Operating experience and recent updates of negative hydrogen ion source at BINP tandem accelerator

A. Sanin, Yu. Belchenko, I. Gusev, A. Ivanov, V. Rashchenko, V. Savkin, I. Shchudlo, I. Sorokin, and P. Zubarev

Citation: AIP Conference Proceedings **2052**, 050012 (2018); doi: 10.1063/1.5083766
View online: https://doi.org/10.1063/1.5083766
View Table of Contents: http://aip.scitation.org/toc/apc/2052/1
Published by the American Institute of Physics

Operating Experience and Recent Updates of Negative Hydrogen Ion Source at BINP Tandem Accelerator

A. Sanin [a)], Yu. Belchenko, I. Gusev, A. Ivanov, V. Rashchenko, V. Savkin, I. Shchudlo, I. Sorokin, and P. Zubarev

Budker Institute of Nuclear Physics, Novosibirsk, Russia

[a)] Corresponding author: sanin@inp.nsk.su

Abstract. A continuous-wave surface-plasma negative hydrogen ion source has been used at 2 MeV tandem accelerator with vacuum insulation at the Budker Institute of Nuclear Physics since 2006. The source uses the hydrogen-cesium Penning discharge with plasma injection from hollow cathodes, and negative hydrogen ion production due to the interaction of plasma particles with the anode electrode surface. It routinely produces dc H- beam in the range 1 ÷ 9 mA in daily runs with accelerated proton beam delivery to the lithium target of our experimental device. Source parameters and maintenance statistics during long-term operation are discussed. Recent upgrades to increase the beam current production and transport are presented as well.

INTRODUCTION

The vacuum insulated tandem accelerator is operated at the Budker Institute of Nuclear Physics (BINP) since 2006 [1]. The accelerator was designed for the development of the accelerator-based boron neutron capture therapy of malignant tumors. A surface-plasma ion source [2] producing continuous-wave (CW) beam was used to inject of negative hydrogen ions into the tandem accelerator. This one ion source has been used for more than a decade. Several improvements were implemented to enhance the ion source and to simplify maintenance. The parameters of the source operation, the maintenance statistics and source modifications are described below.

ION SOURCE DESIGN AND PARAMETERS

The design of the original ion source and its characteristics were described in details earlier [2]. The ion source scheme is shown in Fig. 1. It uses hydrogen-cesium Penning discharge, driven by plasma injection from the hollow cathode inserts. The hydrogen and cesium are fed through channels in the cathode body. Hydrogen flow of 0.1÷0.15 l·Torr/s was controlled by a needle valve and measured by the mass-flow meter. A compact cesium oven with cesium chromate + titanium pellets was used. A triode ion-optical system (IOS) with 3 mm apertures is used for beam extraction and acceleration. The extraction gap is 1 mm, and the acceleration gap is 4 mm. The IOS electrodes are cooled by external water channels in the supporting flanges.

Magnetic field supplies electron confinement in the discharge, fast electron filtering in the near-anode plasma and separation of the negative ion beam from electrons in the extraction gap. A dipole magnetic field of 90 mT is produced by an external magnet. The initial ion source design includes electromagnet (1), which consists of coils and the external iron yoke with two poles inside the vacuum chamber. The discharge current is up to 10 A and working discharge voltage is 55-80 Volts. The extraction voltage is up to 5 kV, and the acceleration voltage is up to 25 kV with total beam energy up to 30 kV.

Sixth International Symposium on Negative Ions, Beams and Sources (NIBS 2018)
AIP Conf. Proc. 2052, 050012-1–050012-6; https://doi.org/10.1063/1.5083766
Published by AIP Publishing. 978-0-7354-1780-9/$30.00

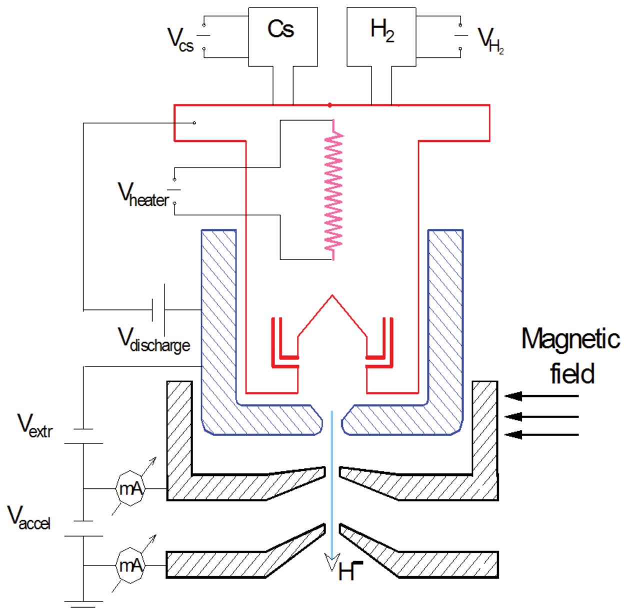


FIGURE 1. Scheme of CW surface-plasma source with Penning discharge, driven by plasma injection from hollow cathodes.

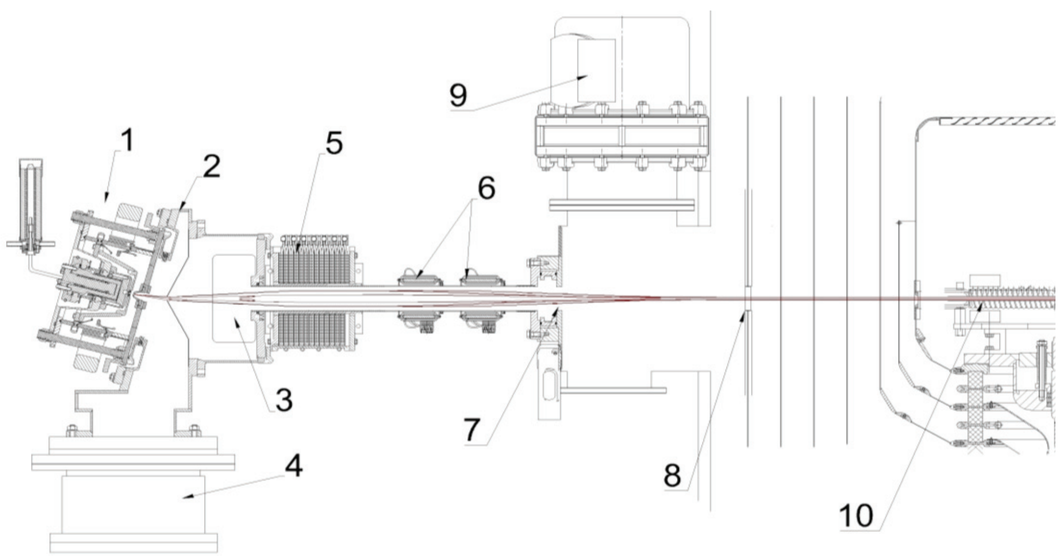


FIGURE 2. Layout of the source and LEBT attaching to the BINP tandem. 1 - Ion source; 2 - 15° bending chamber; 3, 4 - two stage differential pumping; 5 - magnetic lens; 6 - correctors; 7 - tandem input aperture; 8 - first tandem electrode; 9 - cryopump; 10 - stripping target.

The ion source is mounted to the low energy beam transport line (LEBT), shown in Fig. 2, via a 15° bending chamber (2) and bellows adjustment unit. The bending chamber compensates for the initial turn of the beam in the magnetic field of the Penning discharge. The beam passes coaxially into the transport channel through the cone of differential pumping with a 28 mm aperture. A focusing magnetic solenoid lens (5) provides matching of 100 mrad regular beam divergence with the tandem input acceptance. The beam is directed through the transport channel by two magnetic correctors (6). Gas pumping is produced by differential pumping system with two turbomolecular pumps (3, 4) with 3000 l /s pumping speed.

The ion source power supplies and control system consist of two racks. Discharge and heating power supplies are biased at − 30 kV potential. The extraction and acceleration voltages are connected in series between the accelerator electrode and anode. The high voltage power supplies have a long-term stability of 0.5%, and the discharge arc current has a stability of 1%.

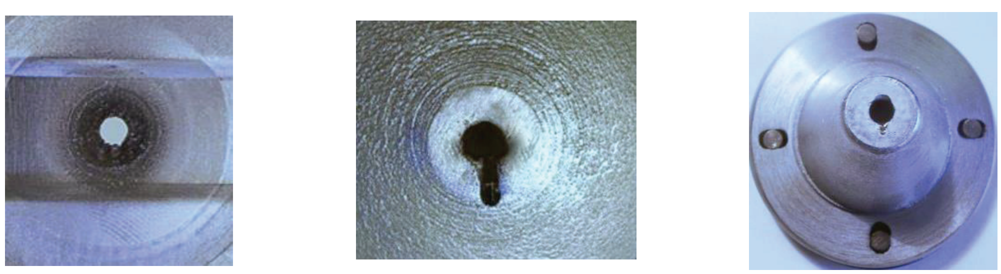
Beam properties were measured on a separate test stand, equipped with an electric sweep emittance scanner. The 90% beam intensity has regular divergence of about 80 mrad. The measured normalized 1 RMS emittance for an 8.0 mA, 22.5 keV beam was 0.18 π·mm·mrad in XX' plane and for a 9.0 mA, 23.5 keV beam was 0.15 π·mm·mrad – in YY' plane [3].

ION SOURCE PARTS WEAR

Several parts of the ion source wear out during the source long-term operation. The cathode is sputtered due to the presence of cesium in the Penning discharge. Sputtered material is deposited on the emission surface and can exfoliate as flakes. Picture of the cathode erosion is shown in Fig. 3a. Damaged cathodes should be replaced after average lifetime of 1000 hours. The three cathode bodies have been replaced during 12 years ion source operation. The flake formation on the anode surface can be reduced by the anode temperature control. Molybdenum deposits on the anode cover area were cleaned after 3 months source operation. The lifetime of the anode is limited by sputtering of the emission aperture edge at the extraction gap side. This sputtering is caused by high energy protons and cesium ions produced in the extraction gap. The picture of the emission aperture erosion is shown in Fig. 3b. In 12 years of ion source operation 3 anode units were replaced with an average lifetime of 1000 hours.

a) b)

FIGURE 3. Discharge electrodes erosion. a) Cathode tips sputtering after 1000 hours of operation; b) erosion of emission aperture at anode cover after 3 month use.



a) b) c)

FIGURE 4. IOS electrodes wear. a) Extraction electrode sputtering by backstreaming positive ions after 100 hours use; b) slit in extraction electrode tip melted by electrons after 200 hours; c) - acceleration electrode wear after 11 months use.

IOS electrodes are eroded during the ion source operation as well. The area around the aperture of the extraction electrode is sputtered by positive ions generated in the acceleration gap, as it can be seen in Fig. 4a. Electrons co-extracted from the plasma with negative ions are deflected by the transverse magnetic field and intercepted by the extraction electrode. As a result, the inlet aperture of the extraction electrode is gradually melted by the co-extracted electrons. Fig. 4b shows the slit, melted in the extraction electrode by electrons after ~200 hours CW operation. The acceleration electrode cone is gradually melted by the accelerated electrons, as it is illustrated in Fig. 4c.

SOURCE MODIFICATIONS

Several ion source modifications, increasing the ion source lifetime and simplifying the maintenance, were introduced during the past decade [2, 3]. The layout of the upgraded ion source, operated at the BINP tandem is shown in Fig. 5.

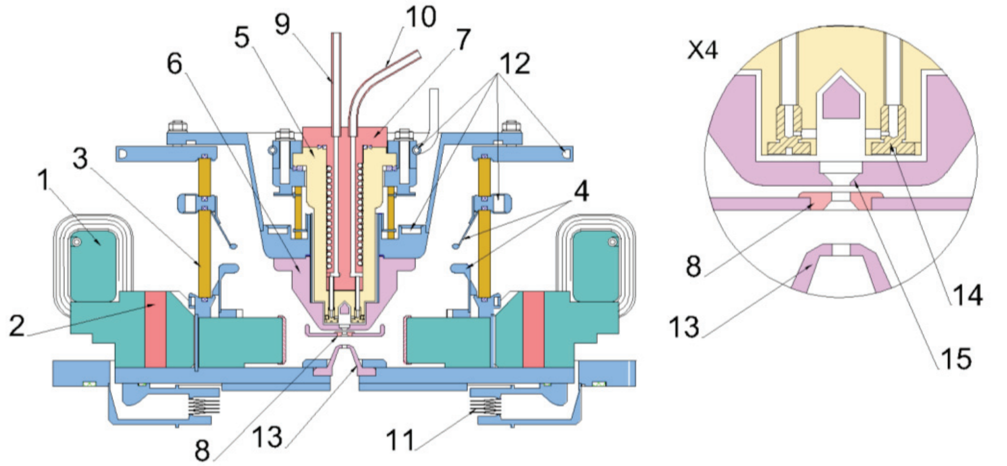


FIGURE 5. Upgraded ion source layout (on the left) and the scaled-up cross section of the discharge chamber and IOS (on the right insert). 1 –electromagnet, 2 – NdFeB inserts, 3 – HV insulator, 4 –shields, 5 – cathode body, 6 – anode, 7 – cathode heater, 8 – removable tip of extraction electrode, 9 – H_2 feeding tube, 10 - cesium feeding tube, 11 – bellows; 12 – water cooling channels; 13– acceleration electrode; 14 – hollow cathode insert; 15 – emission aperture in the anode cover.

The initial design of the ion source HV insulators consisted of ceramic rings brazed to the supporting flanges. The insulators are exposed to electrons drift in $\vec{E} \times \vec{B}$ direction from the extraction and acceleration gaps, and the insulator surface charging initiates the leak currents and occasional breakdowns. It results in gradual erosion of the IOS ceramics. To simplify the damaged insulator change, the brazed insulators were replaced by ceramic tubes sealed to the supporting flanges (3 in Fig. 5). The ion source with the replaceable insulators is shown in Fig. 6. The Viton seals between the ceramics tubes and flanges were tightened by the four external dielectric studs (Fig. 6).

FIGURE 6. Source version with the replaceable IOS insulators.

Additional stainless steel shields (4 in Fig. 5) were introduced to protect the replaceable insulator from erosion by drifting electrons. The implementation of shields increases the average lifetime of insulators several times, up to 500 hours of CW work. Figure 7 illustrates the erosion of the HV shielded replaceable insulator after 500 hours CW operation.

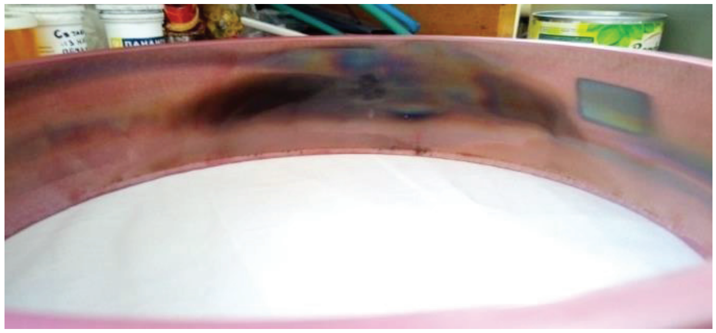
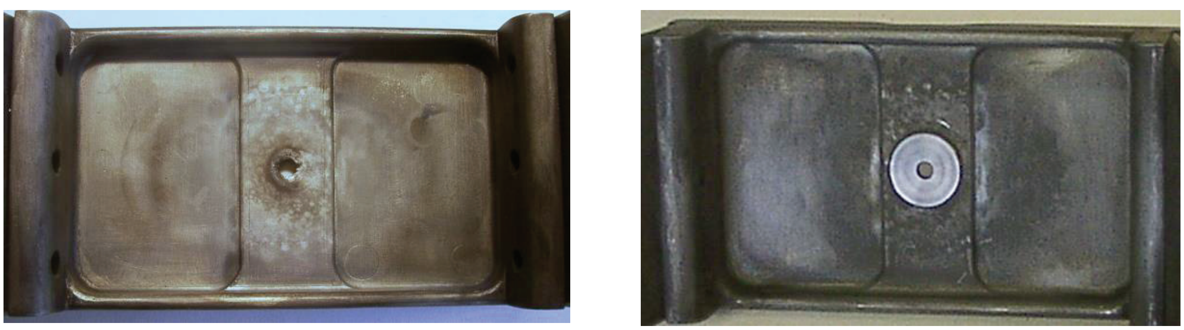


FIGURE 7. Shielded HV insulator tube after ~500 hours of operation.

The discharge electrodes heating is necessary to supply cesium seed at the source start and to prevent cesium clogging inside the feeding tubes. The miniature powerful quartz lamps, inserted into the cathode body cavities, were used in the initial ion source design for the cathode heating [2]. The quartz lamps were replaced by the ohmic heater (7 in Fig. 5), immersed into the cathode body. It facilitates the ion source start and increases the reliability and lifetime of the heating system. The only ohmic cathode heater was operated in the source without replacements from 2010 till 2018.

A circular replaceable insert was introduced into the extraction electrode plate (8 in Fig. 5) in order to simplify and to cheapen the repair of extraction electrode. The insert is made of molybdenum, and it is screwed into the extractor electrode plate. The pictures of the extraction electrode without and with replaceable insert are shown in Fig. 8. In 12 years of ion source operation the three extraction electrode inserts were replaced with average insert lifetime of ~1000 hours.



(a) (b)

FIGURE 8. Extraction electrode modifications without and with the replaceable insert. (a) - deterioration of extraction electrode plate after 100 hours of operation; (b) - extraction electrode plate with the replaceable insert.

H^- beam current increases with the growth of magnetic field of Penning discharge [3]. To increase the field, the additional NdFeB magnet inserts (2 in Fig. 5) were added into magnetic system. It increases the ion source magnetic field from 70 to 96 mT and decreases the electromagnet coil current with improving the magnetic field stability. The maximal negative ion current, measured at the tandem entrance by sweep wire scanner [4] increases from 7 to 9 mA.

The ion source pumping was enforced by installing turbo pumps with pumping speed of 3000 L/s each (3, 4 in Fig. 5).

ION SOURCE OPERATION STATISTICS

The ion source has begun regular operation on the tandem accelerator in 2006. The operational statistics are shown in Table 1. The ion sources total operation time was 3257 hours with average daily runs of about 5 hours. Each daily run consists of a 50 minute startup to condition the electrodes and to get the nominal beam parameters. The ion source startup time decreases if the source was pumped overnight or during weekend stops. No additional cesium release is necessary to start the source if pumping is continued. Cesium pellets replacement takes about 4 hours, and the discharge electrodes and IOS parts replacement takes 6 - 8 hours. During the 12 years long operation of the ion source, 5 HV insulators, 3 gas-discharge chamber insulators, 3 cathodes, and 3 extraction electrode inserts were replaced. The source negative ion current and the duration of the ion source working runs were determined by the tandem users program.

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

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Days	31	22	29	19	12	46	62	57	80	53	70	121	45	646
Hours	150	110	140	95	62	233	293	251	359	265	341	692	266	3257

CONCLUSION

The single ion source unit has been used at the tandem accelerator since July 2006 until September 2018. Several upgrades to the ion source design were made to improve reliability of operation and to extend the lifetime. A more than threefold increase (from 1.6 to 5 mA) in the current of accelerated 2 MeV protons has been achieved [5]. With the further upgrades of negative ion beam transport the maximal current of 2 MeV accelerated protons up to 8 mA was obtained at the tandem exit.

An advanced ion source version for the prolonged CW operation with beam current of 15 mA and energy 32 keV was designed and has been successfully tested in the several long-term >100 hours runs [6]. The CW negative ion beam with current of 25 mA was obtained from the source with the enlarged (from 3.5 to 5 mm) diameter of the anode and IOS electrodes apertures.

REFERENCES

1. A. Kudryavtsev, Yu. Belchenko, A. Burdakov et al., Rev. Sci. Instrum. **79**, 02C709 (2008).
2. Yu. Belchenko and V. Savkin, Rev. Sci. Instrum. **75**, 1704 (2004).
3. Yu. Belchenko, A. Sanin, I. Gusev et al., Rev. Sci. Instrum. **79**, 02A521 (2008).
4. T. Bykov, Ia. Kolesnikov, A. Makarov, I. Shchudlo, E. Sokolova, S. Taskaev, "Measurement of a H^- Ion Beam with D-Pace's OWS-30 Wire Scanner", *these proceedings*.
5. A. A. Ivanov, D. Kasatov, A. Koshkarev, A. Makarov, Yu. Ostreinov, I. Sorokin, S. Taskaev, and I. Shchudlo. Technical Physics Letters **42**(6), 608 (2016).
6. Yu. Belchenko, A. Gorbovsky, A.A. Ivanov, A. Sanin, V. Savkin, and M. Tiunov. AIP Conf. Proc. **1515**, 448 (2013).
7. Yu. Belchenko, A. Gorbovsky, A. Sanin, and V. Savkin. Rev. Sci. Instrum. **85**, 02B108 (2014).