CALIBRATION TESTING OF THE STRIPPING TARGET OF THE VACUUM INSULATED TANDEM ACCELERATOR

A. Kuznetsov, V. Aleynik, I. Sorokin, S. Taskaev, M. Tiunov, I. Shchudlo,
BINP SB RAS, Novosibirsk, Russia

Abstract

Presented work is aimed on modernization of the gas stripping target that is used in the Vacuum Insulated Tandem Accelerator (VITA) to recharge negative hydrogen ions into protons. The target was modernized to get higher efficiency of the beam transportation and to raise the current of the accelerated proton beam. The design of the modernized stripping target, the calculated data on the gas flow rate and recharge effectiveness, also the results of experimental measurement of transported current depending on the gas flow rate are presented. The method of the target thickness determination and the procedure to adjust the regime of the gas flow rate to get the required recharging effect were suggested.

INTRODUCTION

The Vacuum Insulated Tandem Accelerator (VITA) was developed in the Budker Institute of Nuclear Physics [1] to produce epithermal neutrons for boron neutron capture therapy in the $^{7}Li(p,n)^{7}Be$ reaction. The parameters of the generated radiation allow us to carry out in vitro and in vivo investigations of BNCT. In present moment the modernization of the facility elements is carrying out to meet the parameters required for clinical usage.

The design of the VITA facility is shown at figure 1. The principle of the tandem accelerating scheme is accelerating of the negative hydrogen ions to the 1 MeV energy determined by the high voltage electrode potential, recharging the ions into protons in the gas stripping target and then accelerating to the 2 MeV energy by the same accelerating potential. The vacuum insulation of the electrodes, the circumstance that the feedthrough insulator is located at significantly big distance to the accelerating gaps and the gas pumping realized through the electrode shutters allows us to believe in capability of the VITA to produce a high current proton beam.

The optimal stripping target is supposed to be the argon gas target constructed as a cooled tube with the gas injection in the middle of the tube [2]. The tube length is 400 mm, inner diameter was made 10 mm, and from 2011 year the diameter was increased to 16 mm. The photo of the new target is shown at the figure 2.

The protons equilibrium yield is 99.9880%. The beam charged components and the full current in the output of the stripping target in dependence on the linear density of the argon in the target are presented at figure 3. The gas consumption for the 16 mm tube with length 400 mm and 300 K temperature is in linear dependence on the target density and described as an equation:

$$Q\ [10^{18}\ s^{-1}] = 2.63\ nl\ [10^{16}\ cm^{-2}],$$
$$\text{or } Q\ [mTorr\ l\ s^{-1}] = 75\ nl\ [10^{16}\ cm^{-2}].$$

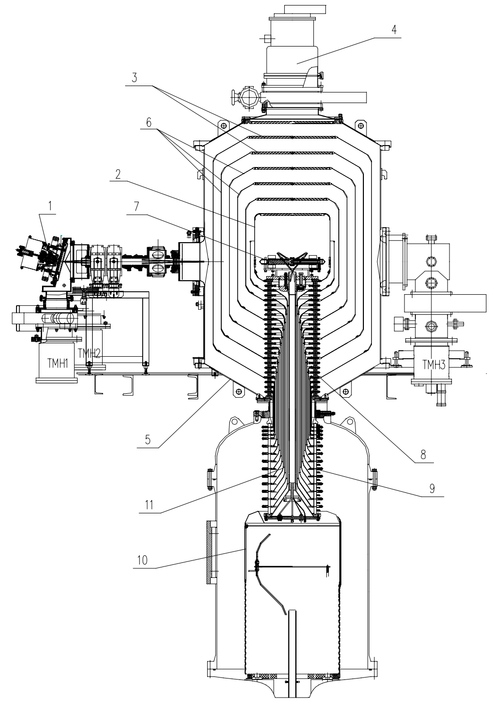

Fig. 1. Scheme of the VITA facility. 1 – ion source (H^-); 2 – high voltage electrode; 3 – electrode shutters; 4 – cryo pump; 5 – accelerator vacuum volume; 6 – intermediate electrodes; 7 – stripping target; 8 – feedthrough insulator (vacuum part); 9 – feedthrough insulator (gas part); 10 – high voltage source; 11 – coaxial feeding tubes.

Fig. 2. New Ø16-mm stripping target placed on the feedthrough insulator.

ISBN 978-3-95450-125-0

EXPERIMENTAL LAYOUT

The gas injection system consists of the gas vessel with pressure regulator, electromechanical gas flapper, the buffer volume and high precision leak valve which are located in the high voltage source. The gas flows from the buffer to the target through the leak valve and long tube with 2 m length and 4 mm inner diameter placed inside the feedthrough insulator. The gas flow rate can be managed with help of the gas flapper by manual or automatic control. The pressure of the gas in the buffer volume is determined by the frequency of the gas flapper opening. In the experiments carried out the duration of the gas pulse was 160 ms and output pressure of the pressure regulator was 4 atm. Characteristic time of the gas extraction is 500 s.

The gas pressure in the accelerator volume was controlled by the vacuum lamp located in the output of the accelerator.

The measuring of the high voltage feeding current (accelerator current) I_{acc}, the current in the feedthrough insulator resistive divider I_{div} and the current in the output beam collector I_{out} allows us to determine the full injected current as $I_{inj} = I_{acc}$- I_{div}- I_{out} taking into account that the dark currents become almost negligible after good accelerator training.

EXPERIMENTAL RESULTS

The measurements of the accelerator output beam current and the residual pressure in dependence on the gas flow rate was carried out. With out gas puffing the residual pressure was about 0.5 10^{-4} Pa. With the gas puffing frequency 1/40 Hz the pressure come to the stationary level 6 10^{-4} Pa, with the frequency 1/20 Hz – 11 10^{-4} Pa, with the frequency 1/10 Hz – 22 10^{-4} Pa, with the frequency 1/5 Hz – 33 10^{-4} Pa. The dependence of the residual pressure on the gas puffing frequency is almost linear up to 1/10 Hz frequency. So the gas target density can be mediately determined by the residual gas pressure.

The negative hydrogen ion beam with 21 keV energy was injected into the accelerator with 800 kV high voltage electrode potential. The injected current was 225 ± 10 mA, and the dark current was 24 ± 4 mA (Fig. 4).

With the gas target density 0.29 10^{16} cm^{-2} (the value calculated for the 800 keV ion beam) the output proton current is equal to the output negative ion current and the total registering current I_{out} equals zero. Registering of the residual gas pressure in this moment allows us to calibrate the target density and the gas flow rate in the context of pressure.

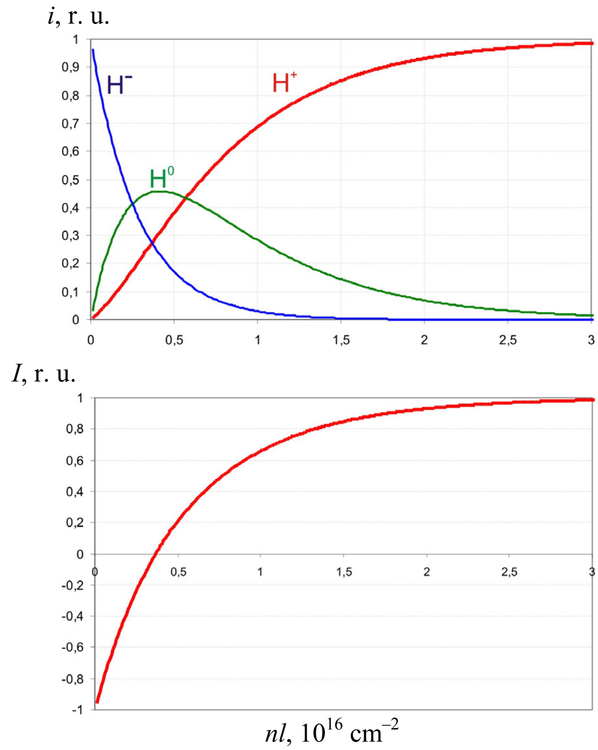

Fig. 3. The beam charged components (a) and full current in the output of the stripping target (b) in dependence on the linear density of the argon gas target..

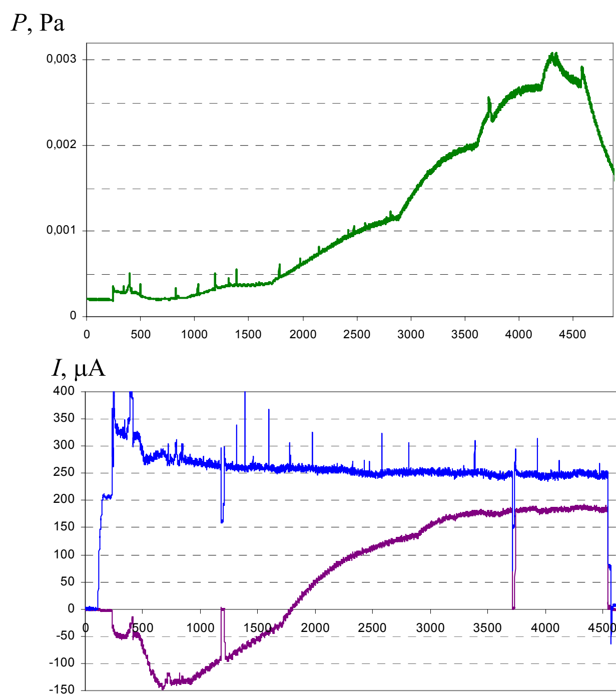

Fig. 4. Time dependence of the residual gas pressure P (a), the accelerator current I_{acc} (b, upper line) and beam collector current I_{out} (b, bottom line).

ISBN 978-3-95450-125-0

The measured and calculated dependences of the output current on the residual gas pressure is presented at figure 5. The measurement was made after the time 690 s when no any corrections were made in the magnetic focusing and beam correctors of the low energy beam line. In the calculation it was supposed that maximum output proton current equals 188 mA and 20% of accelerated particles were lost in the accelerating tract between the stripping target and accelerator output. The particle loss in the accelerator tract coming from the decelerating of negative ions by contrast to protons and the beam diameter expanding to the bigger size then accelerating apertures allows to transport. (The apertures diameters were 43, 43, 35, 30, 25 and 20 mm in the negative ions accelerating tract, and all by 20 mm in the proton accelerating tract).

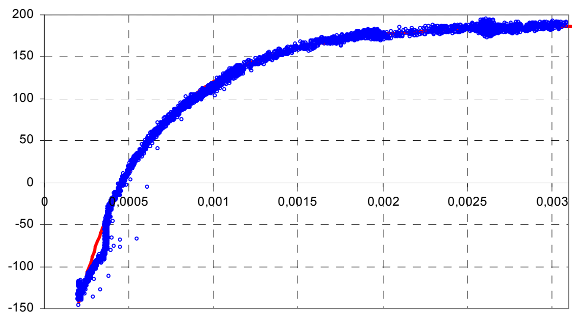

Fig. 5. Measured and calculated output current in dependence on the residual gas pressure.

Result of the ions trajectory calculations is presented at figure 6. It was calculated that the last 3 electrodes capture 20% of particles and this value is in the good agreement with 22% experimental particle loss determined as a relation of 146 mA maximal registered negative ions current to 188 mA maximal proton current in the output collector (Fig. 5).

At the figure 5 one can see the good agreement of measured and calculated dependences of the output beam current on the target density, and using the point of measured zero current the dependence can be normalized.

To guarantee recharging of the 90% of ions to protons at the energy 0.82 MeV the argon gas target with linear density 1.5 10^{16} cm^{-2} is required. The gas consumption should be 0.1 Torr l s^{-1}. With cryo pumping speed limited by the electrode shutters in the range about 3 000 l/s, the pressure in the high voltage electrode will be 4 10^{-3} Pa.

Thus, the experiments carried out allowed us to calibrate the stripping target and to test the procedure of the gas flow regulation to get the required recharging of the injected negative hydrogen ion beam.

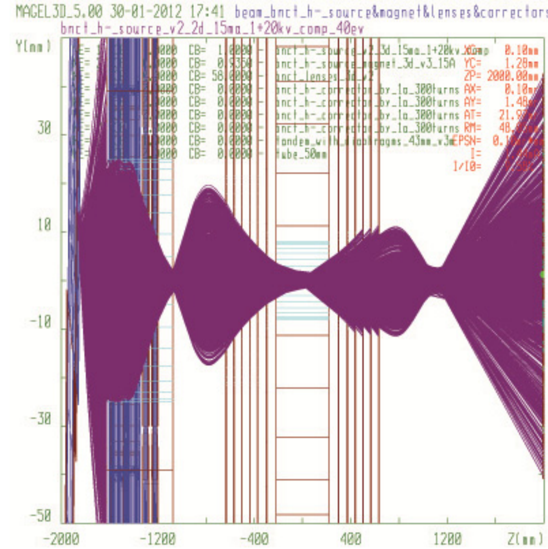

Fig. 6. Calculated trajectories of negative ions in the tandem-accelerator (ion source is located at the left side, Z=0 corresponds to the middle of the stripping target and the output beam collector is located at the right side at the point Z = 1500 mm.

SUMMARY

To provide recharging of the negative hydrogen ions to protons in the Vacuum Insulated Tandem Accelerator the stripping target is used, that is an oil-cooled tube with length 400 mm and diameter 16 mm with gas injection in the middle of the tube.

In the paper the calculated data on the beam components and current in dependence on the linear target density was presented alone with the experimental results on output current measuring in dependence on the gas flow rate. The method of regulation of the gas flow rate using the residual pressure measurements to get the required negative hydrogen ions recharging is tested. All experimental measurements are in good agreement with calculations. The residual pressure in the accelerating channel is estimated.

The work was partially supported by the Ministry of Education and Science of the Russian Federation.

REFERENCES

[1] V. Aleynik, et al., Applied Radiation and Isotopes, 69 (2011) 1635-1638.

[2] V. Davydenko, et al., AIP Conference Proceedings, v. 763, NY, 2005, p. 332-335.