BEAM INJECTOR FOR VACUUM INSULATED TANDEM ACCELERATOR*

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Abstract

The Vacuum Insulated Tandem Accelerator (VITA) is built at the Budker Institute of Nuclear Physics. The accelerator is designed for development of the concept of accelerator-based boron neutron capture therapy of malignant tumours in a clinic [1]. In the accelerator the negative hydrogen ions are accelerated by the high voltage electrode potential to the half of required energy, and after conversion of the ions into protons by means of a gas stripping target the protons are accelerated again by the same potential to the full beam energy. The epithermal neutrons generation reaction is $^{7}Li(p,n)^{7}Be$, and the estimated proton current for minimal therapeutic neutron flux should be higher than 3 mA @ 2.5 MeV energy [2] meanwhile about 10 mA required for comfortable BNCT treatment. During the facility development, the proton beam was obtained with 5 mA current and 2 MeV energy [3]. To ensure the beam parameters and reliability of the facility operation required for clinical applications, the new injector was designed based on the ion source with a current up to 15 mA [4], providing the possibility of preliminary beam acceleration up to 120-200 keV. The paper presents the status of the injector construction and testing.

INTRODUCTION

The VITA facility design is shown at Fig. 1. The first stage of acceleration – acceleration of ions – takes place in the area between the entrance volume of the accelerator and the high voltage electrode and the second stage – acceleration of protons – between the high voltage electrode and the beginning of high energy beam line. The gas stripping target is located inside the high voltage electrode and inflates up to 0.23 l×Torr/s into the accelerator volume to provide up to 99% conversion of ions into protons. Several innovative ideas were realized in the accelerator design to allow stable acceleration of intense beam in a compact facility.

The initial ion beam is produced by the injector composed of the ion source, low energy beam line and magnetic elements providing focusing and correction of the beam. Series of investigations have revealed the limitations of injecting current. The main problems are the ions loss due to high residual gas concentration and the ability of the stripping gas to rich the injector and corrupt the stability of the ion source [4]. To provide a reliable H- beam for clinical application of the facility the new injector is designed.

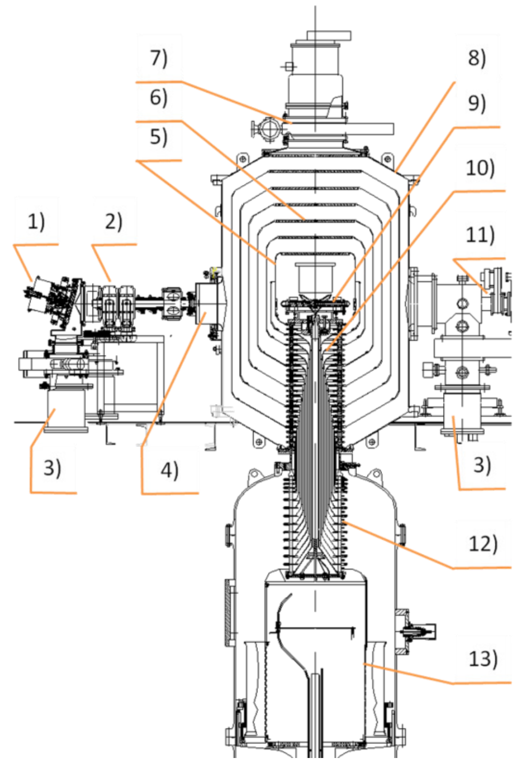

Figure 1. Scheme of the VITA facility: 1 – H^{-} ion source; 2 – low energy beam line; 3 - turbomolecular pump; 4 – entrance volume of the accelerator; 5 – high voltage electrode; 6 – electrode shutters; 7 – cryo pump; 8 – accelerator vacuum volume; 9 – stripping target; 10 – feedthrough insulator (vacuum part); 11 – high energy beam line; 12 – feedthrough insulator (gas part); 13– high voltage source.

INJECTOR DESIGN

The new injector proposed for the VITA facility [5] is under construction at BINP. The final design scheme of the injector is presented at Fig. 2. The surface-plasma ion source with Penning discharge and with hollow cathode (1) is used to generate the 15 mA H^- beam with energy up to 32 keV. The generated beam is bent by the magnet (4) and directed into the pre-accelerating tube. The usage of this magnet allows solving several tasks: splitting the beam from the gas and caesium flux, additional beam focusing to ensure axially symmetric parallel beam with round profile in the output, protect the ion source from the back streaming particles from the accelerator channel. The diaphragm with the beam diagnostics is located between the magnet and the accelerator tube. Measuring

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the temperature profile of the diaphragm provide feedback information about the beam position which allows to tune the magnet. The diaphragm makes possible differential pumping of the ion source.

The injector design does not implement focusing lenses or correctors to tune the beam convergence and direction in the input of the accelerator, but the injector support provides an adjustment of the device as a whole to direct the output beam to the accelerator axis precisely. The accelerator tube also operates as focusing lens to make the beam match the accelerator acceptance.

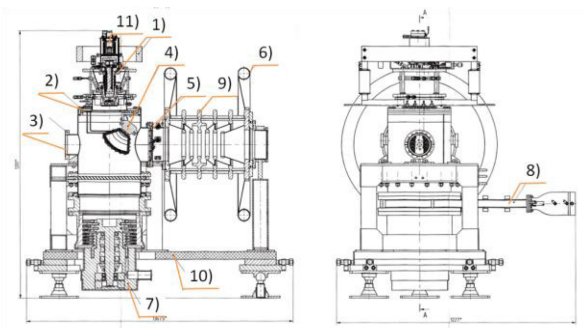

Figure 2. New injector design: 1 –15 mA H- ion source; 2 – positioning flange; 3 – vacuum chamber; 4 – beam magnet; 5 – diaphragm with the beam diagnostics; 6 – high voltage screen; 7 – turbomolecular pump; 8 – vacuum valve; 9 – pre-acceleration tube; 10 – insulated support; 11 – Cs heater.

The estimation of the H^- beam stripping by the residual gas demonstrates higher efficiency of beam delivery using this design of the injector in comparison to existing version.

Operation of the injector will require additional equipment including Faraday cages for high voltage part of the injector system and isolating transformer to provide 5 kW electric feeding to the 120-150 kV potential. The VITA facility arrangement with the injector equipment is presented at Fig. 3.

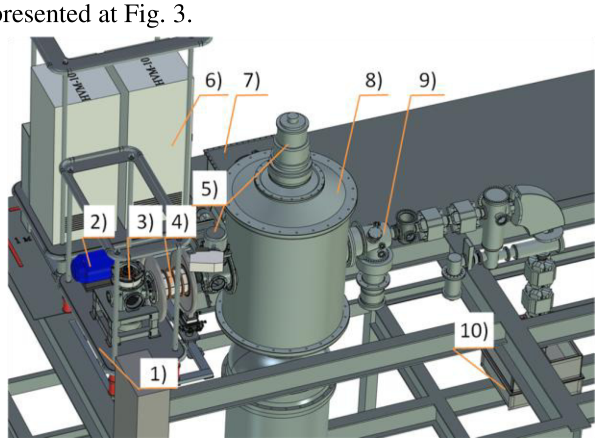

Figure 3. Facility arrangement with the beam injector equipment: 1 – Faraday cage with the injector, 2 – for-pump, 3 – H- ion source, 4 – pre-acceleration tube, 5 – cryo pumps, 6 – Faraday cage with the injector power and control cabinets, 7 – isolating transformer, 8 – vacuum insulated tandem accelerator, 9 – high energy beam line, 10 – neutron beam shaping assembly.

COMPUTER SIMULATIONS

Computer simulations of the beam transportation through the pre-acceleration tube and VITA were carried out using UltraSAM code developed at BINP [6-7]. Computation was made considering the temperature of the beam and space charge. It was demonstrated that 120 keV pre-acceleration provides very fast shrinking of the beam that leads to significant grows of the chaotic angles of the beam trajectories, so the transportation of the beam through the stripping target becomes problematic. Acceptable pre-acceleration energies have lower values with the optimum about 75 keV which corresponds to 105 keV of total injecting beam energy.

Transportation of the beam with 1 mA current through the pre-accelerator tube and the VITA is shown at Fig. 4 Coordinate Z=0 mm corresponds to the input flange of the accelerator tube, area of Z between 800 and ~1000 mm – 1-st accelerator gap of the VITA, and coordinates between ~1500 and ~2000 mm – the area of stripping target. The voltage of pre-acceleration is 75 kV and VITA voltage is 1 MV. The effects of input focusing and output defocusing of the pre-accelerator tube could be seen by the beam trajectories as well as focusing effect of the 1-st accelerator gap of VITA. The beam crossover is located near the 3 electrode of VITA (Z=1200 mm).

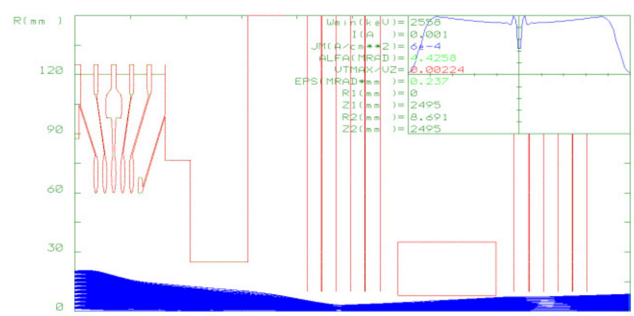

Figure 4. Transportation of 1 mA beam through the pre-accelerator tube and the VITA.

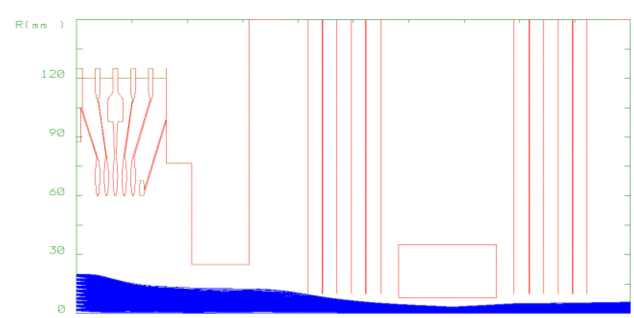

Figure 5. Transportation of 10 mA beam through the pre-accelerator tube and the VITA.

The trajectories of 10 mA beam demonstrate the effect of space charge (Fig. 5). The beam has bigger diameter and the crossover is inside the stripping tube. The beam

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diameter is close to the diameter of the 1-st VITA aperture, which means necessity to choose the electrodes diaphragms diameters carefully. The output beam is almost parallel with the diameter less than 16 mm. One can see that space charge provides better beam parameters inside the stripping tube and in the output of the accelerator, that should be took into account while projecting the vacuum system to avoid space charge compensation by ionized residual gas.

As the main parts of the injector are already fabricated and the Faraday cages and some other equipment are still in fabrication it is possible to carry out preliminary injection of the beam using the pre-accelerator tube as an electrostatic lens. When the input and output electrodes of the tube has ground potential and the central electrodes has +60 kV potential the focusing provide ideal injection into the VITA with 1 MV potential at the high voltage electrode (Fig. 6). Computation proves that the beam space charge provides better transportation of the beam through the entrance electrostatic lens of the VITA. This experiment could prove the ability of the VITA to operate with more than 5 mA beam current.

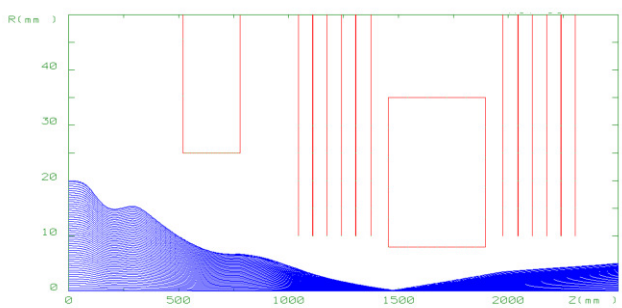

Figure 6. Transportation of 5 mA beam through the pre-accelerator tube (used as electrostatic lens) and the VITA.

BEAM DIAGNOSTICS

To check the beam quality at the VITA input it was decided to measure the beam emittance using pepper-pot method. The pepper-pot matrix will be located at the output of the pre-accelerator tube and the ceramics screen will be placed in the entrance volume of the VITA where the image could be registered using CCD camera. The converging beam makes compact beam picture at the screen surface, so it is necessary to provide high space resolution of the beam image to get sufficient angle measurement accuracy. With the convergence of the beam ~25 mrad, the necessary angle accuracy should be at least ~2 mrad or better.

PRELIMINARY TESTING

The stand was constructed for high voltage training of the accelerator tube with the ion beam (Fig. 7). The beam propagates from the ion source through the accelerator tube into the Faraday cup directly without bending. The tantalum foil is located at the bottom of the Faraday cup, and it is possible to register the total beam current and the light from the foil using vacuum window and CCD camera during the experiments. The profiles of the beam are presented without correction of the angle view. The tube was trained up to 80 kV.

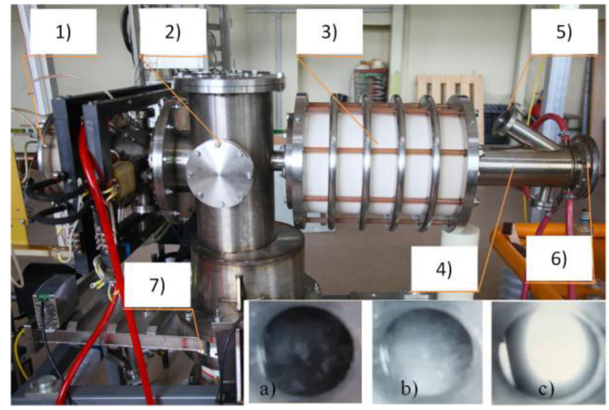

Figure 7. Stand for preliminary accelerator tube testing: 1 – 15 mA H^- ion source; 2 -vacuum chamber; 3 – accelerator tube; 4 – Faraday cup; 5 – view port; 6 – location of the tantalum foil; 7 – vacuum valve and pumping. Photo of the tantalum target: a) no beam; b) 6 mA, no acceleration; c) 6 mA @ 50.5 kV acceleration (82 keV total energy).

SUMMARY

The injector for VITA facility is under construction now at BINP. Preliminary testing of the ion source and accelerator tube is carried out. Optimal voltages for pre-acceleration tube are determined by computer simulation. Before the Faraday cage will be constructed it is possible to test the ability of VITA power system to operate with more than 5 mA beam currents by injecting the H- beam without acceleration. It is possible if we use the accelerator tube as an electrostatic lens. According to computer simulation 60 kV voltage at the central electrodes of the tube provide perfect injection of the beam into the accelerator.

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