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Proton beam of 2 MeV 1.6 mA on a tandem accelerator with vacuum insulation

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ABSTRACT: A source of epithermal neutrons based on a tandem accelerator with vacuum insulation for boron neutron capture therapy of malignant tumors was proposed and constructed. Stationary proton beam with 2 MeV energy, 1.6 mA current, 0.1% energy monochromaticity and 0.5% current stability has just been obtained.

KEYWORDS: Accelerator Applications; Instrumentation for particle accelerators and storage rings - low energy (linear accelerators, cyclotrons, electrostatic accelerators); Instrumentation for hadron therapy; Neutron sources

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1 Introduction

Currently, boron neutron capture therapy (BNCT) is considered as a promising technique for treatment of malignant tumours [1]. It provides selective destruction of tumour cells by prior accumulation inside them a stable boron-10 isotope and subsequent irradiation with epithermal neutrons. As a result of the absorption of a neutron by boron a nuclear reaction takes place with a large release of energy in the cell, leading to its death. Clinical trials on nuclear reactors showed that BNCT can treat glioblastoma, brain metastases of melanoma and several other tumours. For the widespread introduction of this technique in practice compact sources of epithermal neutrons based on charged particle accelerators are required.

1.1 Design of the accelerator

The source of epithermal neutrons based on the original tandem accelerator with vacuum insulation and lithium neutron producing target was proposed and constructed in BINP [2]. Figure 1 shows the accelerator. Coming from the source 1 [3] negative hydrogen ion beam with 23 keV energy and 5 mA current is rotated in a magnetic field at an angle of 15 degrees, focused by a pair of magnetic lenses 2, injected into the accelerator and accelerated up to 1 MeV. In the gas (argon) stripper 7, which is installed inside the high-voltage electrode 5, negative hydrogen ions are converted into protons. Then protons by the same 1 MV potential are accelerated to 2 MeV energy. The potential for the high-voltage 5 and five intermediate electrodes 6 of the accelerator is supplied by a high-voltage source 10 (most of the source is not shown) through the insulator 9, wherein the resistive divider is set. Evacuation of gas is performed by turbomolecular pumps 8 mounted at the ion source and at the exit of the accelerator, and a cryogenic pump 4 via jalousies in the electrodes.

50 kW sectitioned rectifier of industrial electron accelerator ELV is used as a high-voltage source providing voltage stability of 0.05% [4]. Vacuum part of the high-voltage feed-through insulator (figure 2) is collected from 24 annular glass insulators with a diameter of 400 mm and a height of 35 mm, vacuum tightly strapped with intermediate electrodes through the rubber seals. The gas part of the insulator situated in a tank of a high voltage rectifier is composed of 14 ceramic rings with a diameter of 400 mm and a height of 60 mm, glued with their electrodes. The inner

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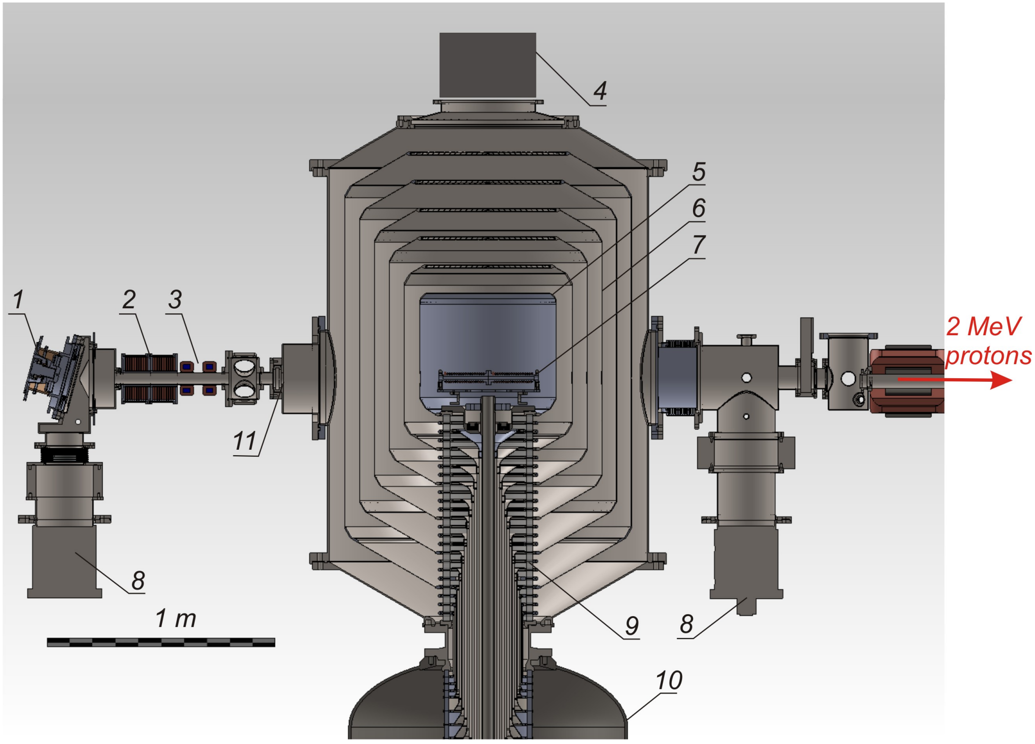

Figure 1. Tandem accelerator with vacuum insulation: 1 — source of negative hydrogen ions, 2 — magnetic lenses, 3 — correctors, 4 — cryogenic pump, 5 — high voltage electrode, 6 — intermediate electrodes, 7 — the gas stripper, 8 — turbomolecular pump, 9 — insulator, 10 — high-voltage power supply, 11 — inlet diaphragm.

part of the feed-through insulator is filled with SF_6 gas at a pressure of 0.3 MPa, the high-voltage rectifier tank of 0.8 MPa. Maximum gradient along the surfaces of the insulators on the vacuum side is 12 kV/cm, on the sulfur hex side — 14 kV/cm, peak fields of the gaps in the gas region — 95 kV/cm.

Gas stripper is designed as a cooled cylindrical copper pipe length of 400 mm, an inner diameter of 16 mm with an inlet for argon injection in the middle [5]. Operating mode of gas injection provides 90% of the injected beam stripping.

Proton beam with a typical size of 10 mm is delivered to the lithium neutron generating target [6] by a pair of quadrupole magnetic lenses, bending magnet, another pair of quadrupole lenses and scanner. Scanner provides uniform illumination across the target surface 100 mm in diameter by the beam [7]. Total neutron yield is 1.1 10^{11} s^{-1} at 1 mA 2 MeV proton beam [8].

A photograph of the tandem accelerator with vacuum insulation is shown in figure 3.

1.2 Features of the accelerator

The accelerator is characterized by fast acceleration of charged particles (25 kV/cm), large distance between ion beam and insulator (on which electrodes are mounted), large stored energy in the accelerating vacuum gaps (up to 26 J) and strong input electrostatic lens. The high-voltage strength of centimetre vacuum gaps with large stored energy (up to 50 J) was investigated [9]. The way of consistent training of accelerating gaps proposed and realized and the required voltage of 1 MV

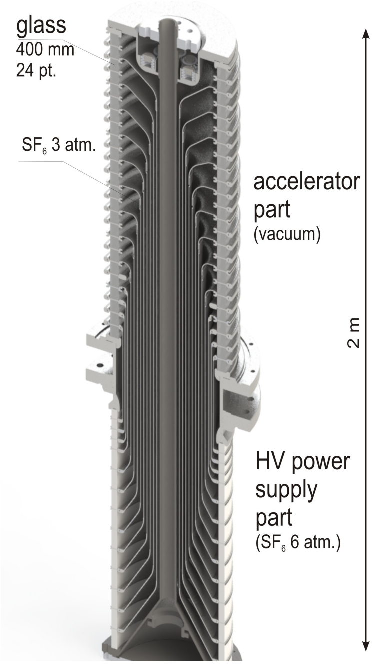

Figure 2. Scheme of the high-voltage feed-through insulator.

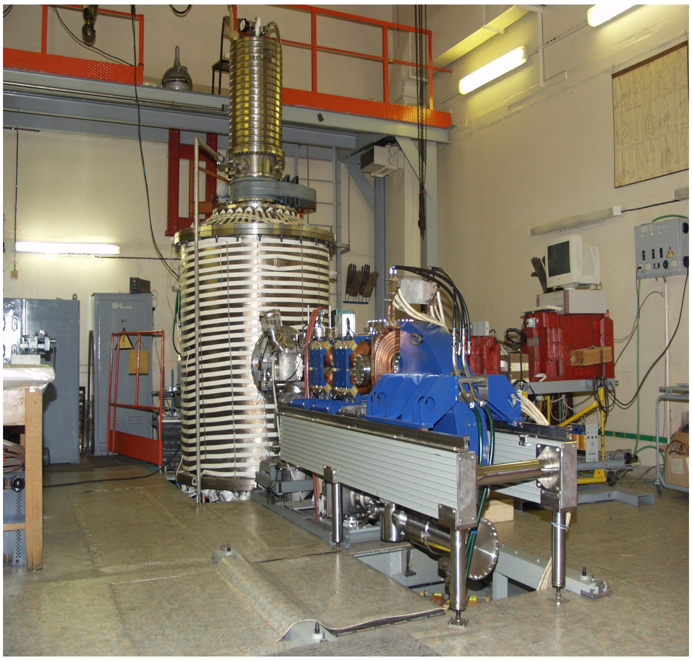

Figure 3. Photo of the tandem accelerator with vacuum insulation.

was obtained [10]. The behaviour of dark currents was studied and then they were reduced to an acceptable level by long staying under voltage [11]. An auto-emission current was detected, the cause of its occurrence was established, and changes in the design of the accelerator to prevent it were made [11]. The reason for the reduction of the first electrode potential was fixed. It was associated with the emission of electrons from the surface of the uncooled inlet diaphragm (11 in figure 1) heated by the peripheral part of the injected beam. It was proved that the application of a magnetic focusing lens allows realizing a consistent input of a beam of negative hydrogen ions in the accelerator without loss [12]. A method of calibrating a gas stripping target was proposed and implemented. It is based on the measurement of the gas flow when the proton current is equal to the negative hydrogen ion current at the output of the accelerator [5].

2 Experimental results

These investigations allowed us to significantly increase the proton beam current. In the initial experiments the characteristic value of the current was 100–200 μA [13, 14], but at the present time we obtain more than 1 mA in a long steady mode. Figure 4 shows the time dependence of the ion beam current measured at the output of the accelerator, when the supply of gas to the stripper was provided, then the accelerator operated in a stationary mode, and at last the gas supply was turned off. We see that in continuous operation a proton beam with a current 1.6 ± 0.007 mA is obtained. In this experiment the gas supply was carried out by briefly opening the electromechanical valve (the stripper and the gas flow system are described in [5]). At figure 4 arrow 4 shows two breakdowns at full voltage, after which the current recovery occurred for 20 seconds. In the short-term modes proton beam current reached 3 mA.

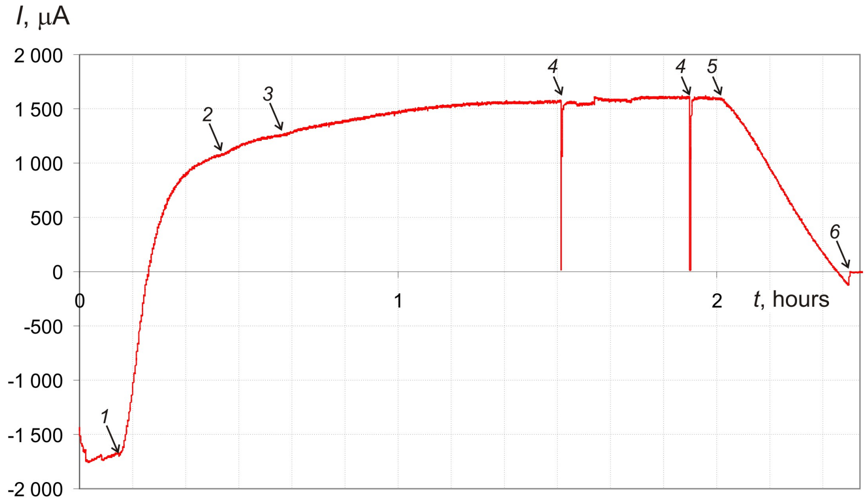

Figure 4. The time dependence of the ion beam current. Arrow 1 indicates the beginning of the gas flow in the stripper with a valve opening frequency of 1/10 Hz, 2 — 1/7 Hz, 3 — 1/5 Hz; arrow 4 marks the breakdown of the full voltage, 5 — turn off the gas supply, 6 — turn off power.

The energy of the proton beam was measured using a resistive voltage divider inside the high voltage power supply. To calibrate the divider the reaction ^{7}Li(p,n)^{7}Be, characterized by an energy threshold of 1.882 MeV, was used. It is possible to obtain a proton beam with energy from 600 keV up to 2 MeV on the accelerator.

Monochromaticity of the proton beam energy is 0.1%. It was measured by two ways. The first way used generation of 9.17 MeV gamma rays from the reaction ^{13}C$(p,\gamma)^{14}$N, when the proton beam with energy higher than 1.747 MeV irradiated a graphite target enriched with the carbon-13 isotope. BGO-spectrometer was used to measure the count rate of gamma rays depending on proton energy. Since the resonance of gamma rays is narrow ($\pm$0.9 keV [15]), the slope of the excitation curve is determined entirely by the instability of the proton energy. The energy spread of the protons defined using this curve was $\pm$2 keV. During measurement of the neutron spectrum using time-of-flight technique a long-term stability of the proton beam energy was also evaluated — better than $\pm$5 keV [16].

3 Future plans

To conduct BNCT it is planned to increase the beam parameters to at least 2.5 MeV and 3 mA. It is planned to achieve the current increase by improving the vacuum conditions in the beam transporting channel and by using of a new source of negative hydrogen ions with pre-acceleration. It is also expected to conduct research on the development of operative detection of explosives and drugs [14] and of the monoenergetic neutron generation for calibration of dark matter detector [17].

Acknowledgments

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