement. Plasma is generated by an arc discharge with LaB6 cathodes, installed at the periphery of the central plane. Working gas (hydrogen) is injected to the chamber center. It was observed, that the considerable negative potential develops in the plasma, decreasing the ion outflow, and the plasma losses through the ends are suppressed by the inverse magnetic mirrors. It was founded that a relatively low power of the discharge is required to sustain ~1019 m−3 density plasma in the plasma neutralizer prototype with the inverse end mirrors [4].

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Fig.3. H- beam neutralization test bench with prototype plasma target [4]

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