RAISING THE GENERATING CURRENT IN THE VITA NEUTRON SOURCE FOR BNCT*

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Abstract

At the BINP, a pilot epithermal neutron source is now in use. It is based on a compact Vacuum Insulation Tandem Accelerator (VITA) and uses neutron generation from the reaction $^7Li(p,n)^7Be$. The parameters of the generated radiation allow us to carry out *in vitro* and *in vivo* investigations of BNCT. At the present moment the modernization of the facility elements is carried out to meet the parameters required for clinical usage. As the first modernization step the stripping target was optimized. The experiments on fine beam injection were carried out as well as experiments on high current transportation. The output current in the range 1.5-2.5 mA with proton beam energy of 1 – 2 MeV was obtained in the routine regimes of generation.

In presented work the results of the experiments and possible way to raise the proton current higher then 3 mA level with energy 2 MeV are discussed.

INTRODUCTION

Presently, Boron Neutron Capture Therapy (BNCT) [1] is considered to be a promising method for the selective treatment of malignant tumours. 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 [2, 3]. The broad implementation of the BNCT in clinics requires compact inexpensive sources of epithermal neutrons. At the BINP the source of epithermal neutrons based on 2 MeV Vacuum Insulation Tandem Accelerator (VITA) and neutron generation through $^7Li(p,n)^7Be$ reaction was proposed [4] and realized. Although the accelerator is designed to obtain a 5 mA proton beam, but in the experiments carried out in 2008-10 we usually got the proton beam currents of hundreds of microamperes and a few milliamps for a short time operation. Such a current was enough to demonstrate the generation of neutrons [5] and monochromatic gamma-rays [6], to carry out initial in vitro investigations [7], but it is clearly not sufficient for the thorough BNCT research and other applications.

This paper presents the results of experiments aimed at increasing the current of the proton beam and improving the stability of the accelerator. We also discuss plans of works and strategies of applying the facility for clinical use.

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 stripping target and at last the protons are accelerated up to 2 MeV by the same potential. Pumping of the gaseous stripping target 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 insulator which has a resistive divider.

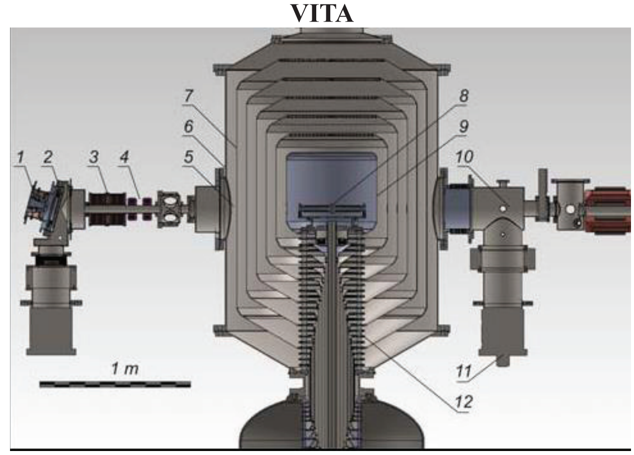

Figure 1: High-current vacuum insulation tandem accelerator. 1 – H^- ion source, 2 – diaphragm, 3 –magnetic lenses, 4 – corrector, 5 – aperture of the first electrode, 6 – accelerator body, 7 – electrodes, 8 – stripper, 9 – high voltage electrode, 10 – high energy beam transporting channel, 11 – turbo molecular pumps, 12 – insulator.

LOW CURRENT TRANSPORTATION

To increase the current a new stripping target has been made [8]. It is designed as a cooled tube having length of 400 mm and internal diameter of 16 mm, with argon gas valve in the middle. Previously we used a tube with diameter of 10 mm. In the Fig. 2 the output accelerator current is presented depending on the stripping target gas density while injecting low ion current of 225±10 μA.

In the experiment the residual gas pressure raises up to $3\cdot10^{-3}$ Pa while the target density gets up to $1.8\cdot10^{16}$ cm^{-2} level which corresponds to more then 90% stripping effect. This experiment allows us to conclude that more then 84% of the injected current is able to pass the accelerating system in a good vacuum condition.

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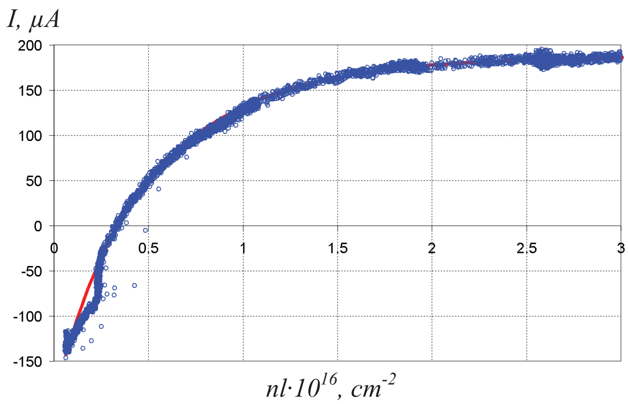

Figure 2: Measured and calculated (solid line) dependence of the accelerator output current on the stripping target gas density.

HIGH CURRENT TRANSPORTATION

The proton current up to 1.5 mA was reached in a routine regime wile injecting up to 2.5 mA of ion current (Fig. 3). This result was obtained with low stripping gas puffing limited by vacuum conditions in the accelerator. Residual gas pressure exceeded $4 \cdot 10^{-3}$ Pa, accelerating voltage was 900 kV (protons with 1820 keV energy) and stable. Working stability with high current was significantly improved: representative time between breakdowns achieved 20 minutes with 30 seconds recovery processes.

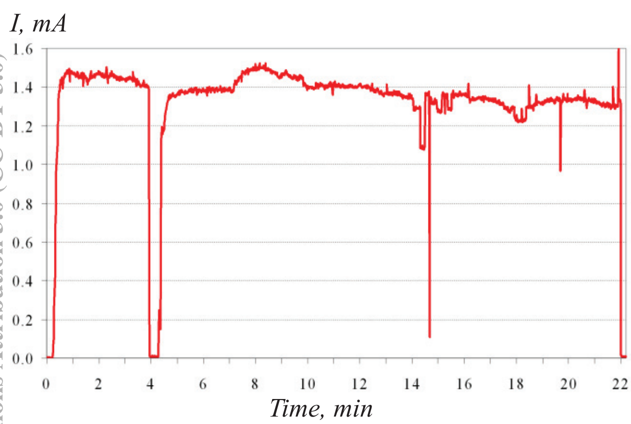

Figure 3: Output proton current in the experiments on high current transportation.

To determine the maximum current passing the accelerating system the experiments without stripping gas puffing were carried out. In this regime the ions accelerated up to 1 MeV pass the stripping tube without charge exchanging and then decelerate down to injection energy 20 keV. In this case the vacuum conditions are determined by a residual gas extracted from the accelerator electrodes and can be significantly better.

The ion current measured in the output of the accelerator is presented at Fig. 4. Residual gas pressure remained in the level $1 \cdot 10^{-3}$ Pa. The ion current reached 2.5 mA but transportation effectiveness was still 60%. This result confirmed the thought about different emittance of a high and low current ion beam in the output of the ion source.

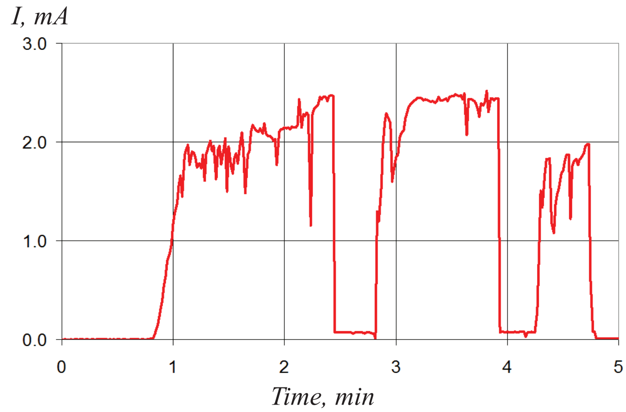

Figure 4: Output ion current in the experiments on high current transportation.

Computer simulation of the ion trajectories is presented at Fig. 5. 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 in low current transportation experiments as a relation of 146 µA maximal registered negative ions current to 188 µA maximal proton current in the output collector (Fig. 2). Taking this consideration into account we can expect that modifying the output apertures to avoid the particle capturing will make possible to raise the ion current higher then 3 mA. And improving the pumping of accelerator volume to remove a high amount of stripping gas makes it possible to reach the same value of proton current.

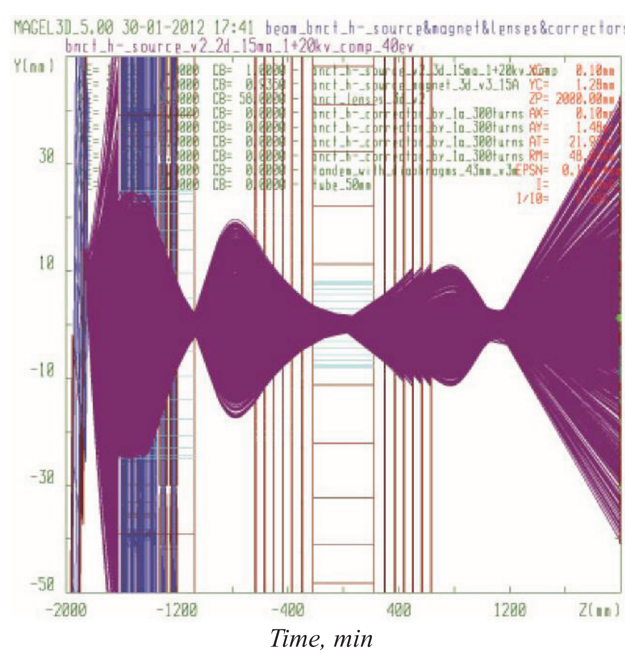

Figure 5: Computer simulation of the ions transportation through the accelerator system.

HIGH CURRENT AND LOW VOLTAGE

Special experiment was made for high proton current transportation with voltage decreased to 500 kV (protons with 1020 keV energy). In this situation the working stability and transportation effectiveness are significantly better. The result of the experiment is shown at Fig. 6.

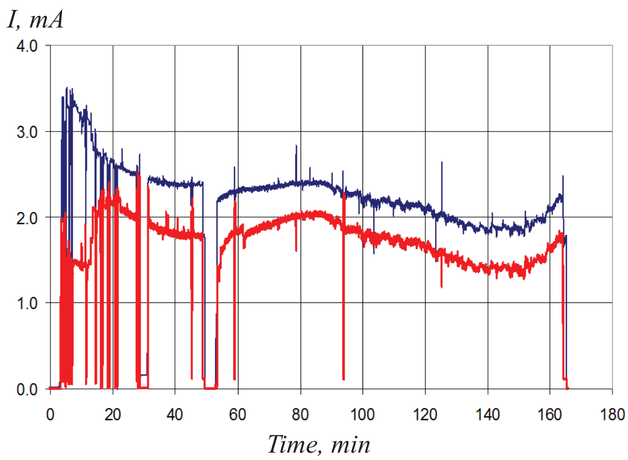

Figure 6: Output proton current (lower line) and input ion current (upper line) in the experiments with 1 MeV beam transportation.

The proton current was in the range 1.5-2.5 mA and transportation effectiveness raised up to 75-85%. The time between breakdowns decreased to 40-70 minutes.

CONCLUSION

The experiments on high current transportation using the Vacuum Insulated Tandem Accelerator were carried out after modernization of the stripping target. Stability of the current transportation was improved significantly and the current was raised up to 2.5 mA in a stable regime of generation. According to neutron transportation calculations for new neutron generating target and beam shaping assembly [9] it is possible to get 1 Gr/min dose rate for patient while using 3 mA proton beam with energy 2.3 MeV. Investigations presented in this paper confirm the possibility to get 3 mA proton current in a routine generation regime and meet the parameters required for medical usage.

The way to raise the current to higher levels is concerned with optimizing the vacuum pumping, optimizing the emittance of high current ion beam, optimizing the accelerating apertures form to reduce the electric field stress.

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REFERENCES

[1] G. Locher, Am. J. Roentgenol. Radium Ther. 36 (1936) 1.

[2] H. Hatanaka, Basic Life Sci. 54 (1990) 15.

[3] H. Hatanaka and Y. Nakagawa, Int. J. Radiat. Oncol. Biol. Phys. 28 (1994) 1061.

[4] B. Bayanov, et al., NIM A 413 (1998) 397.

[5] A. Kuznetsov, et al., Tech. Phys. Lett. 35 (2009) 346.

[6] A. Kuznetsov, et al., NIM A 606 (2009) 238.

[7] L. Mostovich, et al., Bulletin of Experimental Biology and Medicine 151 (2011) 264.

[8] A.S. Kuznetsov, et al. Calibration Testing of the Stripping Target of the Vacuum Insulated Tandem Accelerator. Proceedings of XXIII Russian Particle Accelerator Conference RUPAC2012, September, 24 - 28, 2012, Saint-Petersburg, Russia, p. 560-562.

[9] Ya.Kandiev, S.Taskaev, et al. Optimization of the Target of an Accelerator-Driven Neutron Source Through Monte Carlo Numerical Simulation of Neutron and Gamma Transport by the PRIZMA code. Applied Radiation and Isotopes, 69 (2011) 1632-1634.

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