OPTIMIZATION OF THE NEGATIVE HYDROGEN ION BEAM INJECTION INTO THE TANDEM ACCELERATOR WITH VACUUM INSULATION

A. Makarov#, V. Aleynik, A. Kuznetsov, I. Sorokin, S. Taskaev, M. Tiunov,
BINP SB RAS, Novosibirsk, Russia,
Bashkirtsev, I. Shchudlo, Novosibirsk State Tehnical University, Russia

Abstract

The beam of negative hydrogen ions is injected into the tandem accelerator with vacuum insulation in order to obtain high-current proton beam. To accurately direct the beam into the accelerator the magnetic focusing lenses are used. In this paper it is described the design of the special beam detector mounted in front of the first accelerating electrode and intended to measure beam profile and the current density. The results of measurements of the dependence of the current density on the power of the magnetic focusing lenses are shown. The parameters of the beam resulting in the best agreement of calculation and experiment are specified. The optimum focusing mode to inject the negative hydrogen ions into the accelerator is determined.

INTRODUCTION

Negative hydrogen ions are injected into the accelerator and accelerated up to 1 MeV by potential applied to the electrodes, then H^- turn into protons in the charge-exchange target and at last the protons are accelerated up to 2 MeV by the same potential [1].

Although the accelerator is designed to obtain a 5 mA proton beam, but in the experiments carried out in 2008-2010 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 [2] and monochromatic gamma-quanta [3], but it is clearly not sufficient for the thorough BNCT research and other applications.

To clarify current-limiting reasons, a detailed study of the transportation of negative hydrogen ions have been carried out using multichannel detector mounted in front of the first accelerating electrode of the accelerator.

EXPERIMENTAL SETUP

The scheme of the experiment is shown on Fig.1. Negative ion beam with energy of 21 keV, current up to 5 mA and angle distribution of 100 mrad 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.

Next, the expanding beam is focused by two magnetic lenses. Each of the magnetic lenses is powered by an independent power supply and currents of lenses may be different, but in our experiments they were set the same and opposite. For a typical current of 50 A maximum magnetic field on the axis of the lens has a value of 2.1 kG. Following the lenses it is installed magnetic corrector. Each of the two elements of the corrector consists of two pairs of coils, powered by independent power sources. The angular displacement of the beam from each pair of coils is characterized by 10 mrad/A.

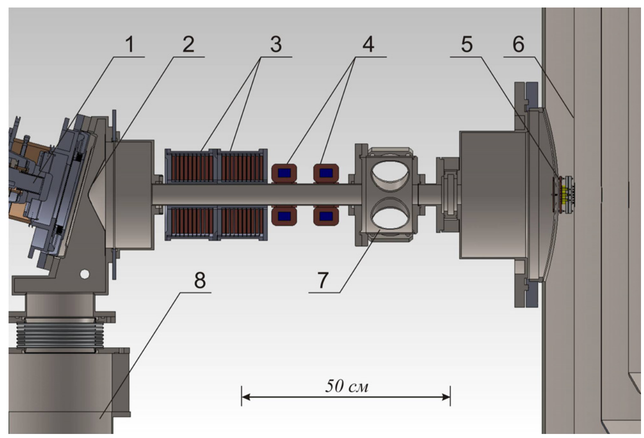

Fig. 1. Experimental setup: 1 - the source of negative hydrogen ions, 2 - cone aperture, 3 - magnetic focusing lenses, 4 - corrector, 5 - beam detector, 6 - the first electrode of the accelerator, 7 - diagnostic chamber, 8 - TM pump.

Focused and corrected the beam then strikes the detector mounted in front of the accelerator so the surface of the beam receiver is 47 mm in front of the surface of the first electrode. The detector is centered along the transporting channel using a laser (Fig. 2).

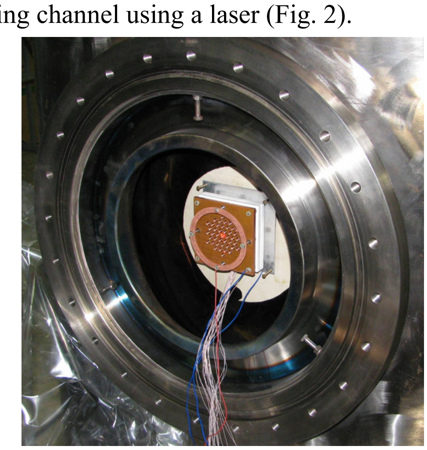

Fig. 2. Photo of the beam detector.

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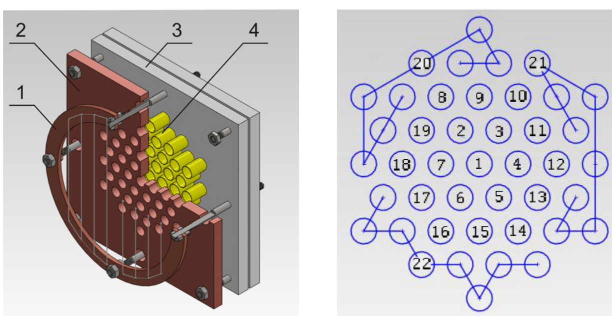
Tandem accelerator with vacuum insulation is characterized by rapid acceleration and strong input electrostatic lens. Entering of the beam into the accelerator assumes it refocuses in front of the input lens, i.e. prior to the first electrode. The desire to measure experimentally beam parameters in this area has determined the choice of the detector location. Also it should be kept in mind that during the experiment the voltage on the accelerator and, accordingly, on the first electrode was not supplied.

THE DESIGN OF THE BEAM DETECTOR AND SOFTWARE

The main element of the detector is a copper plate having size 10x10 cm, 6 mm thick, serving as the receiver of the beam (Fig. 3a). To prevent the secondary electron emission and to measure the ion current properly the grid is mounted under suppressing potential. In the copper plate 43 holes of 5 mm diameter are made. The distance between the centers of adjacent holes is 7.5 mm. Behind each hole it is installed a copper Faraday cup, 10 mm high with an internal diameter of 5 mm. All cups are mechanically fixed between two square insulating plates and centered to the holes of the copper beam receiver. Peripheral Faraday cups are combined into 3 groups of 8 cups in each, as shown on Fig. 3b.



a b

Fig. 3. a) Beam detector: 1 - suppressing grid, 2 - copper plate, 3 - insulating plates, 4 - Faraday cups. b) Numbering of detector channels.

Currents taken from the copper beam receiver, from 19 central Faraday cups and 3 groups of peripheral cylinders through the 24-pin vacuum socket were supplied to the inputs of 32-channel ADC PCI-1713 (Advantech, Taiwan). Shunt resistance at the input of the ADC had a value of 1 kOhm.

ADC is installed into a PCI slot in the computer placed near the accelerator. The computer is connected to the network and using the server transmits an array of digitized voltage values to the client interface in the control room. Client interface software recovers the current density distribution of the beam by voltages of ADC channels. Also in real time it is constructed a normal distribution approximation of the discrete current distribution using a Levenberg-Markvadt algorithm [4]. Application of the algorithm for the two-dimensional distribution and necessity for assuming the presence of a maximum in the center of the beam limits the reliability of this approximation. However, the use of this approximation, as it turned, became a convenient operational tool for estimation of the beam size and its position in real time. Example of the user interface of the beam registration program is shown on Fig. 4.

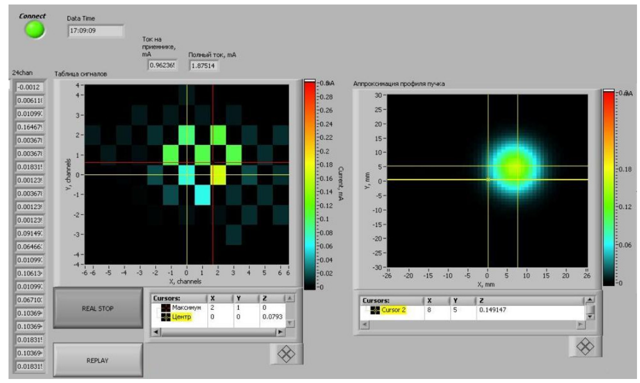


Fig. 4. User interface of the beam registration program.

RESULTS AND DISCUSSION

In Fig. 5 shows the current-voltage characteristics of the detector, measured at focusing lenses current of 46 A.

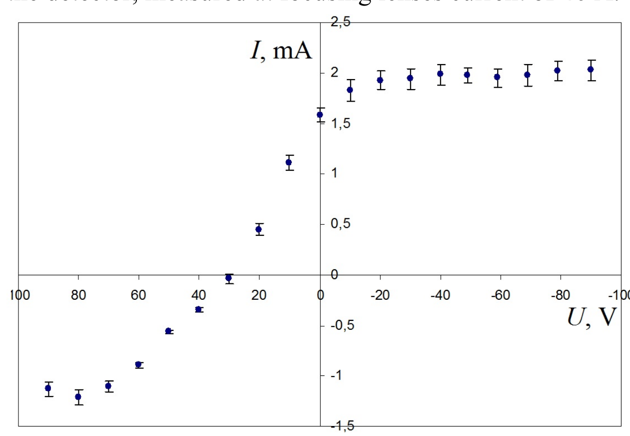


Fig. 5. Dependence of the total current recorded by the detector on the grid voltage.

It is determined that the coefficient of secondary electron emission is 1.6±0.2 and the suppressing grid voltage must be at least -20 V for accurate measuring of the beam current.

All currents in Faraday cups were normalized to the total current, and then maximum values were taken and analyzed for reliability. These measurements were taken at different currents in magnetic lenses - from 40 to 62 A. It is found that the maximum focusing is achieved with a lens current of 50 A. In this case, single 5 mm hole of the detector gets 57% of the beam.

Fig. 6 shows the experimentally measured maximum current (normalized to the total), recorded by one Faraday cup with a diameter of 5 mm, with different currents of magnetic focusing lenses. Also Fig. 6 shows the calculated dependences of the percentage of the current in the axial region of 5 mm in diameter, assuming the "cold"

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and "hot" beam, when the transverse temperature on the plasma boundary of the ion source is set to either 0 eV, or 10 eV respectively. The calculations assumed full compensation of the space charge of the beam from the output of the ion source to the Faraday cup. It can be seen that the calculation of "cold" beam corresponds much better to the measured values.

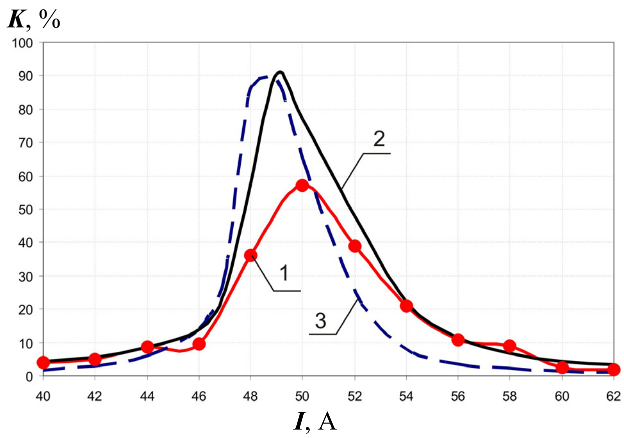

Fig. 6. The dependence of the percentage ***K*** of beam current in the axial region with a diameter of 5 mm on the current of magnetic focusing lenses ***I***: 1 - measured, 2 - calculated at T = 0 eV, 3 - calculated at T = 10 eV.

Thus, we can conclude that the study has helped to clarify the parameters required for the proper calculation, and to improve the transportation of negative hydrogen ions.

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