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TECHNOLOGIES OF HIGH VOLTAGE NEUTRAL BEAM INJECTORS FOR MAGNETIC FUSION DEVICES

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High-energy neutral injectors based on the acceleration and stripping of negative ions are developed in Budker Institute of Nuclear Physics (BINP SB RAS). The scheme of the BINP injector is shown in Fig. 1. The special features of the BINP injector are the original high-current RF surface-plasma negative ion source with heated electrodes of the ion-optical system (IOS) for beam extraction, the low energy beam transport (LEBT) section from the source to the accelerator and a wide-aperture acceleration tube pumped from both sides [1]. The LEBT tank is pumped by high-performance cryopumps, dipole magnets installed in it deflect the beam to the entrance of a wide-aperture accelerator tube. This purifies the 120 keV beam outgoing from the source from gas and related impurities, increases the electrical strength of the accelerator and the reliability of the ion source operation. The ion source and the LEBT section are mounted on a high-voltage platform, and the output electrode of the accelerator tube is grounded. After acceleration in the tube and additional focusing by quadrupole lenses, negative ions pass through a plasma neutralizer, which provides up to 84% neutralization efficiency of 500 keV negative ions [2]. The beam of high-energy atoms obtained as a result of stripping is directed to the calorimeter, and the residual ions are deflected from the beam to recover their energy [3].

The report presents results of the production, transportation and acceleration of NI beams with a current up to 1.5 A, as well as the first experiments on a full-scale source with a designed beam current of 9 A.

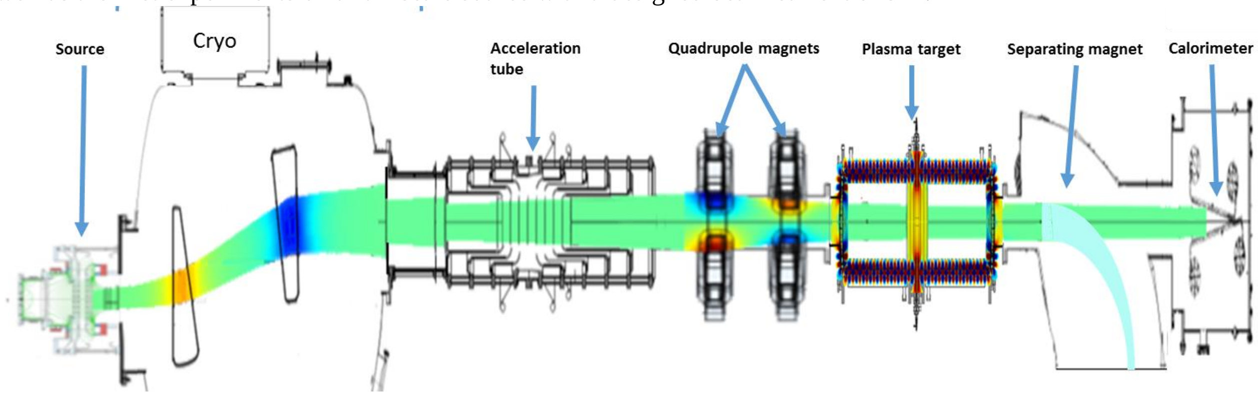

Fig. 1. Scheme of BINP negative ion based neutral beam injector.

PRODUCTION OF 1.5A NEGATIVE ION BEAM

The essential features of BINP surface-plasma source are: 1) an active temperature control of the ion-optical system electrodes by circulation of hot thermal fluid, 2) the concaved transverse magnetic field in the extraction and acceleration gaps, which provides increased high-voltage strength and 3) directed cesium deposition via distribution tubes adjacent to the plasma grid [4, 5]. Prototype surface-plasma RF source with 21 apertures for beam extraction and formation was manufactured and studied. H^- beams with a current of 1.2 – 1.5 A and an energy of up to 120 keV in pulses lasting up to 20 s are routinely produced. To operate in high-current mode with beam current of I_b = 1.5 A, special algorithm was developed for gradually increasing the RF and IOS voltages, as illustrated in the waveforms in Fig. 2 at left. To gradual switch the source to operating mode (the pulse range highlighted by blue in Fig. 2), an RF discharge of reduced power P_{RF} ~ 5 kW is first ignited and sustained (the interval is -6 ÷ 0 s in Fig. 2), then the RF power is increased to the level of 60 kW. In a similar way, the voltages of the IOS electrodes are gradually increased: in the pulse range of -5 ÷ 0 s, the extraction U_{ex} and acceleration voltages are switched on at a reduced level, and then gradually increase to operating values. It should be noted that the obtained value of the 1.5 A NI beam at the source exit corresponds to a record initial average emission current density of 45 mA/cm^2 (taking into account 20% stripping of negative ions on the accompanying gas in the IOS).

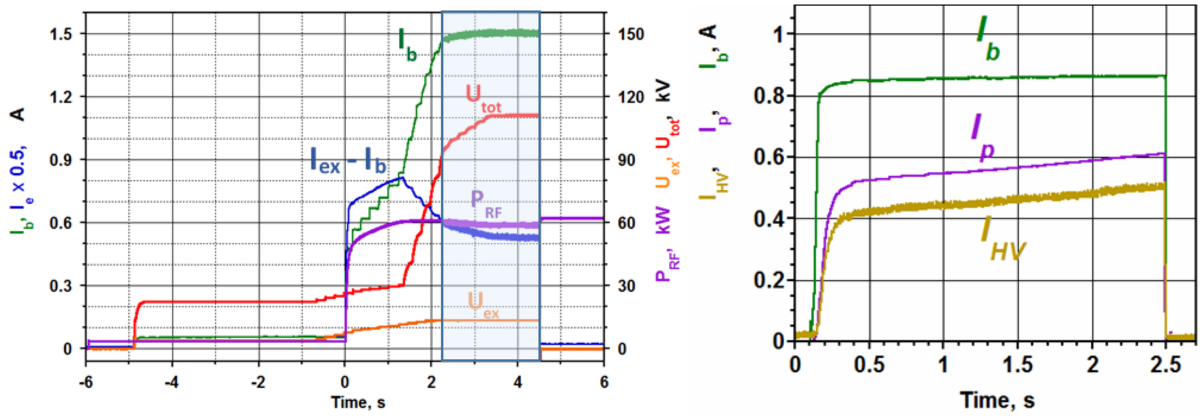

Fig. 2. At left) Waveforms of the source operation parameters with a beam current of 1.5 A and an average emission density of 45 mA/cm^2. At right) Oscillograms of the accelerated 380 keV NI beam current I_{HV}, the beam current at the input of the accelerator I_p, and the NI beam current at the output of the NI source I_b..

EXPERIMENTS ON BEAM TRANSPORTATION THROUGH LEBT AND BEAM ACCELERATION

The LEBT and the accelerator tube were pumped by two cryopumps with a total pumping rate of $2{\cdot}10^5$ liters/sec in hydrogen, which reduces ion beam stripping in the LEBT to 12% level and also reduces the formation of secondary electrons in the acceleration tube. Movable Faraday cup installed in the LEBT, provides direct electrical measurements of the beam current and density profile. In particular, up to 75% of the beam I_b outgoing from the source was transported to a distance of 2.5 m, and up to 70% was transported to the accelerator input window. Fig. 2 at right illustrates the waveforms of the beam currents corresponding to several beam positions: at the source output I_b = 0.85 A, at the accelerator tube input window I_p = 0.6 A, and at the accelerator output window I_{HV} = 0.5 A.

STUDIES OF A FULL-SCALE 9A NEGATIVE ION SOURCE

Tests of a full-scale multi-aperture source with a designed beam current of 9 A (Fig. 3) have begun on a separate stand. The source consists of 4 RF plasma drivers connected to an expansion plasma chamber and to three-electrode 145 aperture ion-optical beam extraction system. The high-voltage strength of the source IOS was tested in the absence of H^- beam using low-current 80 kV rectifier. Simultaneous operation of four RF plasma drivers was achieved, and the uniformity of plasma flux entering the plasma electrode was studied using probes installed in the plasma grid apertures. Probe measurements showed 2-3–fold increase in plasma density in the direction of ExB drift. This plasma heterogeneity should have little effect on the uniformity of the beam production, since H^- are mainly formed by the conversion of suprathermal hydrogen atoms formed by the dissociation of hydrogen molecules in the RF driver volume.

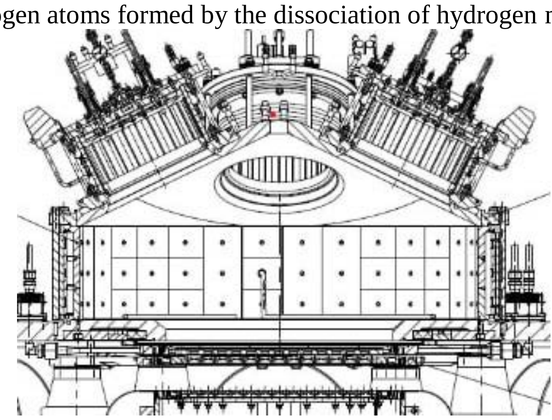

Fig. 3. 9 A surface-plasma negative ion source with 4 RF drivers and an expansion chamber of ø700 mm. The green lines show the magnetic field.

Power supply systems and auxiliary systems of the 9 A source are currently being tested (thermoregulation, cesium, vacuum systems) at the ion source stand.

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