Development and study of cw H^- source for BNCT

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Status of cw hydrogen negative ion source development for tandem accelerator of boron capture neutron therapy is described. The experimental source study and upgrade was continued. The electrodes enforcing, its water cooling and introducing of the electrons interception permitted to increase the source discharge power up to 0.7 kW and to obtain regularly the H- ion beam with energy 25 kV and current up to 8 mA. The experimental optimization and modelling of the beam formation is in progress. The flange version of the source is designed for cw beam study at the new test bed under construction.

I. Introduction

A dc negative ion source delivering 10 mA beam is necessary for operation of the tandem accelerator for BNCT. It is important to have the long-term stability and an easy maintenance for the source. Experimental surface-plasma source based on the Penning discharge was developed, upgraded and studied. The flange version of the source, its power supplies, control and data systems were designed.

II. Experimental source

Experimental surface-plasma source based on the Penning discharge with hollow cathodes[1] was developed for cw 5 mA beam production recently[2]. This source has a simplified start. It uses no heated cathodes, and the discharge are supported by plasma injection from hollow cathodes, inserted into the massive cathodes of Penning discharge. The scheme of this cw SPS is shown in Fig.1. Gas-discharge chamber consists of the cylindrical anode with the massive cathode body enclosed. Penning discharge is supported by electron oscillations in the magnetic field, produced by external electromagnet. The hydrogen and cesium was fed to the hollow cathode cavities through the channels in the cathode body. The triode beam extraction and acceleration system is applied. The experimental source was wholly located in a vacuum box and was well pumped from the sides. Discharge electrodes were cooled by the compressed air. A linear increase of the beam current with the emission aperture area growth and with arc current increase was recorded. The latter fact was used for the source upgrade.

III. Experimental source upgrade

The source upgrade was done to increase the discharge current and to enlarge proportionally the beam current[3]. The principal scheme of the upgraded source is shown in Fig.2. The water cooling of discharge electrodes was applied. Special cooler of the anode cover was installed (not shown in Fig.2) for keeping the optimal anode temperature at the enlarged discharge power. Additional bars were erected at the extractor sides (Fig. 2) for the accompanying electron flux interception at extraction potential. It permitted to operate with cw discharge current up to 9 A and

NI beam current up to 8 mA at the same hydrogen and cesium feed and with emission aperture diameter of 3 mm. Parameters of upgraded source are listed in the Tables 1 and 2.

TABLE 1. Upgraded source discharge parameters.

Distance cathode-to-cathode	7 mm
Discharge area at one cathode side	5 x 10 mm^2
Discharge volume	0.3 cm^3
Magnetic field	0.5 –1 kGs
Discharge voltage	60 - 90 V
Discharge current	6 - 9 A
Discharge current density (at cathode)	6 - 9 A/cm^2
Power load at cathode	< 0.7 kW/cm^2
Hydrogen feed	0,1 L Tor/s
Cesium feed	< 1 mg/h

TABLE 2. Upgraded source beam extraction parameters

H^- beam current (emission aperture 3 mm)	8 мA
Beam energy	25 (2 + 23) keV
Accelerated current	25 mA
Extraction circuit current	40 mA (at 2 kV)
Emittance XX' (1RMS normalized)	0.4 π mm mrad
Emittance YY' (1RMS normalized)	0.3 π mm mrad

IV. Experimental source reliability and maintenance

The source has a simplified start. The special ohmic heater inside the cathode provides the electrodes outgassing and heating before the cesium seed. The full extraction voltage and the acceleration voltage of about 7-10 kV are applied at the start. The acceleration voltage is increased to values up to 23 kV within the next 3-5 minutes after the discharge on. No breakdowns occurred, if the source was not exposed to air during the pause in operation.

The upgraded source cw operation was tested for 4-6 hours per day during about two months study. Photo of the thermal spot, produced at Faraday cup plate by the **7** mA, 20 KeV H^- beam is shown at Fig.3. No sizable erosion of discharge electrodes was recorded. Two of vincible problems in a long-term cw operation are shown in the Fig. 4 and 5. Molybdenum, sputtered at low rate from the cathode was gradually deposited to the anode bottom plate (Fig.4 shows the flakes formation after one month of experimental operation). Moly flakes formation could be depressed by the discharge mode control. The gradual (in several months) sputtered metal deposition to the cathode-anode insulator is shown in Fig.5. This deposition does not prevent the source from standard functioning.

V. Beam formation modeling and optimization

PBGUNS (Particle Beam GUN Simulations) computer program was purchased for simulation of NI beam formation. This program produces axisymmetrical 3D computing of beam extraction, formation and transport. Its essential features are the fine matrix, applied in the emission region to improve the simulation, and the computing of plasma boundary position with the self-consistent model of transient plasma sheath.

Two types of plasma emission (uniform plasma emitter and Maxwellian angular distribution) were applied for simulation of beam extraction from the source. Various sizes, geometry and potential of the triode ion-optical system (IOS) were simulated. An examples of PBGUNS output data for 10 mA H^- beam formation with two various emitters and the axisymmetrical triode IOS is shown in Fig. 6.

An experimental optimization of the triode IOS was done. Fig.7 illustrates the optimal value of the extraction potential for the different acceleration voltage of the optimized triode IOS. The tetrode IOS was tested also, and a gas mixturing was applied for the beam quality improvement. Example of the beam with the improved divergence is shown in Fig.8 and 9. Work on IOS optimization and modeling is in progress.

VI. Flange source design

New source flange version to be installed at the test bed and at the accelerator LEBT was designed and is under manufacturing. Its principal scheme is shown in Fig.10. The flange source has several novel features to be tested:

- Most parts of the source (gas-discharge electrode flanges, discharge insulator, cesium system) will contact with the air
- IOS water cooling will be done
- Source differential pumping will be done from the IOS bottom only
- Cesium system with precise seed control will introduced

VII. Test bed, power supplies and control systems

The second, special test bed for the long-term test of flange source and for the beam study is under construction. It includes several systems. The vacuum system (Fig.11) consists of the flange source chamber (not shown at the photo), of beam transport chamber and of the receiver volume with the pumps attached. The source power supply consists of various units, listed in the scheme of Fig.12. Elements of power supplies and of control system under construction are shown at the photos of Fig. 13-14.

Summary

Upgraded cw source produces stable 8 mA, 23 kV H^- beam with emittance < 0.4 π mm mrad. Easy source start and maintenance is provided. The flange source version and its supplies are developing and manufacturing at BINP.

References

1. Yu. Belchenko and A. Kupriyanov. Rev. Sci. Instrum. **69** (1998) 929.
2. Y. Belchenko and E. Grigoryev. Abstracts of 9th Intern. Conf. on Ion Sources, September 3-7, 2001, Oakland, California, USA, p. 114.
3. Yu. Belchenko and V. Savkin, Rev. Sci. Instrum. **75** (2004) 1704.

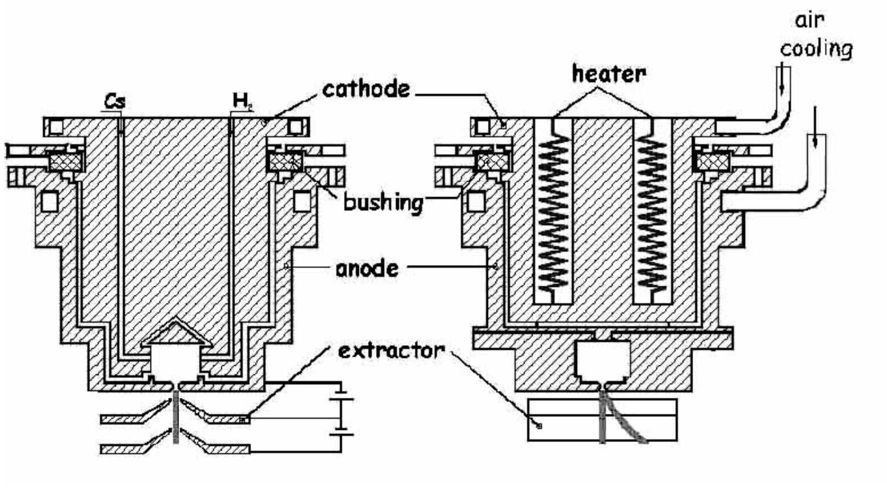

Fig.1. Scheme of SPS with hollow cathodes and Penning geometry of electrodes. Left- cross section along magnetic field lines, right- across magnetic field.

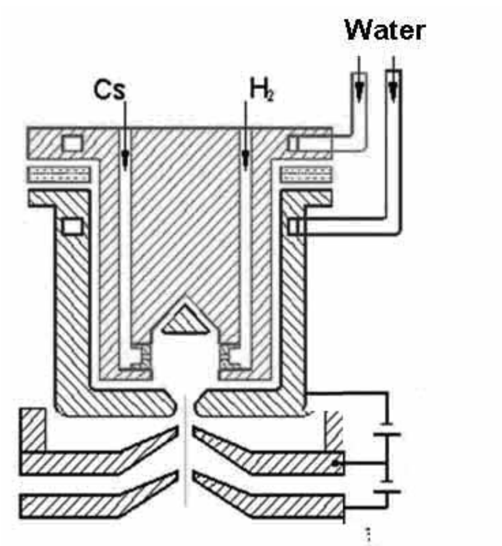

Fig.2. Scheme of upgraded Penning SPS

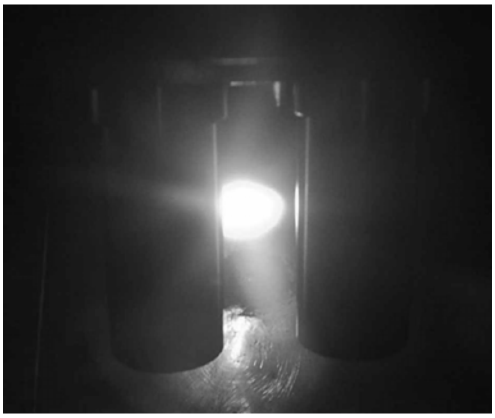

Fig.3. Thermal spot, produced at Faraday cup plate by 7 mA, 20 KeV H^- beam

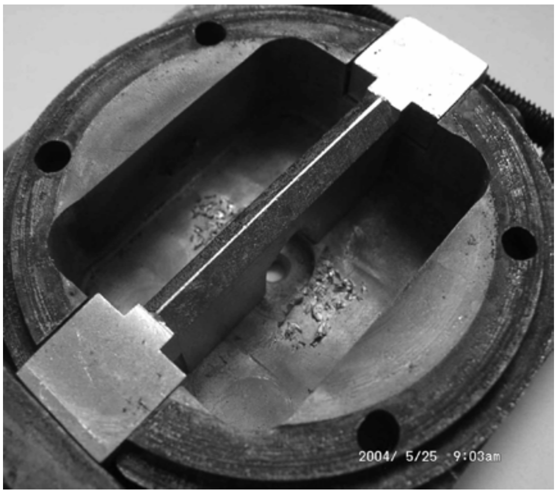

Fig.4. Molybdenum flakes on anode plate

Fig.5. Metal deposited to cathode-anode insulator

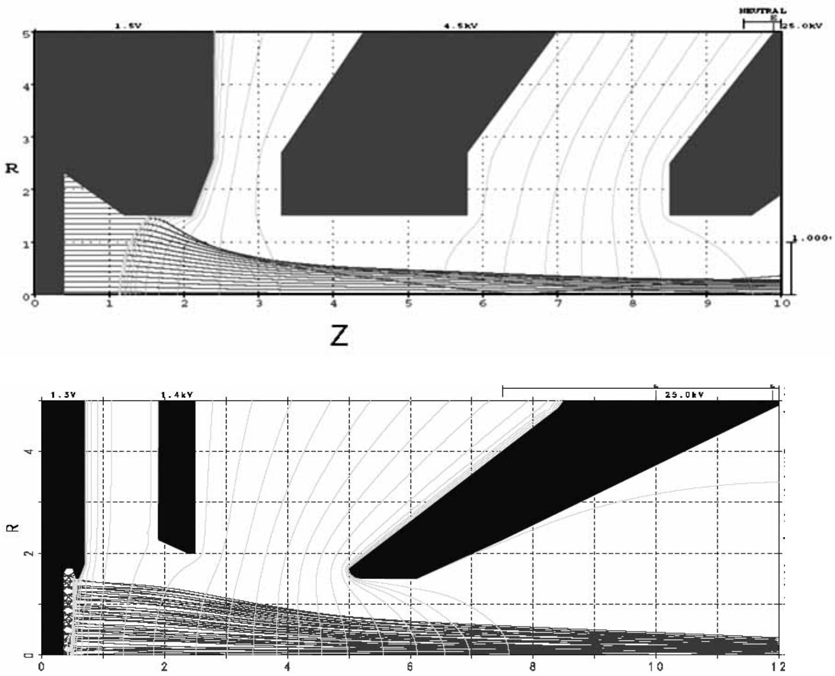

Fig. 6. NI trajectories simulated for various emitters. 3D axisymmetrical triode IOS

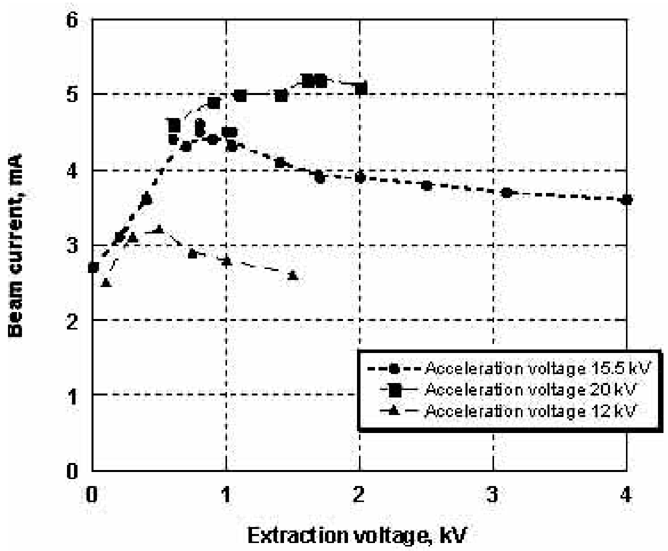

Fig.7. Beam current to collector with aperture 16 x 16 mm^2 vs extraction voltage for various acceleration voltages. Triode IOS. Discharge 70 V / 5 A

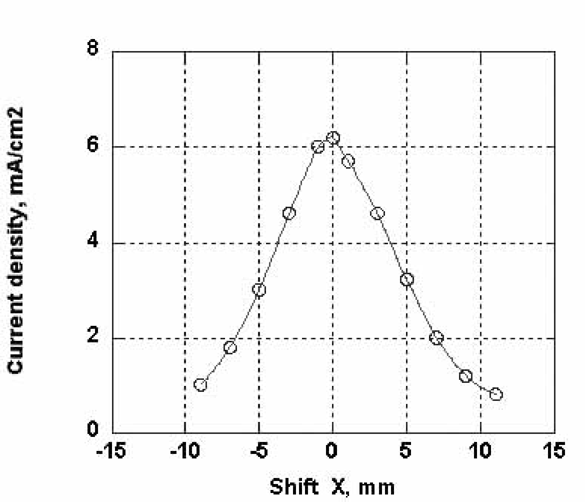

Fig.8. Current density distribution for 7.5 mA, 24 kV beam (X direction). Discharge 75 V / 6.2 A

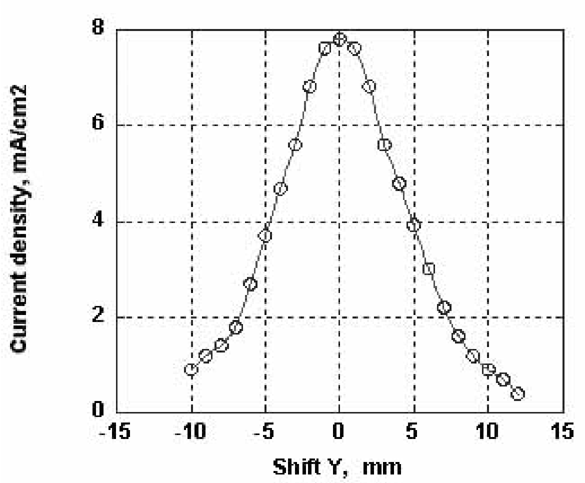

Fig.9. Current density distribution for 8 mA, 24 kV beam (Y direction). Discharge 75 V / 7.3 A

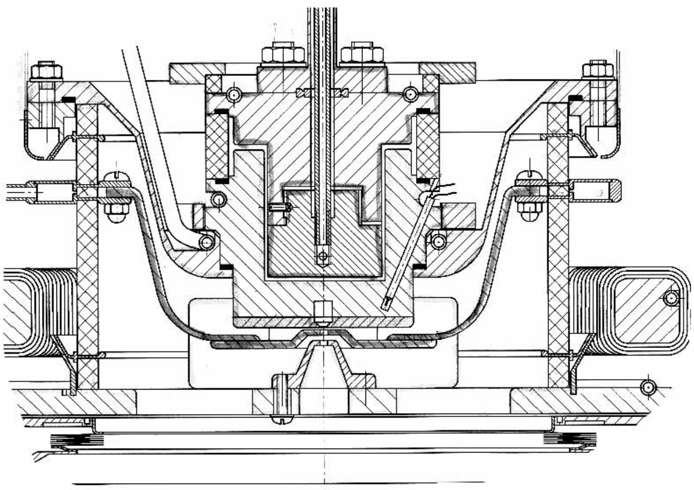

Fig.10. Principal scheme of flange source (cross section across magnetic field)

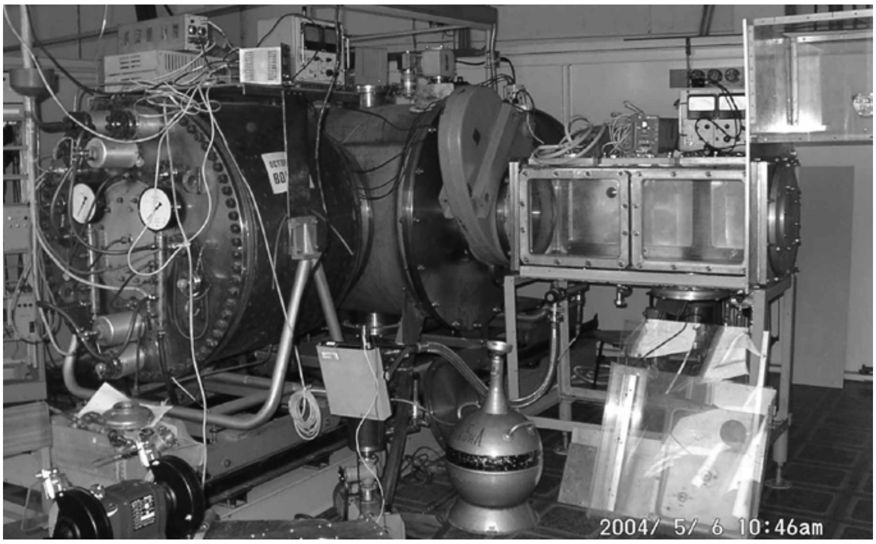

Fig.11. Photo of test bed under construction

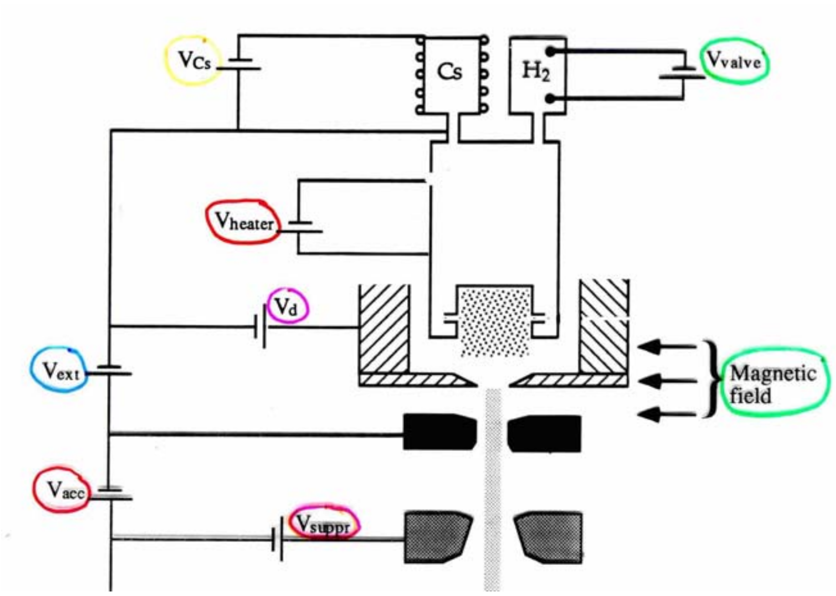

Fig.12. Schematic of source power supplies

Fig.13. Photo of invertor unit for power supplies.

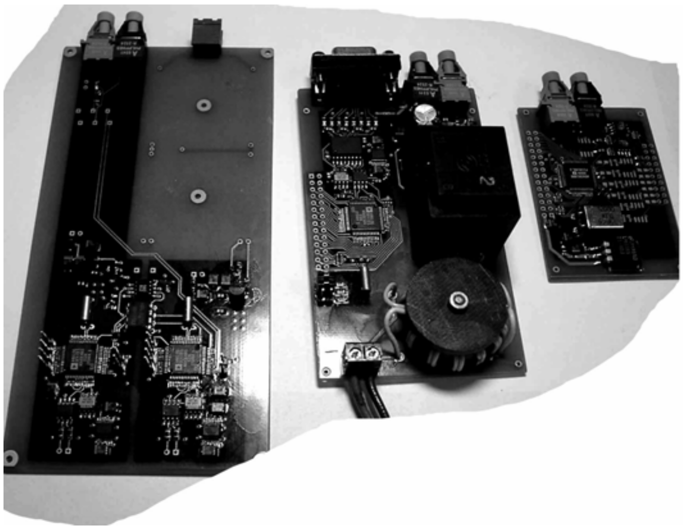

Fig.13. Biased controllers of control and data systems.
Left - temperature controller, center- universal digital multimeter,
right - power supply controller