# DEVELOPMENT OF THE INJECTOR FOR VACUUM INSULATED TANDEM ACCELERATOR

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*Abstract*

The new beam injector of negative hydrogen ions was designed for modernization of the epithermal neutron source based on the tandem accelerator with vacuum insulation. The parameters of the ion source used in the injector construction allow one to increase the $H^-$ current from 5 mA to 15 mA. Preliminary acceleration of the injecting beam can provide more reliable operation of the facility when changing the parameters of the injecting beam or the tandem accelerator voltage. Realization of this injector will make the next step towards the creation of a compact source of epithermal neutrons for boron neutron capture therapy of malignant tumors in clinics. The paper presents the injector design and computer simulations of the beam transportation.

## INTRODUCTION

The tandem accelerator with vacuum insulation of electrodes (VITA) [1, 2] built at BINP is designed specifically for the development of the AB-BNCT concept [3]. 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 [4] meanwhile about 10 mA required for comfortable BNCT treatment.

The VITA facility design is shown at Fig. 1. The particles acceleration takes place in two stages in a tandem accelerator. At the first stage the negative hydrogen ions are accelerated by the high voltage electrode potential to the half of required energy, and then the ions meet the gas stripping target to be converted into protons and accelerated again by the same potential to the full beam energy. Several innovative ideas were realized in the accelerator design to allow for 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. The paper presents the design scheme of the injector and the results of calculations performed.

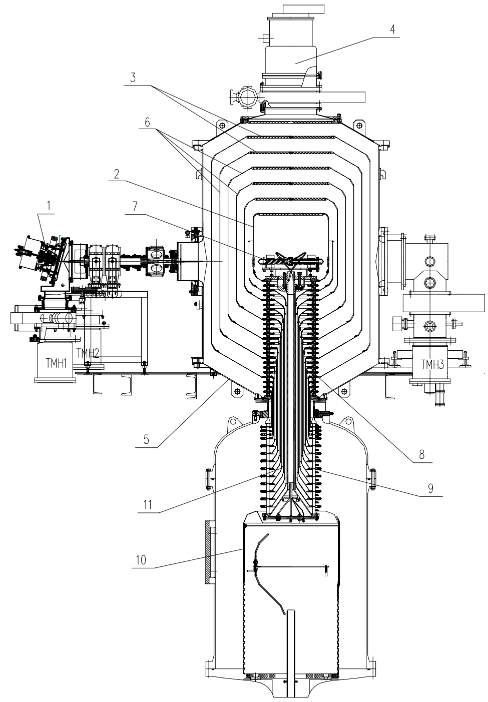


Figure 1: Scheme of the VITA facility. 1–ion source ($H^-$); 2 – high voltage electrode; 3 – electrode shutters; 4 – cryo pump; 5 – accelerator vacuum volume; 6 – intermediate electrodes; 7 – stripping target; 8 – feedthrough insulator (vacuum part); 9 – feedthrough insulator (gas part); 10 – high voltage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

## EXISTING INJECTOR CONSTRUCTION

The scheme of the existing injector is shown at Fig. 2. The surface-plasma ion source with Penning discharge and with hollow cathode is used to generate the beam of negative hydrogen ions with the energy of 21 keV and the current up to 5 mA. The output aperture of the ion source has the diameter of 3 mm and the beam angular divergence is about ±100 mrad. The magnet required for Penning discharge turns the beam to the angle of 15°, and the cone diaphragm passes the axial part of the beam into the transport channel through the aperture with 28 mm diameter. Then the beam is focused by two magnetic solenoids and directed to the accelerator through the beam diagnostics chamber. The beam transport channel is a long tube with 50 mm diameter that limits the pumping speed significantly and does not provide the appropriate vacuum level resulting in up to 50% of generated ions loss due to interaction with the residual gas.



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In addition, the is a back streaming of the stripping gas ionized by the H⁻ beam and accelerated to an energy of 1 MeV. A strong electrostatic input lens of the accelerator makes the beam transportation to be very sensitive to the range of parameters: the alignment of the magnetic elements of the low-energy beam line, the adjustment of the accelerating voltage and H⁻ beam parameters.

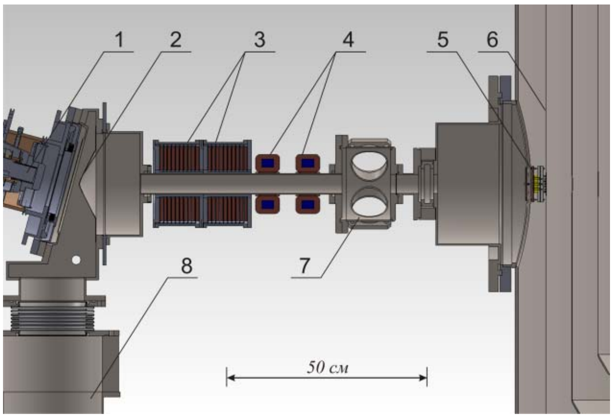


Figure 2: The scheme of existing injector: 1 – H⁻ ion source; 2 – cone diaphragm; 3 – focusing solenoids; 4 – magnetic beam corrector; 5 – beam aperture; 6 – first accelerator electrode; 7 – beam diagnostics; 8 – turbomolecular pump.

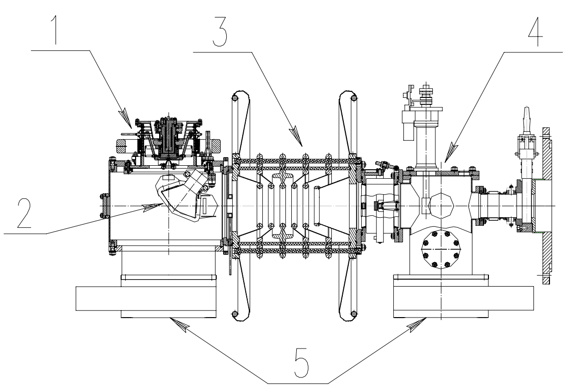


Figure 3: The new injector for BNCT facility: 1 –H⁻ ion source; 2 – bending and focusing magnet; 3 – accelerating tube; 4 – beam diagnostics; 5 – valves for turbomolecular pumps.

## PROPOSED INJECTOR CONSTRUCTION

To raise the injecting current and to improve the beam quality the new injector is proposed and designed. The scheme of the injector is presented at Fig. 3.

The construction implements the new ion source with the current increased up to 15 мA [5-7]. The bending magnet is placed inside the vacuum chamber to direct the beam into the electrostatic tube for preliminary acceleration. The magnet is designed to provide additional beam focusing and ensure axially symmetric round beam profile in the output (Fig. 4). The vacuum chamber has several inputs and windows to hold the beam probes and to improve the construction elements adjustment using a laser. To provide high vacuum level and to reduce particle loss the turbomolecular pump of 3000 l/s pumping speed is used. The acceleration tube and diagnostic chamber are pumped by separate pump with the same pumping speed.

The ion source with vacuum chamber and the cabinet with power supply and control electronics are placed on the isolated platform with Faraday cage. This platform can be at high potential while being supplied by an external power source. With the preliminary acceleration the injector can produce the beam of 120-200 keV energy that provides more stable operations with adjustable accelerator voltage and beam parameters.

The trajectories simulation made by MAGEL code proves the effective transportation of the beam through the acceleration system (Fig. 5, 6).

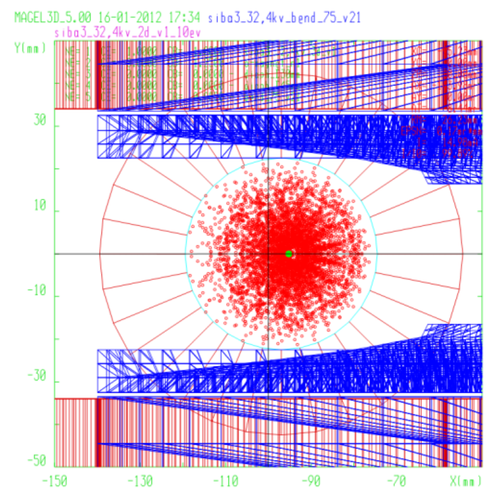


Figure 4: Beam profile at the bending magnet exit.

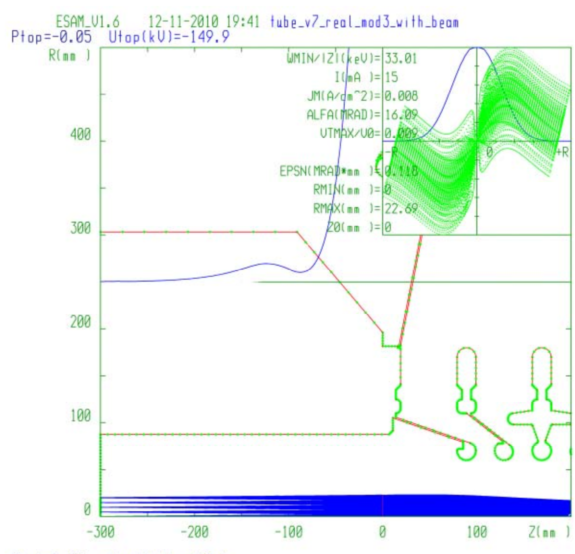


Figure 5: The ion beam transportation through the pre-acceleration tube.



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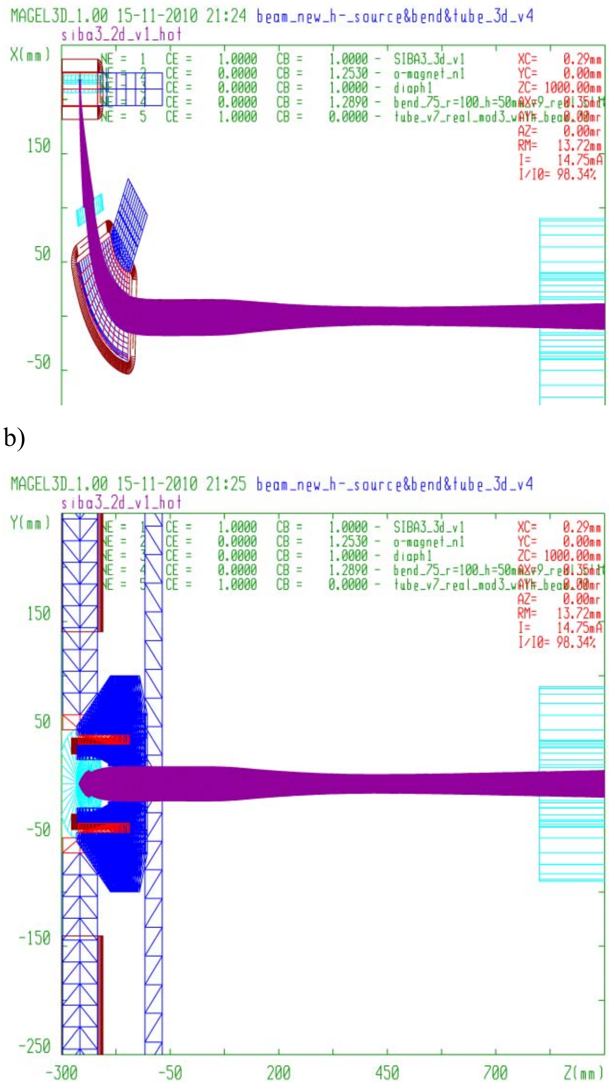


Figure 6: The ion beam transportation through the low energy beam line, 1-st stage of tandem acceleration and stripping target.

## SUMMARY

The new injector was developed to modernize the epithermal neutron source based on the Vacuum Insulated Tandem Accelerator. This injector designed to produce $H^-$ beam of 15 mA current and energy of 120-200 keV. Better vacuum condition, more stable operation and effective beam transportation provide the ability to generate high power proton beam with VITA and create compact facility for clinical AB-BNCT.

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