CSNS H^- ion source test stand

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Abstract: The Penning surface plasma source is adopted as the China Spallation Neutron Source (CSNS) H^- ion source. The designed energy and beam current of the source are 50 keV and 20 mA, respectively, with a normalized root mean square (norm. rms.) emittance of 0.2 πmm·mrad. The construction of a H^- ion source test stand has been completed, and the commissioning of the source is in progress. Stable H^- ion beams with energy of 50 keV and current up to 50 mA are attained. Emittance measurement for the H^- beam is being prepared.

Key words: H^- ion source, energy, current, emittance

PACS: 29.20.Ej, 29.25.Ni **DOI:** 10.1088/1674-1137/35/7/014

1 Introduction

The CSNS is an accelerator-based high power project currently under research and development in China [1]. The accelerator complex consists of an 81 MeV H^- linear accelerator (linac) as the injector and a 1.6 GeV rapid cycling synchrotron (RCS). The linear accelerator consists of a 50 keV H^- Penning surface plasma ion source, a low energy beam transport line (LEBT), a 3.0 MeV Radio Frequency Quadrupole (RFQ) accelerator, a medium energy beam transport line (MEBT), an 81 MeV Drift Tube Linear Accelerator (DTL) and a high energy beam transport line (HEBT). As the origin of the linac, the H^- ion source plays a significant role for the reliable, stable operation and good performance of the CSNS. At present, there are basically two kinds of H^- ion sources being used for spallation neutron sources in the world: multi-cusp volume plasma source (RF multi-cusp volume plasma source (SNS) [2] or thermal filament multi-cusp volume plasma source (J-PARC) [3]) and surface plasma ion source (ISIS) [4]. The ISIS Penning Surface Plasma H^- Ion Source has been chosen as the ion source for the CSNS for the following reasons: (1) it completely satisfies the CSNS Phase-I beam requirements; (2) it has the lowest cost compared with other types of ion source; (3) there is a good collaboration between the Rutherford Appleton Laboratory (RAL) and the Institute of High Energy Physics (IHEP). The main parameters of the CSNS H^- ion source are listed in Table 1. As shown in Table 1, a pulsed beam current of 20 mA with a norm. rms. emittance of 0.2 πmm·mrad, which is also basically the performance of the ISIS H^- ion source [5]. In addition, a pulsed beam width of about 500 μs also satisfies the multi-turn injection requirement of the RCS with a 100 kW beam power for the CSNS Phase-I.

Table 1. Main parameters of the CSNS H^- ion source.

ion type	H^-
output energy/keV	50
repetition rate/Hz	25
pulsed beam current/mA	20
emittance (πmm·mrad norm. rms.)	0.2
pulsed beam width/μs	∼500
lifetime (months)	∼1

R&D of the CSNS H^- ion source started with the manufacture of the discharge chamber and the extraction electrode. Due to collaboration, the RAL provided a complete set of mechanical drawings. Several sets of discharge chambers and extraction electrodes were manufactured domestically. Tests with these components were performed on the RAL front

Received 25 September 2010

end test stand (FETS). The result demonstrates that the performance of these components is exactly the same or better than those made in the UK for ISIS.

After the successful manufacture of the discharge chamber for the CSNS H^- ion source, an H^- ion source test stand is constructed as one of the CSNS R&D projects. The main objective of the test stand is to build a stable and reliable ion source for the CSNS.

2 Construction of the test stand

The schematic layout of the H^- ion source test stand is shown in Fig. 1. The test stand consists of many subsystems, such as the ion source main body, the power supply system, the control system, the vacuum system, the beam diagnostic system, the grounding system, the water-cooling and Freon-chilling system, the Cesium delivery system, the hydrogen delivery system, the high voltage platform, etc.

The main body of the ion source is shown in Fig. 2. It includes the discharge chamber, vacuum chamber, extraction electrode, Penning and deflecting magnets, cold box, accelerating electrodes, feed-through for the chilling circulator, vacuum chamber for the beam diagnostics, etc.

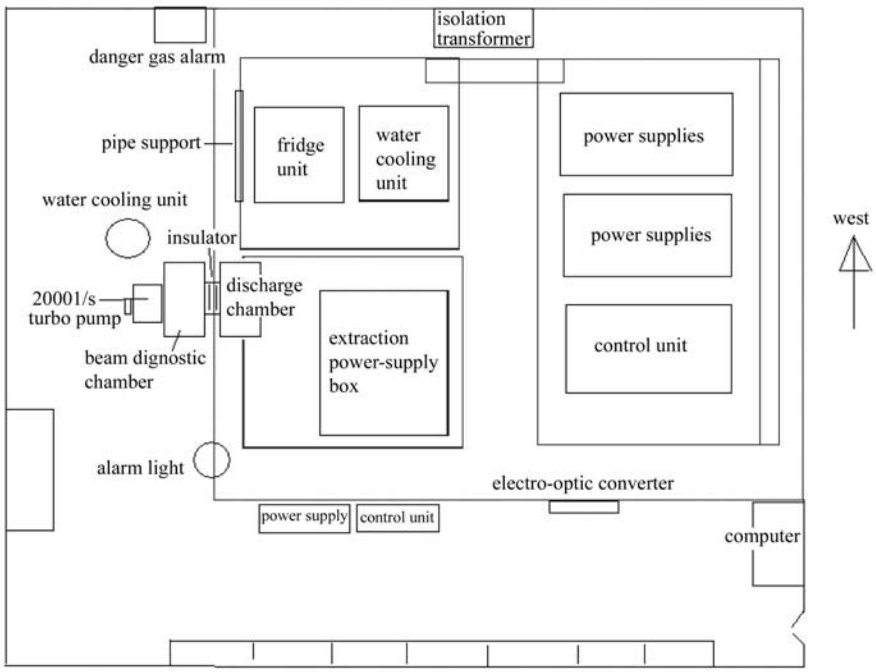

Fig. 1. Schematic layout of the H^- ion source test stand.

Fig. 2. Main body of the H^- ion source.

The power supplies include the Penning and deflecting magnets power supplies, the accelerating voltage power supply, the DC/AC discharge power supplies, the piezoelectric hydrogen valve power supply, the extraction power supply, the Cesium oven and Cesium transport pipe heater, the high-voltage isolating transformer, etc. The main power supplies are shown in Fig. 3.

The control system is developed using Yokogawa FA-M3R Programmable Logic Controllers (PLCs) and Experimental Physics and Industrial Control System (EPICS). It is a local and two-level control system and will be linked with the remote control system through an Ethernet in the future. It is composed of a front-end controller, field control equipment (device interface) and an Ethernet network. The schematic of the control system structure is shown in Fig. 4. Some of the devices controlled and monitored are shown as an example in Fig. 4. The communication between the PLC and the PC employs the Ethernet based TCP/IP protocol by in- stalling a driver supporting the Ethernet under EPICS.

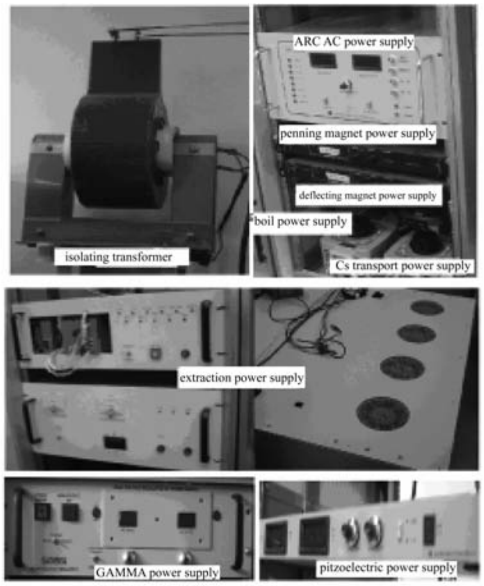

Fig. 3. Main power supplies for the H^{-} ion source.

In order to realize the integration of extendable systems, and to set up a friendly operator interface, the EPICS software is adopted and installed in the PC. The PC working as the front-end controller is the top-level control. The Operator Interface (OPI), Channel Access (CA) and the soft Input/Output Controller (IOC), based on the EPICS software toolkits, form the upper layer of the control system. The soft IOC on the upper control layer functions as a hardware controller running the device interface modules (i.e. the PLCs). CA connects the client in OPI with the server in IOC, and provides the OPI with transparent access to the IOC database. This software architecture allows the user to implement both control and monitoring through the graphical user interface developed by the Extensible Display Manager (EDM) toolkit based on EPICS, and to create the state notation program with State Notation Language (SNL) in IOC. The graphical user interface is shown in Fig. 5.

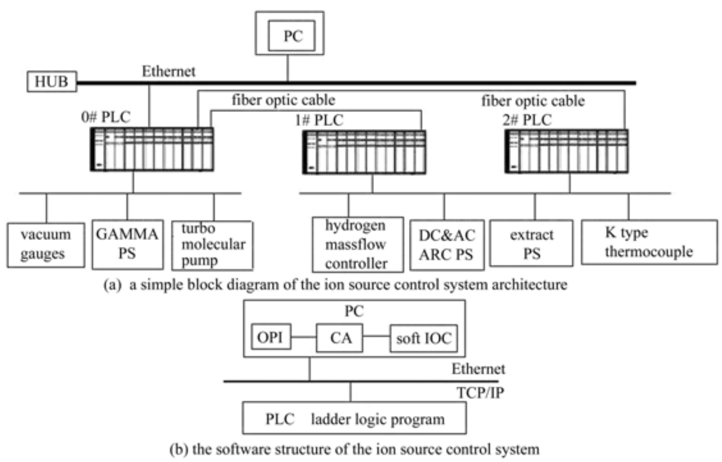

Fig. 4. Scheme of the control system.

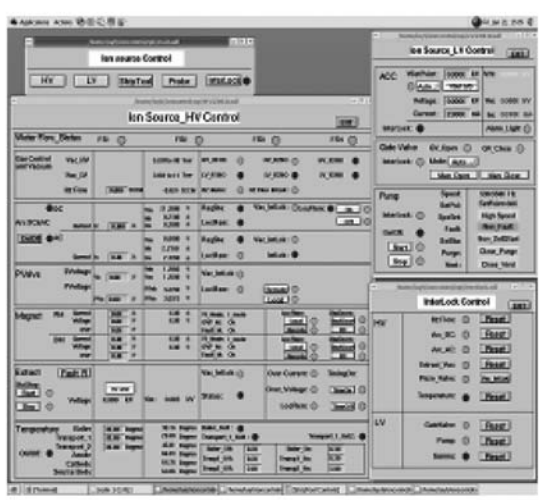

Fig. 5. The graphical user interface of the control system.

The vacuum system consists of a 14 l/s mechanical pump, a 2000 l/s turbo-molecular pump, two sets of vacuum meters and gauges, a CF250 air actuated valve and a KF40 electromagnetic valve. The air actuated valve is remotely controlled and interlocked with the vacuum meter. With the pumps, the static vacuum pressure is about 10^{-7} torr. The construction of the H^- ion source test stand was finished at the end of 2009.

3 Commissioning of the ion source

Before commissioning the ion source, all subsystems for the H^- ion source test stand are tested independently. The extraction electrode system is conditioned for extraction voltages up to 24 kV without H_2 flow and 20 kV with H_2 flow. The post extraction accelerating voltage is conditioned up to 55 kV. The deflecting magnet is tested to 12 A, and the Penning magnet to 10 A.

The commissioning of the ion source starts from the application of the DC discharge. The DC discharge is normally applied for about 30 minutes. The purpose of the DC discharge is as follows: (1) the low current conditions the discharge chamber without Cesium; (2) to heat up the discharge chamber to the operating temperature of around 500 ℃; (3) to allow the examination of the performance of the discharge chamber. Since the maximum output voltage of the DC discharge power supply is 1 kV, the DC discharge parameters (such as vacuum pressure, H_2 flux, the Penning magnetic field and the deflecting magnetic field) requirements are not as strict as for the pulsed discharge. The extraction voltage is applied at the same time to condition the extraction electrode. The stability of the extraction field is highly dependent on the vacuum pressure and the stability of the DC discharge. When the DC discharge current, temperature of the electrodes in the discharge chamber, extraction voltage, temperature of the Cesium oven and transport all satisfy the conditions required for a pulsed discharge, the low current DC discharge can be directly switched to high current pulsed discharge without any adjustment of the discharge parameters. In Fig. 6, a typical DC discharge current curve is shown.

The pulsed discharge and beam extraction must occur simultaneously. Since the Penning surface plasma H^- ion source requires Cesium to operate, there will inevitably be some Cesium vapour diffusing out of the discharge chamber and part of the Cesium will deposit on the extraction electrode. As the

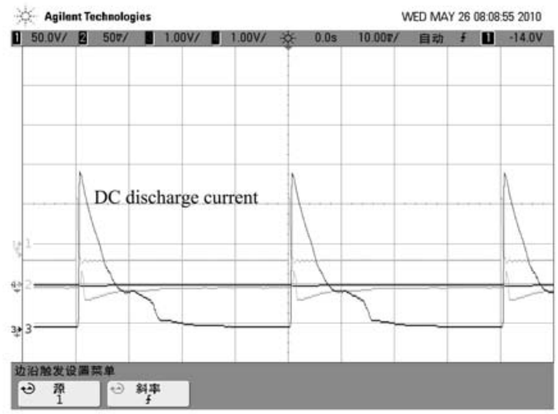

Fig. 6. The DC discharge, the peak current and pulse width are about 18 A, 15 ms, respectively.

Cesium deposited on the electrode accumulates, the capability to withstand the extraction voltage between the discharge chamber and the extraction electrode is diminished. However, part of the extracted particle beam (H^- ions and electrons), especially the electrons, will bombard the electrode and cause heating which serves to prevent the accumulation of too much Cesium on the extraction electrode. Fig. 7 shows the pulsed discharge current and the extraction current (both the H^- ions and electrons). The pulsed discharge current is about 50 A with a pulse width of 800 μs and the extraction current is about 300 mA with a pulse width of 520 μs. The pulsed discharge current is adjustable from about 30 A to 50 A, and the extraction current also varies with the discharge current. In Fig. 7, the voltage output of the piezoelectric hydrogen valve power supply is also shown.

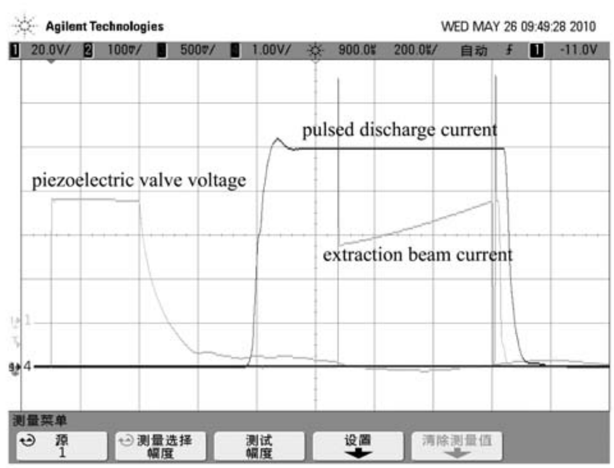

Fig. 7. The pulsed discharge current of 50 A with a pulse width of 800 μs and the extraction beam current about 300 mA with a pulse width of 520 μs.

After the pulsed discharge is stable, the power supplies including the piezoelectric hydrogen valve power supply, the H_2 flow controller, the Penning magnet supply, the deflecting magnet power supply and the pulsed discharge power supply are all switched to remote mode from manual mode. The door of the high voltage cabin is closed. Then the accelerating voltage is applied and raised up to 50 kV. The accelerating power supply is interlocked with the door and the accelerating voltage is automatically increased by the control system. In Fig. 8, the output H^- ion beam with an energy of 50 keV and a current of 53 mA is shown. The pulse width is 520 μs and the repetition rate is 25 Hz. 48 hours' continuous operation of the test stand is also carried out and more than 8 hours' stable operation without interruption has been achieved.

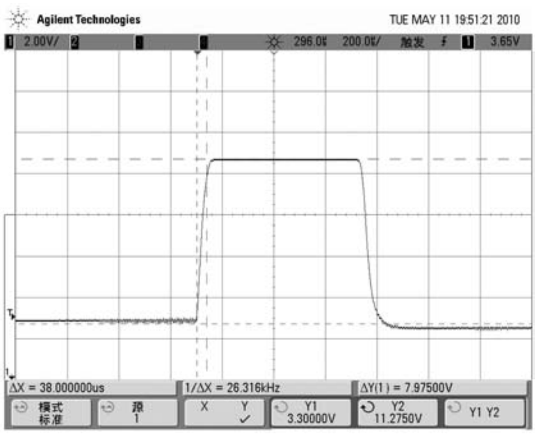

Fig. 8. The extraction H^- ion beam waveform with a current of 53 mA and an energy of 50 keV.

4 Future work

Emittance measurement is being prepared, which will allow detailed study of the beam quality and beam transport. Two or three dimensional modeling (such as thermal [6], electromagnet, particle tracking, plasma meniscus, etc.) will provide a deeper understanding of the H^- ion production in the discharge and beam transport in the extraction region and the post-acceleration line. Optimization of the components and the optical beam will have a significant impact on improving the performance of the H^- ion source for the CSNS.

The authors would like to thank Dr D.C. Faircloth of the Rutherford Appleton Laboratory (RAL), UK, for helpful discussion on the commission of the ion source.

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