Applied Radiation and Isotopes 106 (2015) 53–56

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Modification of the argon stripping target of the tandem accelerator

A. Makarov [a], Yu. Ostreinov [b], S. Taskaev [a,c,*], P. Vobly [a]

[a] Budker Institute of Nuclear Physics, 11 Lavrentiev ave., 630090 Novosibirsk, Russia
[b] Novosibirsk State Technical University, 20 Marx ave., 630073 Novosibirsk, Russia
[c] Novosibirsk State University, 2 Pirogov str., 630090 Novosibirsk, Russia

HIGHLIGHTS

- To increase the proton beam current at the vacuum insulation tandem accelerator and to improve reliability of the accelerator it is proposed to modify the gas stripping target creating a transverse magnetic field in front of the target and after the exit.

ARTICLE INFO

Article history:
Received 20 January 2015
Received in revised form
19 June 2015
Accepted 25 July 2015
Available online 29 July 2015

Keywords:
Tandem accelerator
Charge exchange
Stripping target

ABSTRACT

The tandem accelerator with vacuum insulation has been proposed and developed in 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 protons are accelerated again by the same potential. A stationary proton beam with 2 MeV energy, 1.6 mA current, 0.1% energy monochromaticity, and 0.5% current stability is obtained now. To conduct Boron Neutron Capture Therapy it is planned to increase the proton beam current to at least 3 mA. The paper presents the results of experimental studies clarifying the reasons for limiting the current, and gives suggestions for modifying the gas stripping target in order to increase the proton beam current along with the stability of the accelerator.

1. Introduction

The Vacuum Insulated Tandem Accelerator (VITA) was proposed (Bayanov et al., 1998) and developed in Budker Institute of Nuclear Physics to produce epithermal neutrons for Boron Neutron Capture Therapy (BCNT) in the ^{7}Li(p,n)^{7}Be reaction. Fig. 1 shows the accelerator. Coming from the source (Belchenko and Savkin, 2004) the 23 keV negative hydrogen ion beam is rotated in a magnetic field at an angle of 15 deg; it is focused by a pair of magnetic lenses injected into the accelerator and is accelerated up to 1 MeV. In the gas stripping target, which is installed inside the high-voltage electrode, negative hydrogen ions are converted into protons. The stripping target is made as a 400-mm long tube of 16 mm in diameter with the supply of the stripping gas (argon) in the middle (Fig. 2). Then protons are accelerated to the 2 MeV energy by the same 1 MV potential. The potential for the high-voltage and five intermediate electrodes of the accelerator is supplied by a high-voltage source (the most part of the source is not shown) through the insulator, wherein the resistive divider is set. The evacuation of gas is performed by turbomolecular pumps mounted at the ion source and at the exit of the accelerator and a cryogenic pump via jalousies in the electrodes. Neutron generation is carried out by the proton beam bombardment of the lithium target (Bayanov et al., 2006; Kuznetsov et al., 2009).

2. Experimental results

The stationary proton beam with 2 MeV energy, 1.6 mA current, 0.1% energy monochromaticity, and 0.5% current stability is obtained now (Kasatov et al., 2014). With these parameters, the breakdowns at full voltage do not happen more than once per hour, and they do not interfere with work. After the breakdown all the beam parameters are recovered within 20 s.To conduct BNCT it is necessary to increase the proton beam current to at least 3 mA. Attempts to increase the proton beam current by increasing the injected current or increase in the stripping target gas puffing inevitably lead to frequent breakdowns, making the work impossible. To determine the reasons of breakdowns and causes of current limiting an experiment was carried out with a smooth increase in the supply of gas to the stripping target. Fig. 3 shows the dependence of the current in the accelerating gap on the gas

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[*] Corresponding author at: Budker Institute of Nuclear Physics, 11 Lavrentiev ave., 630090 Novosibirsk, Russia
E-mail address: taskaev@inp.nsk.su (S. Taskaev).

http://dx.doi.org/10.1016/j.apradiso.2015.07.046
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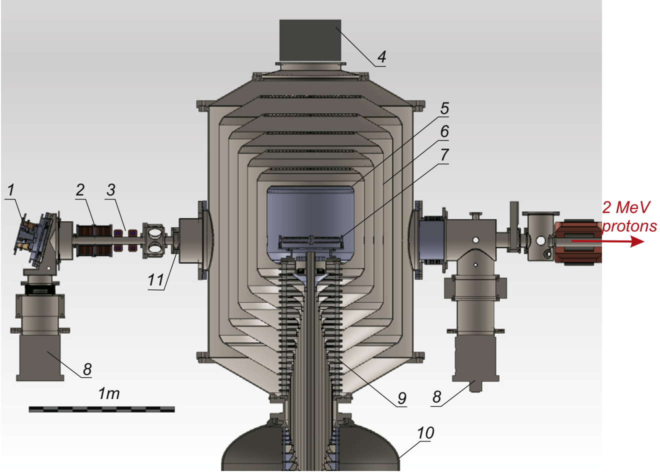

Fig. 1. Tandem accelerator with vacuum insulation: 1 – negative hydrogen ion source, 2 – magnetic lenses, 3 – corrector, 4 – cryogenic pump, 5 – high voltage electrode, 6– intermediate electrodes, 7 – gas stripping target, 8 – turbomolecular pump, 9 – insulator, 10 – high voltage power supply, 11 – inlet diaphragm or detector.

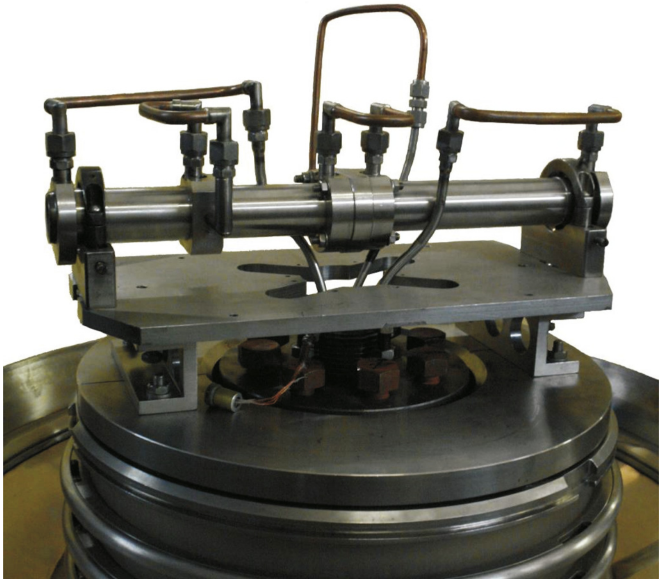

Fig. 2. Photo of the stripping target placed on the feedthrough insulator.

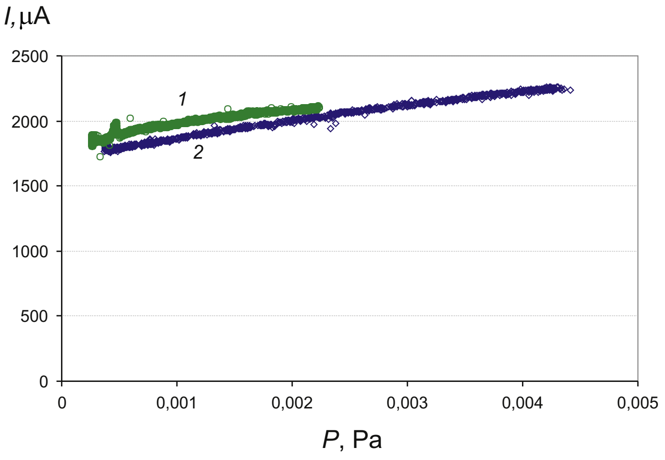

Fig. 3. Dependence of the current in the accelerating gap on the residual gas pressure with an increase in the gas puffing into the stripping target: 1 – cryogenic pumps are switched on, 2 – a cryogenic pump is switched off.

puffing into the stripping target. The amount of gas puffing is indirectly manifested in the measured residual gas pressure at the accelerator exit. Without a supply of gas to the stripping target residual gas pressure has a value of 2.6×10^{-4} Pa while the cryopump enabled, and the current in the accelerating gap has a value of 1850 μA. When a cryogenic pump is off residual gas pressure has a value of 3.9×10^{-4} Pa, and the current in the accelerating gap is 1770 μA. When the gas is supplied to the stripping target the residual gas pressure is increasing and the current is growing in the accelerating gap. Fig. 3 shows that the current increases almost linearly with increasing pressure of the residual gas. When the cryopump is enabled it becomes possible to increase the gas flow rate to a value that provides 90% proton yield. In this case, as seen from Fig. 3, the current in the accelerating gap amounts to 2100 μA, that is 250 μA more that the value with no gas supply to the stripping target. A further increase in the gas supply leads to frequent breakdowns, making the work impossible. When the cryopump is off it is possible to increase the gas flow only to the value that provides 50% yield protons. In this case, the current in the accelerating gap amounts to 2250 μA, which is 480 μA greater than without stripping gas delivery into the target.

Let us compare the measured residual vacuum pressure with the calculated one. In order to provide a 90% recharge of the beam of negative hydrogen ions into protons an argon target with a linear density of 1.7×10^{16} cm^{-2} is required. The gas consumption is expected to be 0.1 Torr l s^{-1} (Kuznetsov et al., 2012). At an evacuation rate of 3000 l/s performed by a cryogenic pump, which is limited by jalousie system of the electrodes, the pressure in the high voltage electrode is expected to be 5×10^{-3} Pa. The fact that a lamp near the turbomolecular pump shows a better vacuum (2×10^{-3} Pa) at this moment is explained by the placement of the lamp. The estimation performed reveals the absence of contradictions and makes it possible to consider the gas pressure in the interelectrode space of the accelerator to be 2–3 times higher than the measured pressure when gas is puffed into the recharging target.

To study the current in the accelerating gap a special detector was designed and mounted at the inlet into the accelerating gap (11 in Fig. 1). The detector (Faraday cup) consists of two concentric annular disks (the internal one with the diameters of 52 and 90 mm, the outer one with the diameters of 92 and 136 mm) and a frame with a stretched mesh to suppress secondary electron emission. The detector measures only the current flowing from the high voltage electrode. Fig. 4 shows diagrams of the current on the detector at the injection of the negative hydrogen ion beam with a

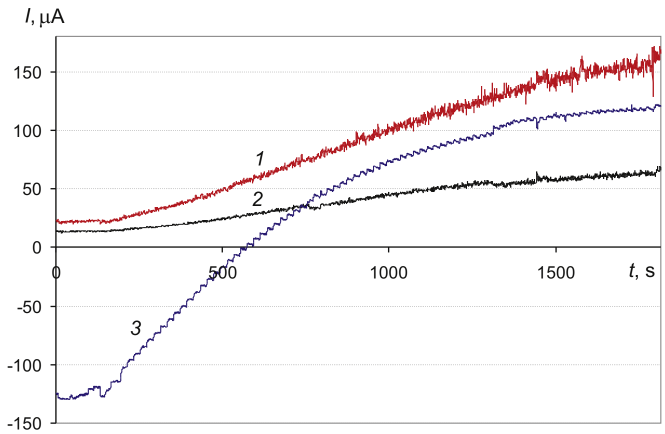

Fig. 4. Diagram of the current to the internal disc of Faraday cup 1 and the external disc of Faraday cup 2 with an increase in the gas puffing into the stripping target. Graph of the current at the output of accelerator 3 is shown (current value is 10 times reduced for convenience).