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Long-Term Performance of CW Negative Hydrogen Ion Source at BINP Tandem Accelerator

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Abstract. A continuous-wave surface-plasma negative hydrogen ion source is routinely used for proton beam production at 2 MeV tandem accelerator with vacuum insulation at the Budker Institute of Nuclear Physics during last decade. The source uses the hydrogen-cesium Penning discharge with a plasma injection from hollow cathodes and negative hydrogen ions production due to surface-plasma mechanism. It delivers H^- ion beam with current up to 8 mA and energy up to 25 keV. Normalized RMS emittance of the beam is less than 0.2 π·mm·mrad. The single source unit was used at the tandem in the ten-year work. Description of source duty at tandem and the source modifications, produced during the ten-year work are described.

INTRODUCTION

A surface-plasma ion source producing continuous-wave (CW) negative hydrogen ion beam was developed at Budker Institute of Nuclear Physics (BINP) for ion injection to tandem accelerator [1]. More than 5 mA, 2 MeV proton beam was produced at the tandem exit [2]. The single source unit has been routinely used in experiments at tandem for more than a decade period, and only several improvements were done to enhance the source and to simplify its maintenance. The parameters of source work, the maintenance statistics and source modifications done are described below.

ION SOURCE DESIGN

The design of original ion source unit, installed at BINP tandem, and its characteristics were described in detail earlier [1]. Source uses the hydrogen-cesium Penning discharge, driven by plasma injection from the hollow cathode inserts (see Fig. 1 below). The hydrogen and cesium are fed through the channels in the cathode body and the hollow cathode inserts. Hydrogen flow of 0.1÷0.15 L·Tor/s was controlled by needle valve and measured by the mass-flow meter. A compact cesium oven with the cesium-chromate-titanium pellets is used. A triode ion-optical system (IOS) with 3 mm apertures is used for beam extraction and acceleration. An external magnet produces 70 mT magnetic field, which supplies the triple action: electron confinement in discharge, electron filtering in near-anode plasma and deflection of electrons out of the extracted negative ion beam. The supporting flanges of IOS electrodes are cooled by water. The source is attached with bellow to the 15° bending chamber, which in turn is directly connected to the low energy beam transport line (LEBT), as it is shown in Fig. 2 below. The source and bending chamber are differentially pumped.

The source power supplies and control system consist of two racks. Discharge and heating power supplies are biased at −25 kV potential. Extraction and acceleration voltages are connected in series between the anode electrode and the accelerator electrode. The high voltage power supplies perform long-term stability as low as 0.5%, and discharge arc current has stability of 1%. The source computer system control provides setting and reading of source parameters.

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Beam properties were measured on the separate test stand, equipped by electric sweep emittance scanner. The beam at 90% of intensity has regular divergence of about 80 mrad. The normalized RMS emittance of 9.0 mA, 23.5 kV beam had the value of 0.18 π·mm·mrad in XX' plane and 0.15 π·mm·mrad – in YY' plane [1].

SOURCE MODIFICATIONS

Several source modifications, increasing the source lifetime and simplifying the maintenance, were done during the ten-year long service. The cross-section of the modified ion source version and the scheme of source attached to the LEBT are schematically shown in Fig. 1 and Fig. 2.

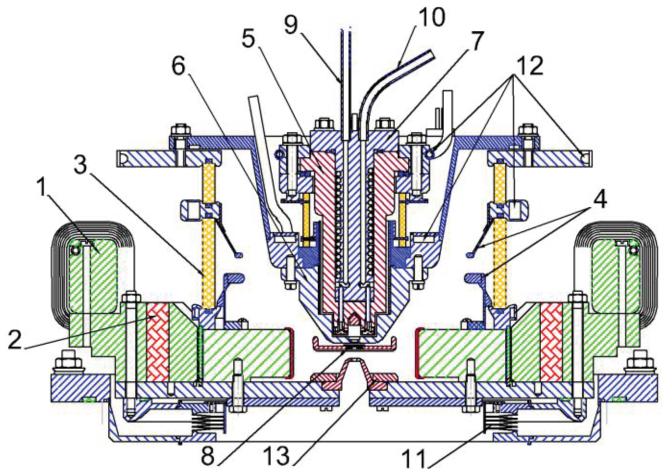

FIGURE 1. The ion source cross-section layout. 1 – additional coils of magnet; 2 – NdFeB inserts; 3 – HV insulator; 4 – stainless steel screens; 5 – cathode body; 6 – anode body; 7 – cathode heater support; 8 – extraction electrode with removable insert; 9 – H_2 feeding tube; 10 - cesium feeding tube; 11 – bellow; 12 – water cooling channels; 13– acceleration electrode.

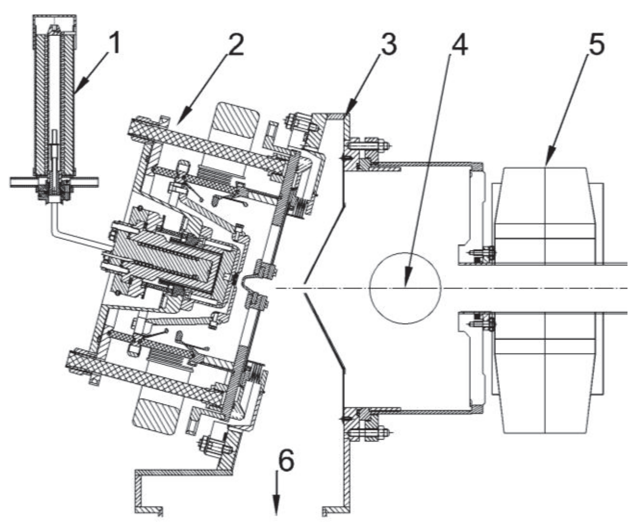

FIGURE 2. Scheme of source attachment to bending chamber and LEBT. 1 – Cs oven; 2 – ion source; 3 – cone for hydrogen differential pumping; 4 – tube to pump #2; 5 – first LEBT lens; 6 – tube to pump #1.

1. Additional permanent NdFeB inserts (2 in Fig. 1) were introduced to increase source magnetic field up to 96 mT. It increases the Penning discharge plasma density and intensifies the negative ion production up to 8.8. mA.

2. The source HV insulators consisted of ceramic rings brazed to supporting flanges. They were replaced by ceramic rings, sealed by viton to supporting flanges (3 in Fig. 1). The viton sealing was tightened by four external dielectric studs. Additional stainless steel screens (4 in Fig. 1) were introduced to protect the insulator from erosion

by electrons and to increase an average lifetime of insulators two times, up to ~ 500 hours. Now the insulator tubes damage were mainly caused by occasional air inrush to the source.

3. The internal cathode heater provides the initial heating, prevents cesium clogging inside the cathode and supplies the discharge easy start. The halogen lamps, inserted into the cathode body cavities were used in the initial source design. In the modified source version the lamps were replaced by ohmic heater immersed into the cathode body (7 in Fig. 1). It increases the reliability of the heater and of the source start.

4. The extraction electrode intercepts the co-extracted electron flux, and the walls of extraction electrode channel are sputtered by back-streaming positive ions. As a result, the surface around the extraction electrode aperture is gradually eroded. A circular replaceable insert were introduced into the extraction electrode plate (8 in Fig. 1) in order to simplify and to cheapen the eroded extraction electrode repair. The insert is made of molybdenum, and it is screwed into the plate. An average lifetime of the insert before repair is about 700 hours.

5. The source pumping was enforced by installing the high speed turbo pumps (3000 L/s each).

A new control system of the source was developed recently and will be installed at tandem source [3]. It consists of the main controller and a set of peripheral local controllers. Each peripheral controller is driven by the stand-alone program, stored in its memory. The local controllers provide the feedback of source parameters to the main controller, so the source start and long-term operation can be provided automatically. The semi-automatic mode with control by the operator is also available.

ION SOURCE MAINTENANCE AND OPERATION STATISTICS

The ion source has started the regular operation at tandem accelerator in August 2006. Its total operational statistics is shown in Table 1. The source total operation time is about 2900 hours with average duration of daily run of about 5 hours. Each source daily run consists of 50 minutes start to condition the electrodes and to get the nominal beam parameters. The source startup time decreases, if the source was pumped during the stops in operation (for the night or holiday). No additional cesium release was necessary in this case at the source start. The standard duration of the stops, needed for cesium pellets replacement was about 2 hours, and in the case of discharge electrodes and IOS parts repairing - $6 \div 8$ hours. 10 years long operation of the source was provided with replacement of 5 HV insulators, of 3 gas-discharge chamber insulators, of 3 cathodes, and of 3 extraction electrode inserts. The source negative ion current and the duration of the source working runs were limited by the tandem users program. The suppression of secondary electron fluxes and of backstreaming positive ions has permitted to increase the current of accelerated 2-MeV protons to 5 mA [2].

TABLE 1. The ion source operation statistics at the tandem accelerator.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Days	31	22	29	19	12	46	62	57	80	53	70	93	552
Hours	150	110	140	95	62	233	293	251	359	265	341	600	2900

An advanced source version for the prolonged CW operation with beam current of 15 mA and energy 32 kV was designed and has been successfully tested in the several long-term >100 hours runs [4].

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