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The vacuum system of the China spallation neutron source

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ABSTRACT

The china spallation neutron source (CSNS) is designed to accelerate pulse proton beams to 1.6 GeV kinetic energy with a beam power of 100 kW at 25 Hz repetition frequency, which are used to strike a solid metal target to produce spallation neutrons. We describe the structure features, technical requirements, design scheme and experimental results of each part of the CSNS vacuum system. The alumina ceramic constructed of isostatically pressed methods is chosen as the material of the dipole and quadrupole vacuum chambers as a result of the rapid cycling magnetic field in the rapid cycling synchrotron (RCS), which were welded by glazing and metallizing, respectively. The inner surfaces of the ceramic chambers were coated with TiN using the magnetron sputtering method in order to reduce the secondary electron yield (SEY); the radio frequency (RF) shielding copper strips were covered around the outer surfaces of the ceramic chambers by a kapton film to decrease the impedance of the image current. The CSNS vacuum system has been installed and tested; an average static pressure of 1.3×10^{-7} Pa was achieved in the RCS. The average dynamic pressure was 1.1×10^{-6} Pa when the first beam power reached the national acceptance target of 10 kW at 25 Hz.

1. Introduction

The CSNS complex is designed to provide multidisciplinary platforms for scientific research and applications by national institutions, universities, and industries. It mainly consists of an H^- Linac and a proton rapid cycling synchrotron (RCS). Negative hydrogen ions (H^-) are firstly generated from a penning ion source. The four-vane radio frequency quadrupole (RFQ) accelerator forms beam bunches at 324 MHz RF frequency and accelerates the beam to 3 MeV. Four drift tube Linac (DTL) tanks further increase the beam energy to 80 MeV. A long beam transport line is followed with the DTL to send the beam a rapid cycling synchrotron accelerator. The H^- beam is stripped to become proton beam and injected into the RCS ring. In the ring the proton beam is accumulated to a high current pulse and then accelerated to 1.6 GeV kinetic energy at 25 Hz repetition rate, which striking a solid metal target to produce spallation neutrons. The high-energy neutrons are then cooled down by moderator to become thermal or cold neutrons, which meet requirements for the neutron scattering experiments. The CSNS is designed to deliver a beam power of 100 kW with the upgrade capability to 500 kW by additional DTL tanks or superconducting Linac in the future [1,2]. Fig. 1 shows the schematic layout of CSNS facilities.

Based on the design experience of the similar accelerator facilities including the ISIS at the Rutherford Appleton Laboratory of UK [3], the SNS at the Oak Ridge National Lab of US [4] and the J-PARC at Japan Atomic Energy Research Institute [5], the main design goals of the CSNS vacuum system follow as below:

- The operating pressure of the RCS with the proton beams is in 10^{-6} Pa range to minimize ion-induced pressure instability.
- The ceramic chambers have been chosen in the RCS dipole and quadrupole magnets to reduce the eddy-current effects which will produce the perturbation of magnetic fields and the large ohmic losses.
  •A RF shielding for the ceramic chambers is necessary to lower the impedance of the image current induced by the circulating beam. The shielding is designed as a high-frequency pass filter, where no eddy current can be generated.
- The inner surface of the ceramic chambers is coated with TiN to reduce the secondary electron yield.

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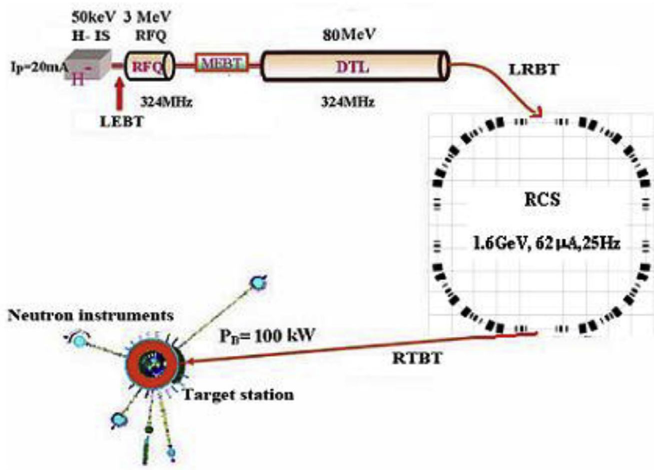

Fig. 1. Schematic layout of CSNS facilities.

2. H^- Linac

H^- Linac consists of ion source (IS), low energy beam transport (LEBT) line, RFQ accelerator, medium energy beam transport (MEBT) line and DTL.

2.1. IS & LEBT

The penning surface plasma H^- ion source has been chosen due to its beam performance and reliability. In order to ensure the stability of H^- ions beam, the hydrogen gas with a flow rate of 10 sccm (1.69×10^{-2} Pa·m^3/s) are input into the ion source chamber by a piezoelectric valve at 25 Hz frequency to produce an beam intensity of 20 mA under the interaction of electric and magnetic field. The H^- ions are extracted from the plasma chamber through a slit of 10 mm × 0.6 mm in horizontal and vertical directions. A dynamic pressure of 2.5×10^{-3} Pa outside of the plasma chamber is kept by two turbo-molecular pumps with pumping speeds of 2000 L/s each, so as to reduce the stripped loss of the H^- ions and avoid diffusion of the hydrogen gas to the other beam chambers [6]. Fig. 2 shows the pumping system of the ion source.

The H^- ion beam extracted from the ion source is matched into the RFQ by means of LEBT with a length of 1.68 m. The LEBT vacuum chambers were fabricated from the 304 grade stainless steel with a low outgassing through vacuum pre-treating, so its main gas load comes from the hydrogen gas of the ion source. A turbo-molecular pump with pumping speeds of 800 L/s is installed to evacuate the LEBT chambers. As the aperture of the LEBT vacuum chamber is small, a differential pumping method is applied to decrease the hydrogen gas of ion source into the RFQ vacuum system.

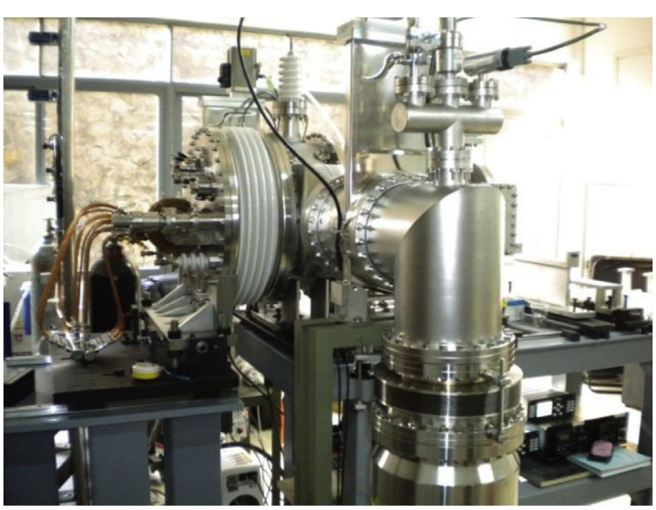

Fig. 2. Pumping system of the CSNS ion source.

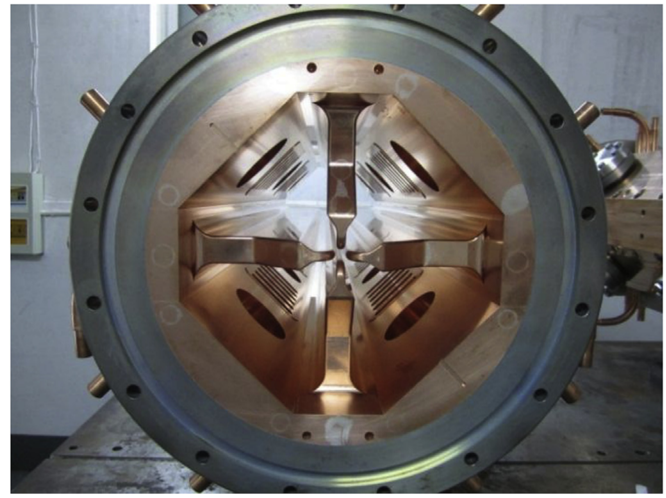

Fig. 3. RFQ four-vanes electrodes structure.

2.2. RFQ &MEBT

RFQ is used to focus, bunch and accelerate the H- ion beam, it can effectively control the increase of the beam emittance and improve the performance of the beam. RFQ cavity with a diameter of about 350 mm and a length of 3.62 m is made of 99.98% oxygen-free copper; it has a high machining accuracy and many welding seals. The geometrical structure of the RFQ electrodes has four vanes, which causes a very limited conductance for pumping down. Fig. 3 shows the RFQ internal structure.

Twelve DN160 conflat flanges on the surfaces of the RFQ cavity are used to pump through the slot conductance. The pumping ports are evacuated in parallel by two turbo-molecular pumps with pumping speeds of 1100 L/s each and three ion pumps with pumping speeds of 1000 L/s each. A dynamic pressure of 5×10^{-6} Pa is achieved after RFQ conditioning, which can effectively suppress arcing. Fig. 4 shows the RFQ pumping manifold.

The main functions of MEBT are to match the beam from RFQ into DTL and further chop the beam into the required time structure. It is comprised of two beam-bunchers, a beam-chopper, eight beam position monitors, four wire scanners for the beam profile measurement, two current transformers for beam intensity measurement, etc. The total length of MEBT is 3.03 m, its diameter is about 50 mm, and the material

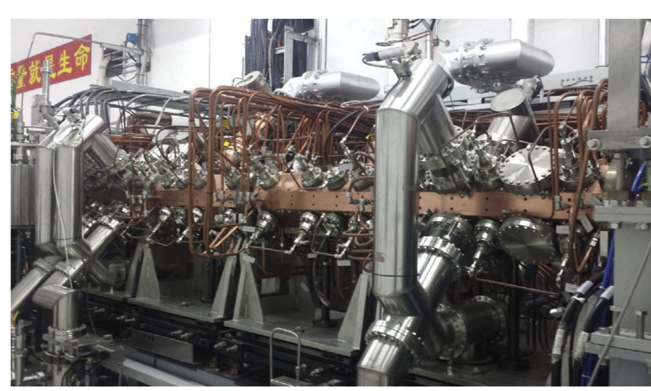

Fig. 4. RFQ pumping manifold.