VITA BASED NEUTRON SOURCE - STATUS AND PROSPECTS *

S. Taskaev#, V. Aleynik, B. Bayanov, A. Kuznetsov, A. Makarov, I. Sorokin, M. Tiunov,
BINP SB RAS, Novosibirsk, Russia,
A. Bashkirtsev, I. Schudlo, Novosibirsk State Tehnical University, Russia,
M. Kamkin, D. Kasatov, Novosibirsk State University, Russia

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 ^{7}Li(p,n)^{7}Be. Generation of neutrons was established and *in vitro* experiments were held. Most recent investigations on the facility are related with: i) studying of the dark currents and breakdowns, ii) analyzing and suppressing the high intensity dark currents, iii) measuring the intensity and the spectra of the X-ray radiation, iv) optimization of the H$^-$ beam injection into the accelerator, v) placing and calibrating the new charge-exchange target. The results of these studies are discussed in the present work. Investigations resulted in increasing of mean current of the proton beam in stable mode (from 0.1 – 0.7 to 1.5 – 2 mA). In the nearest future new experiments are planned, including *in vitro* tests, blistering investigation, spectrum and flux measuring for neutrons and gamma, calculating the dose absorbed by phantom. Different ways of providing additional stability to the accelerator, of increasing the current of the proton beam are discussed in this work, as well as the ways of creating the therapeutic beam and strategies of applying the facility for clinical use.

INTRODUCION

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 ^{7}Li(p,n)^{7}Be 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 occasionally for a short time – a few milliamps. 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 carried out after the IPAC-2011 [8], 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.

VITA

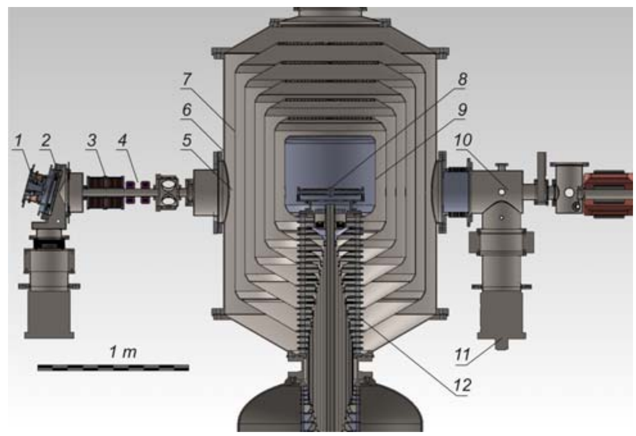

Figure 1: High-current vacuum insulation tandem accelerator. 1 – H$^-$ ion source, 2 – diaphragm, 3 – magnetic lenses, 4 – corrector, 5 – a temporary location of the beam detector, 6 – accelerator, 7 – electrodes, 8 – high voltage electrode, 9 – stripper, 10 – high energy beam transport, 11 – turbo molecular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

DARK CURRENTS

The accelerator has a high electric field in the electrode gap – about 25 kV/cm, and a large total area of the electrodes – tens of square meters. In such a system in the electrode gap dark currents of different nature must inevitably occur, which may have a significant impact on the potential distribution along the accelerating channel.

When training the accelerator, at the time of voltage increasing, a dark current is recorded. It is associated with the appearance of micro-discharges, accompanied by

*Work is supported by Ministry of Education and Science of RF
taskaev@inp.nsk.su

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desorption of adsorbed gases on the surface of the electrodes. Usually within an hour of training the value of the dark current decreases from the typical values of 100 – 300 μA to ten microamperes and then to few microamperes.

In a series of experiments in order to increase the H^- beam current the apertures of electrodes were increased from 20 to 58 mm, except for the high-voltage electrode, in which the diameter of the hole was still 20 mm. This change resulted in frequent registration of dark current of high intensity – up to 3 – 4 mA. Flowing of such a current compared to the standard training mode led to a nearly 100-times increase in radiation. The latter fact assumed high energy of electrons which is possible when the current flows not in the gap between adjacent electrodes but, for example, between the case of vacuum tank and the high-voltage electrode. This assumption was confirmed by measuring the X-ray spectrum by BGO-spectrometer: the maximum of the spectrum was shifted from 120 to 400 keV [9]. It was found that when the aperture of the channel increases, the electric field on the sharp edge of the cathode part of diaphragm mountings increases by 20% – up to 51 kV/cm, which leads to increased emission of electrons directly into the acceleration channel. To prevent the occurrence of this phenomenon the aperture of the channel has been reduced and sharp edges of diaphragm mountings has been rounded. This study shows the danger of exceeding the electric field strength of 50 kV/cm. Earlier in [10] we found that the 70 kV/cm electric field leads to dramatic increase of field emission current in the high-voltage gap.

BEAM INJECTION

Negative ion beam with energy of 21 keV and current of 5 mA is created by surface-plasma source with Penning discharge and hollow cathode. After turning at an angle of 15 degrees the peripheral part of the beam is cut off by 28mm cone diaphragm and the rest center of the beam enters into the transport channel. Then the divergent beam is focused by two magnetic lenses and can be shifted by corrector for subsequent precise input into the accelerator. VITA is characterized not only by a high rate of acceleration, but also by a strong entry electrostatic lens between the cover of the accelerator and the first accelerating electrode. To study the influence of the lens and to optimize H^- beam injection the 22-channel detector has been produced and installed at the entrance of the accelerator. Beam detector is mounted directly on the first electrode of the accelerator. Using the detector we have measured the dependence of the relative maximum beam current density on the focusing magnetic lenses current. 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 [11] resulted in better focusing of the beam required for acceleration of the beam without significant losses.

STRIPPER

To increase the current a new stripping target has been made. 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.

Negative ion beam with energy of 21 keV was injected into the accelerator with the high-voltage electrode potential of 800 kV. When there was no gas supply in the stripping target the Faraday cylinder at the exit of the accelerator registered negative current. This current was the current of negative hydrogen ions, which were first accelerated and then decelerated. When the stripping target is filled with argon it exchanges negative hydrogen ions into protons. When the thickness of the target is $0.29\ 10^{16}\ cm^{-2}$ the number of appeared protons is comparable to the number of negative hydrogen ions and detected current becomes equal to zero. Registration of the moment of the current transition from negative to positive with changing argon pressure has become a useful direct diagnostics of stripping target thickness. Also the thickness of the target is indirectly characterized by the residual gas pressure, because the experimentally measured dependence of the residual pressure on the amount of supplied argon is linear in operating range of parameters. With a further target density increase there is a growth of output current and its saturation. When injected H^- current is around hundreds of microamps the dependence measured experimentally is in good agreement with the calculated one (Fig. 2, [12]). However, when the injected current is around few milliamps there is some reduction in the proton current in the saturation region with increasing gas supply. It is planned to investigate this effect in detail in the near future.

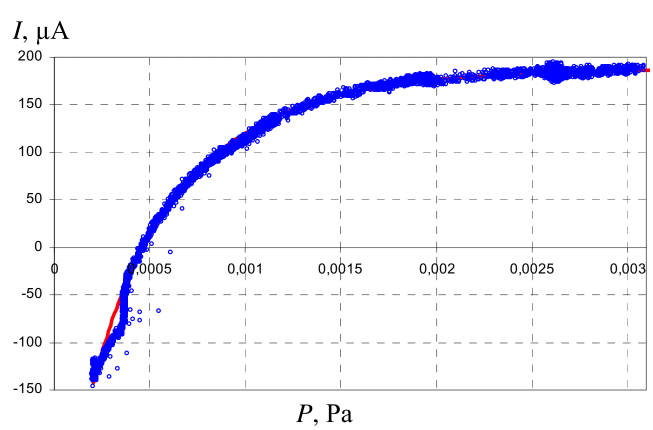

Figure 2: Measured and calculated (solid line) dependence of the detected output current of the accelerator on the residual gas pressure.

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RESULTS AND PROSPECTS

The above-described investigations allowed us to move to a long stable operation with a much higher average current – 1.5 – 2 mA instead of previously achieved 0.1 – 0.7 mA. This current provides the possibility of measuring neutron spectrum by the time-of-flight technique, carrying out *in vitro* and *in vivo* studies and developing other techniques for BNCT. Numerical simulation is used to optimize beam forming unit for epithermal neutrons and, in addition to the standard mode with a 2.5 MeV proton beam, there are determined 2 more acceptable modes: i) at the near-threshold energy of 1.95 MeV, which is characterized by low activation of the lithium target and the facility, and ii) orthogonal at 2.5 MeV, characterized by high therapeutic dose rate – up to 3 Sv/min @ 10 mA [13]. Discovered modes allow changing in the design of installation for hospitals, which can make it more attractive. [14]

Also on the facility it is possible and it is planned to carry out the investigations of i) testing the method of fast detection of explosives and narcotics by resonance absorption of monochromatic gamma rays, ii) measuring the cross section and the spectrum of α-particles from neutronless thermonuclear reaction $^{11}B(p,\alpha)2\alpha$, iii) dating of rock formation (apatite) by inducing the fission of uranium nuclei contained in the rock, iv) forming monochromatic beam of epithermal neutrons for calibration of dark matter detector.

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