Stripping target of 2.5 MeV 10 mA tandem accelerator

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Abstract

An electrostatic tandem-accelerator with 2.5 MeV 10 mA proton beam is under development at BINP. One of the accelerator important parts is a target that converts the half energy accelerated negative hydrogen ions into the proton beam. In the tandem accelerator an argon stripping target with 1 cm tube diameter and 40 cm tube length will be used. To reduce argon flux from the target to accelerator gaps a gas recirculation by turbomolecular pump installed in high voltage electrode is provided. Processes of plasma production and ultraviolet emission due to target ionization by fast ions and stripped electrons are considered in the report.

Neutron therapy facility based on 2.5 MeV tandem accelerator is developed at BINP. [1,2]. Fig. 1 shows view of the vacuum insulation tandem accelerator. Negative hydrogen ion beam produced in ion source and transported by low energy tract is injected into the tandem accelerator. Proton beam produced by stripping of the negative ion beam in gas target placed in high voltage electrode is accelerated to double voltage of the high-voltage electrode. Set of intermediate electrodes of the tandem accelerator provides uniform potential distribution and prevents full voltage effect.

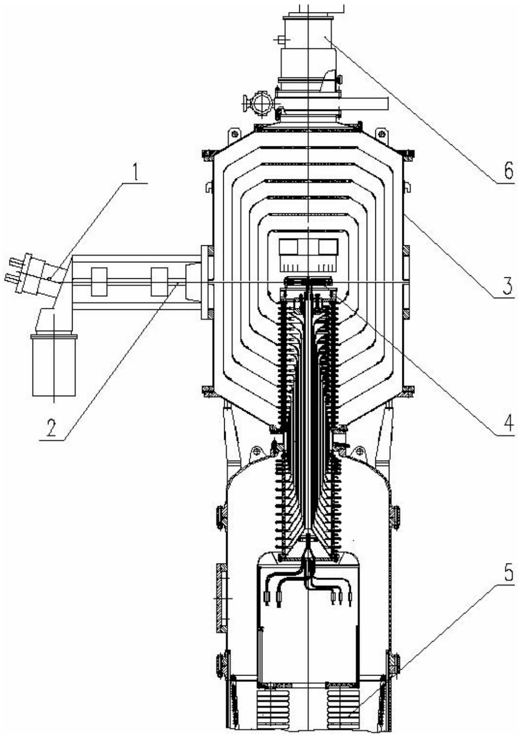

Fig 1. Cutaway view of the tandem accelerator. 1- negative hydrogen ions source, 2- low energy beam tract, 3- vacuum vessel, 4-stripping target, 5- sectionalized rectifier, 6- cryo pump.

Different versions of the stripping target converting half-energy accelerated negative-hydrogen ions into a proton beam have been previously considered in detail [1,3]. As a result, argon stripping target was accepted for the tandem-accelerator. Atomic gases do not dissociate by the energetic hydrogen beam. Argon has sufficiently large stripping cross-section and high pumping efficiency. Dependence of the hydrogen beam composition on the argon target thickness is shown in Fig.1. For the stripping target thickness of $2.1\cdot10^{16}$ cm^{-3} the proton fraction is 95% and for the target thickness $3.3\cdot10^{16}$ cm^{-3} the proton fraction is 99%.

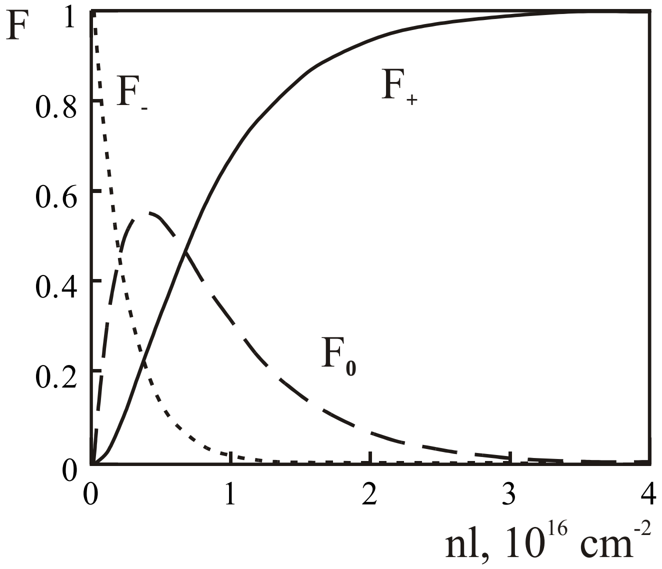

Fig.2. Dependence of beam fractions on target thickness.

The stripping cell is an oil-cooled copper tube with an inner diameter of 1 cm and a length 40 cm installed inside a high-voltage electrode. Argon is puffed into the middle of the stripping cell at a rate ~50 mTorr·*l*/s. At a pumping speed of 1500 *l*/s the argon pressure in the high-voltage electrode is ~$3.5\cdot10^{-5}$ Torr.

The stripping target actively influences tandem-accelerator operation. The target increases pressure in accelerator gaps and emits argon ions and ultraviolet radiation to the accelerator gaps. The influence of the stripping target can reduce electrical strength of the accelerator due to collisions of secondary particles with the electrodes and should be minimized.

To reduce the argon flux from the stripping target to the accelerator gaps, recirculation of argon in the target can be used. Figure 3 shows a scheme of the stripping target with recirculation. Inside the high-voltage electrode an additional recirculation chamber with small apertures for the beam is installed. Argon outgoing from the stripping cell is intensively pumped by a mounted inside the chamber turbomolecular pump. Exit of the turbomolecular pump is joined with the stripping-cell tube and the pumped argon returns to the cell. Our simulations showed that for the presented geometry the recirculation reduces the argon flux to the accelerator gaps more than 10 times. The main problems of the recirculation scheme are operation of the turbomolecular pump inside the high-voltage electrode and high gas pressure at the entrance of the pump. The accepted scheme of recirculation differs from traditional [4,5] where turbomolecular pump is placed in atmosphere. Controller of the ATP 900 turbomolecular pump is installed in the rectifier volume filled with SF_6 gas.

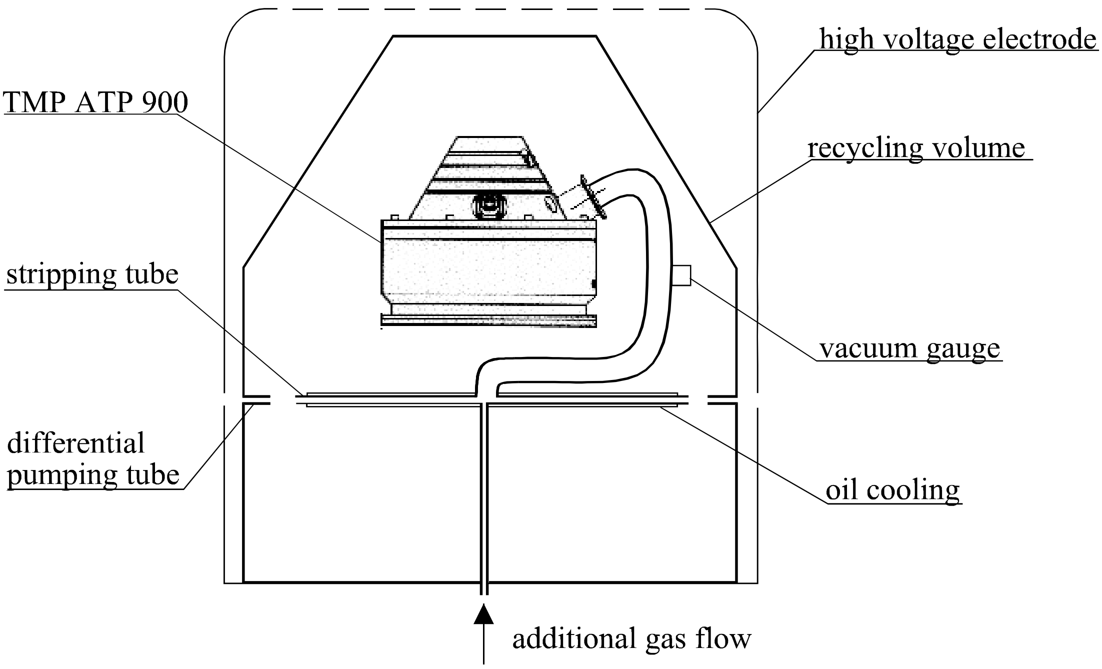

Fig.3. Stripping target with recirculation.

The argon atoms in the target are intensively ionized by 1 MeV hydrogen particles which leads to plasma production in the stripping cell. There are two contributions to ionization of the target atoms. The first one is classical ionization losses. A hydrogen particle loses ~600 eV in the target and produces ~8 Ar^+ ions. The second factor is ionization of the argon atoms by two electrons with an energy ~500 eV stripped from an H^- ion. Estimation showed that these two electrons ionize ~10 Ar atoms. Thus, the number of ionizations in the stripping target produced by one H^- ion is A~18. Rate of ion density production in the target is $\frac{dn_i}{dt} \approx \frac{AI_b}{\pi a^2 L}$, where I_b is the H^- current, a is the stripping tube radius and L is the stripping tube length. The ions leave the target at a rate $dn_i/dt \approx -n_i/\tau_i$, where $\tau \approx a/v_i$ is the Ar^+ ion life-time and $v_i \approx 5\cdot10^5$ cm/s is the velocity of the Ar^+ ions. In equilibrium the rates are equal and the plasma density in the target is estimated as $n_i \approx AI_b/\pi a L v_i \approx 3\cdot10^{10}$ cm^{-3}. The obtained value of the plasma density is much larger than the ion density in the hydrogen beam $n_b \approx I_b/\pi a^2 e v_b \approx 5\cdot10^7$ cm^{-3}. Assuming the electron temperature of the plasma target $T_e \approx 5$ eV we obtain the Debye length $r_D = \sqrt{T_e/4\pi n_i e^2} \approx 10^{-2}$ cm and the plasma potential $\varphi \approx 3T_e/e \approx 15$ V. The arising plasma leads to emission of Ar^+ ions into the accelerator gaps. The total current of the Ar^+ ions produced in the target is $I_i \approx 2\pi a^2 n_i v_i \approx 40$ mA and the current of Ar^+ to the accelerator gaps determined by a solid angle is $I_{ac} \approx I_i\, b^2/s^2 \approx 40$ mkA, where b is radius of high voltage electrode beam aperture, s is distance to the aperture.

After passing of the high-energy hydrogen particles through the stripping target, the Ar atoms are exited and a flux of ultraviolet photons with 10–15 eV energy from the target is generated. A number of photons produced in the target by one hydrogen particle is estimated as $B \approx 30$. The photon flux to the accelerator gaps is $S \approx BI_b\langle\Omega\rangle \approx 5\cdot10^{15}$ s^{-1}. For photoemission coefficient $\gamma \sim 0.1$, the current of secondary photoelectrons in the accelerator is $I_p \approx \gamma S_{ac} \approx 80$ mkA. Coefficient of the ultraviolet reflection from metals is ~ 0.6 and after several reflections the ultraviolet photons can fall to the surface of a ceramic high-voltage insulator.

To reduce dangerous influence of the stripping target on the tandem-accelerator the following actions can be used. To minimize the ion and ultraviolet fluxes from the stripping target, the tube diameter should be taken as small as possible. To reduce the secondary-electron emission from the accelerator electrodes, the area near the beam apertures should be covered by metals with high work function – Mo, Ta, Nb. To avoid direct acceleration of the secondary electrons to the high-voltage electrode, small transverse magnetic fields near the beam apertures deflecting the electrons to the electrodes should be applied. Additional labyrinths shielding the high-voltage insulator can be useful.

To study the argon recirculation and the plasma production in the stripping cell an experimental test stand is under preparation. Figure 4 shows a general view of the test stand. At the initial stage of recirculation study the recirculation chamber will be pumped by a usual turmolecular pump installed at the lower flange of the stand chamber. The turbopump can provide argon pumping from the stripping tube chamber without recirculation. At the next stage a turbomolecular pump ATR 900 will be mounted inside the recirculation chamber and the real recirculation scheme will be checked. To produce plasma in the target, a plasma diagnostic neutral-beam injector providing injection of a 10–100 mA, 10 keV hydrogen or helium beam into the stripping tube will be used. Also ionization of the target by 500 eV electrons will be studied by injecting a corresponding electron beam. Parameters of the target plasma will be measured by Langmuir probes, and ultraviolet emission will be registered by semiconductors detectors.

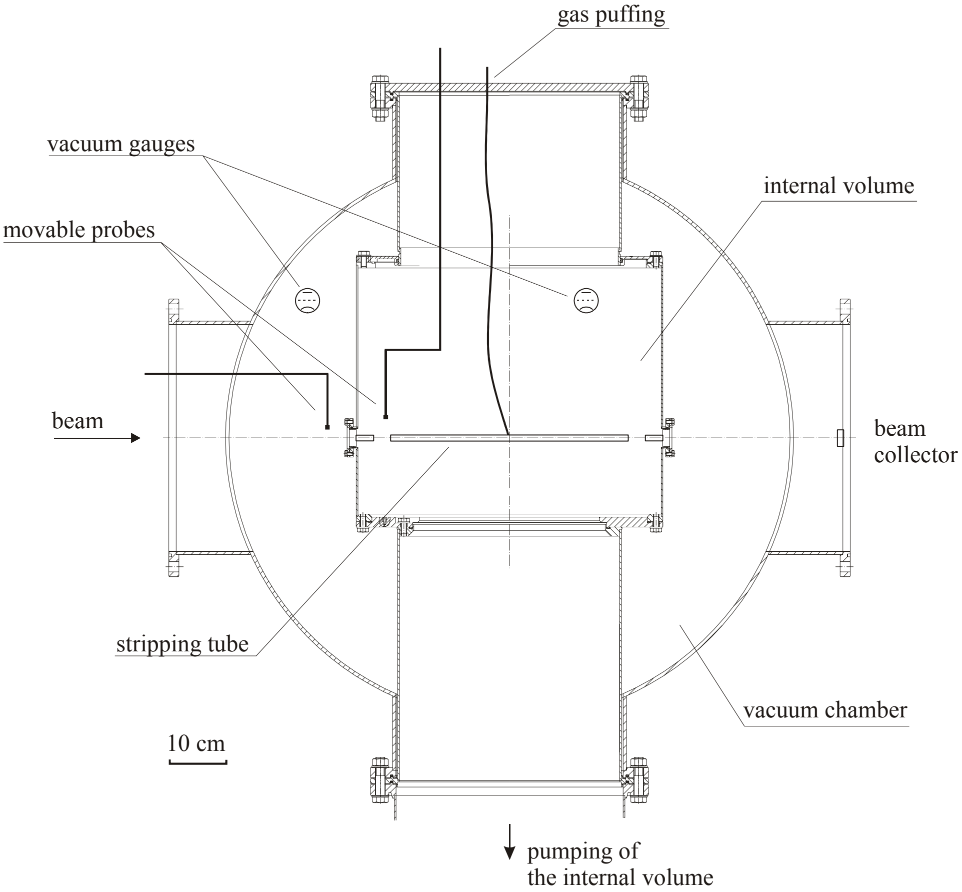

Fig.4. General view of experimental test stand.

At present a version of the stripping tube without the recirculation is prepared for mounting inside the high-voltage electrode. Assembling of the experimental test stand is being completed.

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