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## A new concept of a vacuum insulation tandem accelerator

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### HIGHLIGHTS

- It is proposed to abandon separate placement of accelerator and power supply.
- The source of high voltage is proposed to be located inside accelerator insulator.
- This will reduce the facility height and make it compact for clinic.

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### ABSTRACT

A tandem accelerator with vacuum insulation has been proposed and developed in the Budker Institute of Nuclear Physics. Negative hydrogen ions are accelerated by the positive 1 MV potential of the high voltage electrode, converted into protons in the gas stripping target inside the electrode, and then the protons are accelerated again by the same potential. The potential for high voltage and intermediate electrodes is supplied by the sectioned rectifier through a sectioned bushing insulator with a resistive divider. In this work, we propose a radical improvement of the accelerator concept. It is proposed to abandon the separate placement of the accelerator and the power supply and connect them through the bushing insulator. The source of high voltage is proposed to be located inside the accelerator insulator with high voltage and intermediate electrodes mounted on it. This will reduce the facility height from 7 m to 3 m and make it really compact and attractive for placing in a clinic. This will significantly increase the stability of the accelerator because the potential for intermediate electrodes can be fed directly from the relevant sections of the rectifier.

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### 1. Introduction

A tandem accelerator of charged particles was proposed in the middle of the 20th century. It consists of two accelerating tubes and the stripping (charge exchange) target between them under the high voltage potential. In the interaction with the stripping target an accelerated negative hydrogen ion is converted into a positive one and is further accelerated in the second accelerating tube with the same potential. The double use of the same accelerating voltage allows us to double the final energy of singly charged particles and to increase several times that of multiple charged. An important advantage of the tandem accelerator is the placement of the ion source under the ground potential. The largest commercially widespread tandem accelerators are used in the

complexes of accelerator mass spectrometry and ion implantation with a typical beam current below 1 mA. Usually, in such tandem accelerators a gas stripping target is used in the form of a tube with gas injection in the middle. The interaction of the accelerated beam of charged particles with the residual gas in vacuum leads to the appearance of electrons, ions, and radiation in the ultraviolet range, which reduces the high-voltage strength of the vacuum gaps and vacuum surfaces of insulating rings of the accelerating tube. To save a high voltage strength of the accelerating vacuum gaps with increasing beam current, various solutions are proposed, including a tandem accelerator with vacuum insulation.

The first tandem accelerator with vacuum insulation was proposed in Proudfoot et al., (1994). In this case, the entire tandem accelerator was placed in a vacuum volume. That is, vacuum is created not only inside the accelerating tube, but also in areas outside which are filled with insulating gas in conventional devices. The authors note that such a design eliminates the use of potentially dangerous and expensive sulfur hexafluoride.

Later in the work (Bayanov et al., 1998) a tandem accelerator

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with vacuum insulation was also proposed, but it radically differed from that described above. The idea was not to get rid of the use of sulfur hexafluoride, but to place the insulator far from the charged particle beam to save the high voltage strength of the vacuum gap. There are no accelerating tubes in this tandem accelerator with vacuum insulation. The potential distribution is set by the embedded electrodes which form a multi-layer structure fixed to the vacuum part of a single bushing insulator filled with insulating gas. The insulator is out of the beam. Inside the bushing insulator coaxial pipes are placed conveying the potential to the high voltage electrode from a high voltage source and to the intermediate electrodes of the resistive divider installed on the gas side of the bushing insulator. The high voltage source and the gas side of the bushing insulator are housed in a single volume filled with insulating gas under pressure.

The idea of a tandem accelerator with vacuum insulation was developed in [Beasley et al. \(2010\)](#). They suggested to use the natural capacitance between the electrodes. If you cut the embedded electrodes in half and connect them by diodes in the form of stairs, then the Cockcroft-Walton cascade generator (voltage multiplier) is implemented directly inside the vacuum volume of the accelerator.

### 1.1. VITA

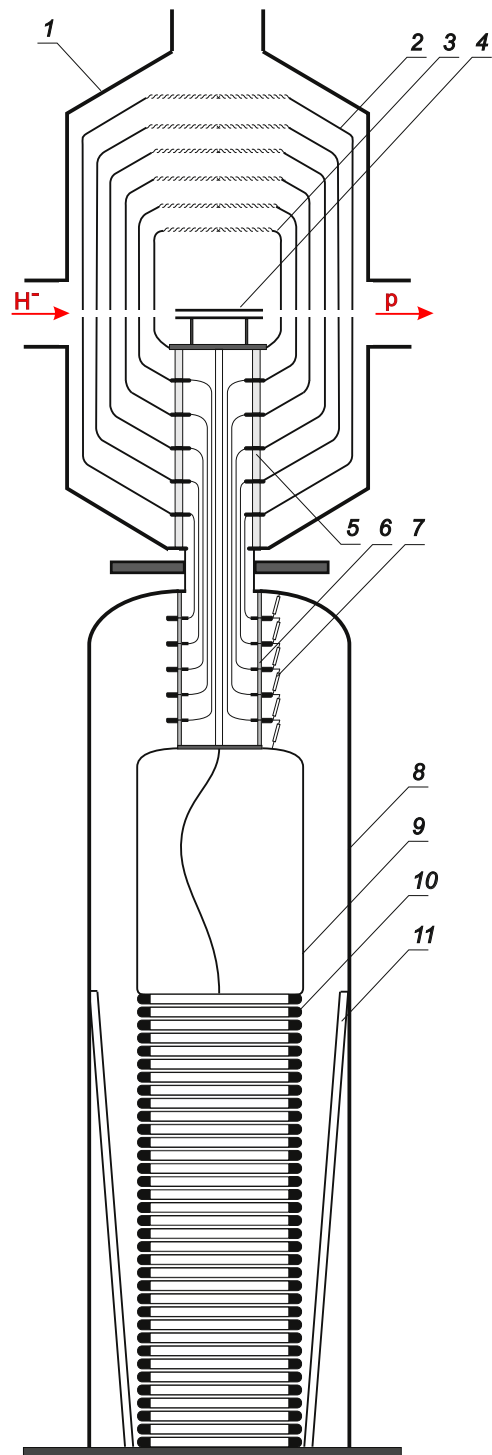
The only scheme ([Bayanov et al., 1998](#)) out of all proposed schemes of the tandem accelerator with vacuum insulation has been implemented. At the moment, the accelerator is used for the development of BNCT ([Aleynik et al., 2014](#)). The accelerator scheme is presented in [Fig. 1](#). A negative hydrogen ion beam is injected into the accelerator 1 and is accelerated in it up to 1 MV. In gas stripping target 4 installed inside high voltage electrode 3 the negative hydrogen ions are converted into protons which are then accelerated by the same potential of 1 MV to an energy of 2 MeV. The potential for high voltage 3 and five intermediate electrodes 2 of the accelerator is fed from high voltage source 8 through the bushing insulator that consists of two parts: vacuum part 5 and gas part 6. On the gas side of the bushing insulator resistive divider 7 is mounted to supply the appropriate potential to the intermediate electrodes of the accelerator. Rectifier electron accelerator ELV 8 is used as a high-voltage source; it has primary winding 11, rectifying sections 10, and high voltage electrode 9. The vacuum volume of the accelerator is pumped out with turbomolecular and cryogenic pumps through the jalousie of the intermediate electrodes. The bushing insulator and the high voltage rectifier are filled with insulating gas SF<sub>6</sub> under pressures of 3 atm and 6 atm, respectively. Arrows in [Fig. 1](#) show the direction of the movement of negative hydrogen ions (H<sup>-</sup>) and protons (p).

This construction is larger in the total height (7 m), since it is necessary to provide the high voltage reliability of the high voltage power supply and both parts of the bushing insulator.

### 1.2. A new concept of VITA

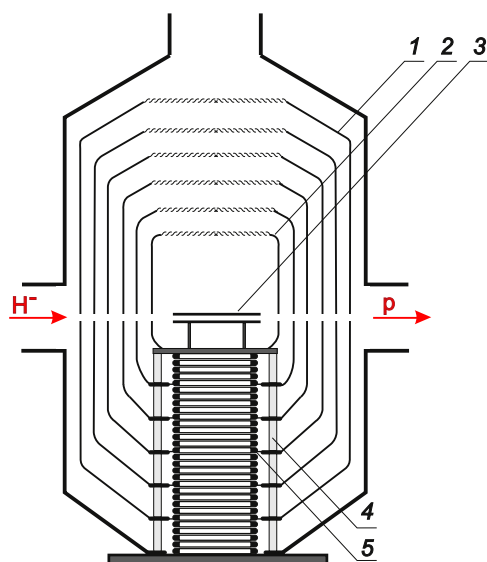
In this paper we propose a radical improvement of the concept of the accelerator. It is proposed to abandon the separate placement of the accelerator and the high voltage power supply and to connect them through a bushing insulator. The high voltage source is proposed to be placed inside the insulator of the accelerator with high voltage and intermediate electrodes mounted on it. This provides a reduction of the height of the facility from 7 m to 3 m and makes it really compact and attractive to be placed in a clinic for the purpose of BNCT.

The scheme of the accelerator proposed is shown in [Fig. 2](#). Using a modern element base (RVF30 high voltage diodes, FHV12AN capacitors) and the transition to a higher frequency



**Fig. 1.** Tandem accelerator with vacuum insulation (operating): 1 – Accelerator, 2 – intermediate electrodes, 3 – high voltage electrode, 4 – gas stripping target, 5 – vacuum part of the bushing insulator, 6 – gas side of the bushing insulator, 7 – resistive divider, 8 – high voltage power source (sectioned rectifier), 9 – high voltage electrode of the rectifier, 10 – rectifying sections, and 11 – primary winding of the rectifier.

(20 kHz instead of 400 Hz) allows us to make high voltage sectioned rectifier 6 much smaller in size than that shown in [Fig. 1](#), and place it inside insulator 5. High voltage 3 and intermediate 2 electrodes of accelerator 1 are directly connected with the corresponding sections of sectioned rectifier 6. In the new design the rectifier is immersed in the insulating gas under pressure. Such a disposition of the rectifier provides the required high voltage



**Fig. 2.** Tandem accelerator with vacuum insulation (new concept): 1 – Intermediate electrodes; 2 – high voltage electrode; 3 – gas stripping target; 4 – insulator; 5 – sectioned rectifier.

strength and heat removal.

Since the body of the sectioned rectifier is an insulator with the distributed potential rather than a grounded metal tank, the high voltage strength of the rectifier is significantly improved, and gaps or pressure of the insulating gas can be reduced. In addition to reducing the size of the device and a higher stability of the intermediate electrode potential, this modification implies a decrease in the number of parts and an increase in the robustness of the accelerator.

In the near future it is planned to create and test a compact sectioned rectifier for a voltage of 1.25 MV. According to the results of these experiments, it is planned to design the compact tandem accelerator with vacuum insulation as a part of a compact source of epithermal neutrons for oncology clinics to conduct BNCT.

## 2. Discussion

Let us discuss the merits and demerits of the new concept by comparing it with the operating accelerator at BINP (Aleynik et al., 2014) and the electrostatic tandem accelerator being developed by Siemens (Beasley and Heid, 2011; Jagwitz-Biegnitz et al., 2014).

In comparison with the operating VITA the new concept of placing the rectifier allows us to decrease the size (from 7 m to 3 m in height) and make it more robust. The potential is directly applied to the intermediate electrodes from the respective sections of the rectifier rather than via a divider with higher ohmic

resistance. This must greatly reduce the effect of dark currents on the optical properties of the beam line. Switching to a high frequency and more compact arrangement of the elements can cause problems in the operation of a powerful high frequency rectifier.

Since in the new concept the rectifier is immersed in the gas and it is possible to remove heat from the heating elements, the rectifier can provide proton beam currents up to 10 mA. In the Siemens accelerator, diodes are placed in a vacuum and the proton beam with a current of only 0.1 mA is expected (Jagwitz-Biegnitz et al., 2014). In this case, in addition to the problem of cooling diodes in a vacuum there can arise complications with dark currents on the diode surface. Certainly, the concept of the Siemens accelerator is attractive, but it requires the solutions of technological aspects, and real experiments on obtaining the proton beam are necessary.

## 3. Conclusion

A new concept of the vacuum insulation tandem accelerator is proposed. The high voltage sectioned rectifier is located inside the accelerator insulator with high voltage and intermediate electrodes mounted on it. The implementation of the concept will enable the creation of a truly compact accelerator for BNCT.

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