PROBLEMS AND PROSPECTS OF THE TANDEM ACCELERATOR WITH VACUUM INSULATION*

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Abstract

A tandem accelerator with vacuum insulation for development of the technique of boron neutron capture therapy (BNCT) is proposed and constructed. The accelerator is characterized by rapid acceleration of charged particles. The article describes the problems of the new type of accelerator, both solved and remain to be solved. Also research plans and prospects for the use of the accelerator are presented and discussed.

INTRODUCION

Presently, Boron Neutron Capture Therapy (BNCT) is considered to be a promising method for the selective treatment of malignant tumours [1]. The results of clinical trials, which were carried out using nuclear reactors as neutron sources, showed the possibility of treating brain glioblastoma and metastasizing melanoma incurable by other methods. The broad implementation of the BNCT in clinics requires compact inexpensive sources of epithermal neutrons. At BINP the source of epithermal neutrons based on Vacuum Insulation Tandem Accelerator (VITA) and neutron generation through ^{7}Li(p,n)^{7}Be reaction was proposed [2], created and operated [3-5].

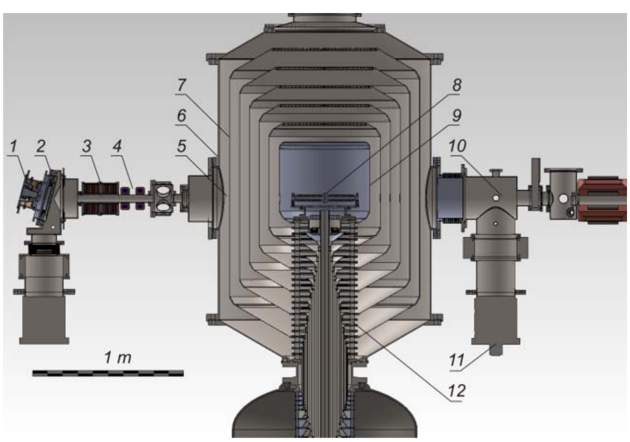

Figure 1: Vacuum insulation tandem accelerator. 1 – H⁻ ion source, 2 – diaphragm, 3 – magnetic lenses, 4 – corrector, 5 – a temporary location of the beam detector, 6 – accelerator, 7 – electrodes, 8 – high voltage electrode, 9 – stripper, 10 – high energy beam transport, 11 – turbo molecular pumps, 12 – bushing insulator.

General view of the accelerator is shown in Fig. 1. Negative hydrogen ions are injected and accelerated up to 1 MeV by potential applied to the electrodes, then H^- turn into protons in the gas stripping target and at last the protons are accelerated up to 2 MeV by the same potential. Pumping of the stripping gas is carried out by cryogenic and turbomolecular pumps through the jalousies. The potential of the high-voltage and five intermediate electrodes is supplied by a high-voltage source through the bushing insulator which has a resistive divider.

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PROBLEMS

The main problem of accelerators is high-voltage strength of vacuum gaps. Because of the large square of the electrodes, great energy is stored in the gaps and the inevitable breakdowns could lead to the gap detraining. The high-voltage strength of 45-mm and 66-mm vacuum gaps was studied. It was found out that the breakdowns at stored energy of 50 J did not lead to the gaps detraining. The stored energy in this accelerator did not exceed 26 J. Training by breakdowns allowed to obtain the required voltage of 1 MV [6].

Another problem of accelerators is strong input electrostatic lens. To provide passage of the beam through the stripping target it was necessary to refocus the beam before the lens without a significant increase in the emittance. To study H^- beam injection, the 22-channel detector has been produced and mounted in front of the first accelerating electrode. It has been determined that the best agreement with the numerical calculation is achieved by assuming the full compensation of the space charge in the transport channel and setting the transverse ion temperature equal to 1 eV at the plasma boundary of the ion source. This study described in detail in [7] resulted in better focusing of the beam required for acceleration of the beam without significant losses.

On the accelerator, stationary proton beam with 2 MeV energy, 1.6 mA current, 0.1% energy monochromaticity and 0.5% current stability was obtained [8]. To conduct BNCT, it is planned to increase the beam parameters to at least 2.5 MeV and 3 mA.

Not good enough vacuum conditions in the beginning of the acceleration of the ion beam seem to be the main current problem. Injected beam ionizes residual and stripping gas mainly in the area before a strong input lens. The born electrons are accelerated to the full voltage of 1 MV and absorbed by construction materials lead to significant power bremsstrahlung [9]. The resulting positive ions were registered by the detector mounted on inlet flange of the accelerator at beam periphery [10]. The magnitude of the current of charged particles reaches 25 % of the current of the accelerated ion beam. Probably, it is the presence of a beam of charged particles in the

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accelerating gap that limits high voltage reliability of the gap and does not allow increasing the proton beam current.

To reduce the flow of charged particles and to improve the vacuum conditions, two solutions are proposed.

The first proposal is to install a cooling aperture and to put a cryopump at the input of the accelerator. This will allow reducing significantly the gas flow from the ion source to an accelerating gap.

The second proposal is to reduce the gas flow to the accelerating gap from the gas stripping target. It is proposed to tilt the stripping target, to place permanent magnets in the space between the target and the input aperture of the high voltage electrode [11] and to put the turbo molecular pump inside the high-voltage electrode. This will make it possible not only to reduce the gas flow to the accelerating gap, but also to reduce the flow of ultraviolet radiation and suppress the flow of positive argon ions from weakly ionized plasma inside the stripping tube.

It was found that the high-voltage strength of the accelerator is limited by the high-voltage strength of the outer surface of the glass rings of the vacuum part of the bushing insulator. To raise the voltage to 1 MV to 1.25 MV a new bushing insulator is under manufacturing, the glass rings in it are replaced by polycarbonate rings with corrugated outer surface.

PROSPECTS

The main advantage of VITA is high rate of acceleration – about 25 keV/cm for singly charged ions. This makes an accelerator compact.

In the paper [12], 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 connecting them through the bushing insulator. The source of high voltage is proposed to be located inside the accelerator insulator, high voltage and intermediate electrodes mounted on it (Fig. 2). This will reduce the facility height from 7 m to 3 m and makes it really compact and attractive for placing in a clinic.

Also Fig. 2 shows the first proposed orthogonal beam shaping assembly (BSA) [13]. Such orthogonal neutron beam can be used to easily direct the beam to the patient at any angle. This solution is "à la gantry" for proton therapy. The change of direction of therapeutic neutron beam is ensured by the rotation of the whole BSA or its part containing moderator about the axis of proton beam propagation.

Obtaining of 2.5 MeV 3 mA proton beam and implementation of the embedded power supply and orthogonal BSA will make it possible to create a source of epithermal neutrons suitable for BNCT.

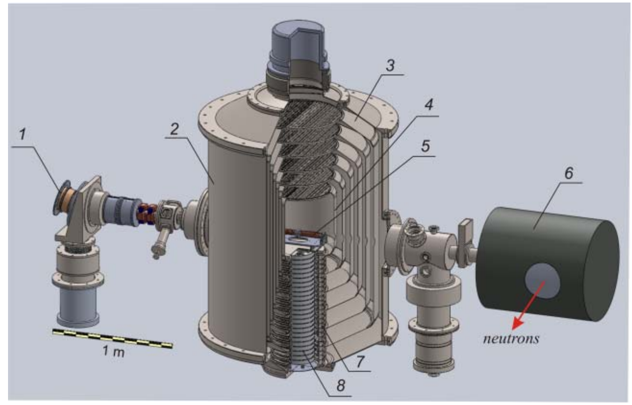

Figure 2. Neutron source for BNCT. *1* – negative hydrogen ion source, *2* – accelerator, *3* – intermediate electrodes, *4* – high voltage electrode, *5* – gas stripping target, *6* – beam shaping assembly, *7* – insulator, *8* – high voltage sectioned rectifier.

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