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PROTON BEAM SIZE DIAGNOSTICS USED IN THE VACUUM INSULATED TANDEM ACCELERATOR*

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Abstract

For the development of a promising method for the treatment of malignant tumors - boron neutron capture therapy - the accelerator-based epithermal neutrons source has been proposed and created in the Budker Institute of Nuclear Physics [1,2]. After the acceleration phase, a proton beam with an energy of up to 2.3 MeV and a current of up to 10 mA is transported in a high-energy path. With a beam size of 1 cm^2, its power density can reach tens of kW/cm^2. Diagnostics of the size of such a powerful beam is a nontrivial task aimed at increasing the reliability of the accelerator. The paper presents such diagnostics as: 1) the use of the blister formation boundary during the implantation of protons into the metal; 2) the use of thermocouples inserted into the lithium target; 3) the use of the melting boundary of the target lithium layer when it is irradiated with a beam; 4) the use of the activation of the lithium target by protons; 5) the use of video cameras; 6) the use of an infrared camera; 7) the use of the luminescence effect of lithium when it is irradiated with protons; 8) the use of collimators with a small diameter of 1-2 mm; 9) the use of the method of two-dimensional tomography [3].

INTRODUCTION

Charged particle accelerators are widely used in scientific research, medicine, and other applications. Tandem accelerators are high-voltage electrostatic accelerators in which the high-voltage potential is used twice: first to accelerate negative ions, and then, after changing the polarity of their charge in the high-voltage terminal, to accelerate positive ions. Thin foils are used for the conversion of the ion charge, or, at a higher ion current, gas stripping targets similar to the argon target in the tandem accelerator. After the acceleration phase, a proton beam with an energy of up to 2.3 MeV and a current of up to 10 mA is transported in a high-energy path. With a beam size of 1 cm^2, its power density can reach tens of kW/cm^2. Diagnostics of the size of such a powerful beam is a nontrivial task aimed at increasing the reliability of the accelerator.

THE EXPERIMENTAL SCHEME

The studies were carried out at the accelerator neutron source of the Budker Institute of Nuclear Physics (Novosibirsk, Russia). The source diagram is shown in Fig. 1 and its detailed description was given in [1]. A tandem accelerator with vacuum insulation was used to obtain a stationary proton beam with an energy of 0.6 to 2.3 MeV and a current from 1 pA to 10 mA, that is, a tandem accelerator of charged particles with an original design of electrodes.

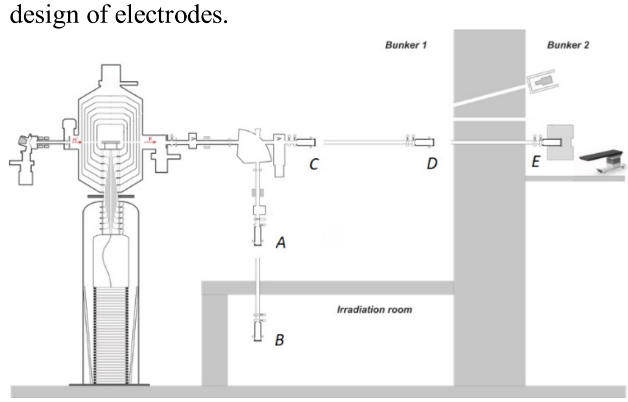

Figure 1: A diagram of an accelerator based source of epithermal neutrons. A-E – sites of the lithium neutron generating target.

RESULTS AND DISCUSSIONS

Below will be briefly discussed 9 implemented at the vacuum-insulated tandem accelerator diagnostics of the proton beam size with a high power density (up to tens of kW/cm^2).

Use a Blistering Effect at Proton Implantation in Metal

Implantation of the protons in the metal cause blistering – deformation of the target surface by the “bubbles” – blisters. Knowing the progress of the blisters appearing we can estimate profile of the proton beam and calculate the proton beam size. Example of this calculations presented in Fig. 2. And details are given in [4]. The effective square of the beam is 0.75±0.07 mm^2.

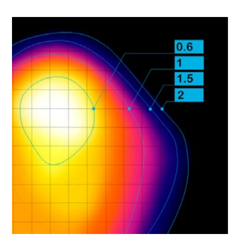

Figure 2: Blistering-covered area of the target versus current fluence (mA·hours).

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Use a Thermocouples, Inserted in the Lithium Target

When the target assembly is equipped with thermoresistors it can be used to determine the beam profile, size and destination. The Fig. 3 shows the layout of the thermocouples in the copper disk of the target. In the paper [5] it was discussed, that using proton beam size dependence versus proton beam current, shown at the fig. 3, we claim that there is no effect of the space charge for proton beam in the high-energy beam line.

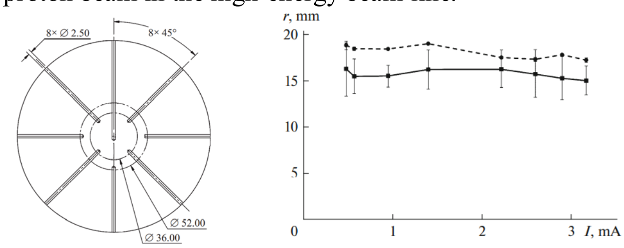

Figure 3: Schematic of thermocouple arrangement in the target copper disk (left). Proton beam radius versus the beam current. Dashed line is plotted according to the data from the thermocouples positioned on a 26-mm radius, solid – 18 mm (right).

Use a Melting of the Lithium Layer of the Target under Powerful Proton Beam

Since the temperature of lithium melting is 180ºC we can estimate the proton beam profile and measure the proton beam size. At Fig. 4 there shown the process of melting lithium layer of the neutrongenerating target under the few kW/cm^2 power density proton beam. The estimation sizes of the ellipse axes on amplitude level 1/e are 10.5 × 8 mm.

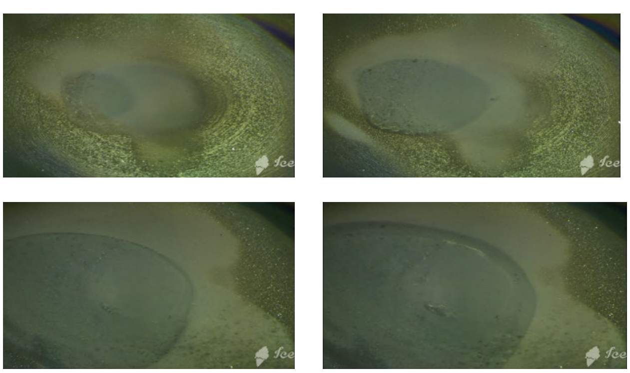
Figure 4: Evolution of the melting lithium layer under bombardment of the proton beam with 2 MeV energy. Upper left is 1.56 mA proton beam current, upper right is 1.81 mA, lower left is 2.59 mA and lower right is 3.05 mA.

Use an Activation of the Lithium Target by Berilium-7

Since radioactive isotope of beryllium is accumulates under proton bombardment of the lithium target, we can measure radioactive target by a gamma-spectrometer and estimate the proton beam profile and size at the lithium target. First results were obtained “by hand” without any automatization [6], so spatial resolution isn’t fine. Later gamma-spectrometry complex has been constructed and used, as it shown in the Fig. 5. The results of the automatized measurements with different time of the integration are also shown at the Fig. 5.

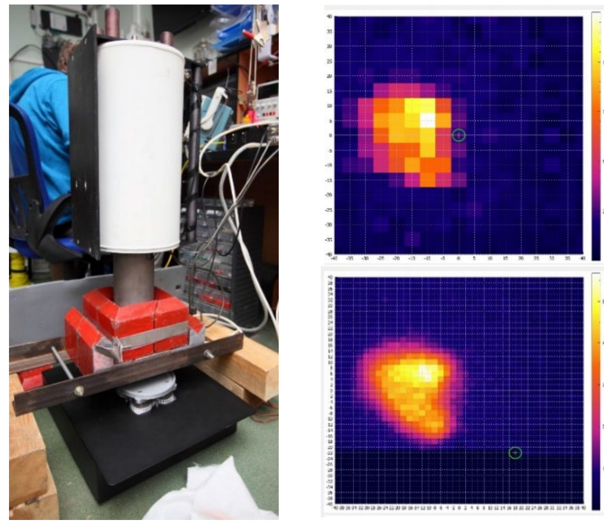
Figure 5: Gamma-spectrometry complex (left) and results of the measurements with 1 hour exposure time (up-right) and 8 hours exposure time (down-right).

Use Video Cameras

One of the features of the tandem accelerators is the need of the gas inlet into the stripping target area. Usually it is considered as disadvantage, but we turned it into advantage – we use video cameras to “see” the beam position, as it shown at Fig. 6 [7]. Using a developed software we also know the actually position of the beam and its size.

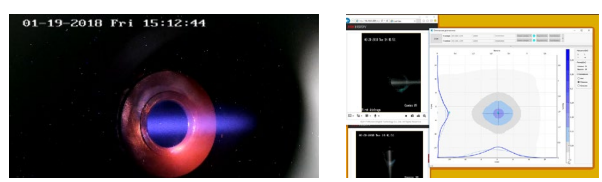

Figure 6: H$^-$ beam entering the accelerator (left) and soft, estimating the proton beam size and profile (right).

Use an Infrared Camera

We using an infrared camera for the monitoring beam position in real-time. This device cannot be used with proton beam energy more than 1882 keV – the energy for the threshold reaction ^{7}Li(p,n)^{7}Be. In the Fig. 7 it is shown the example of determining the proton beam size [5].

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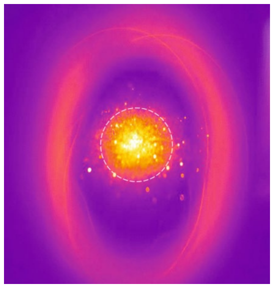

Figure 7: Image obtained from the infrared camera during the target irradiation by a proton beam with a current of 1.4 mA. The dashed circle denotes the diameter of 30 mm.

Use an Effect of the Luminescence of the Lithium under Proton Bombardment

The luminescence of the lithium layer of the target under proton bombardment helps us in all experiments with a lithium target to provide a correct transportation of the proton beam to the target [8]. In the Fig. 8 it is shown typical lithium luminescence under proton beam bombardment. Also, luminescence of the lithium target helped us in an experiment for determining argon beam current, accompanying the proton beam [9].

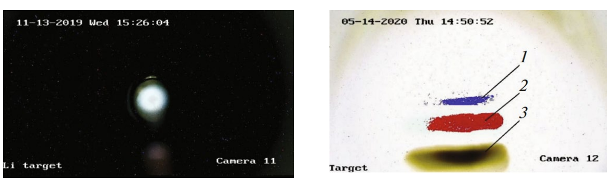

Figure 8: The luminescence recorded by a Hikvision video camera when a lithium target is irradiated with a proton beam (left). Image from a video camera looking at the surface of a lithium target at a bending magnet current of 14 A. *1* - glow caused by neutrals (hydrogen atoms); *2* - argon ions; *3* - protons (colors are partially inverted).

Use a Collimator with 2 mm Aperture

Proton beam was scanned, using a bending magnet or vacuum three-dimensional motion input, cooled collimator with an aperture and Faraday cup [9]. The profile obtained shown in the Fig. 9.

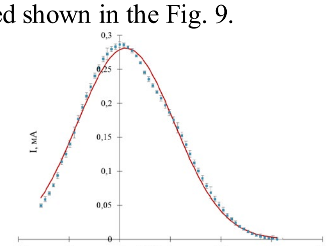

Figure 9: The dependence of the proton beam current, passed through the hole from its coordinate on the collimator and Gaussian distribution, approximated this dependence.

Use Two-Dimensional Tomography

We can use vacuum two-dimensional motion input for obtaining two-dimensional tomography of the proton beam. [3] In Fig. 10 are shown 3d-picture of the proton beam current distribution and profile of the beam along one axe, passing through the current peak.

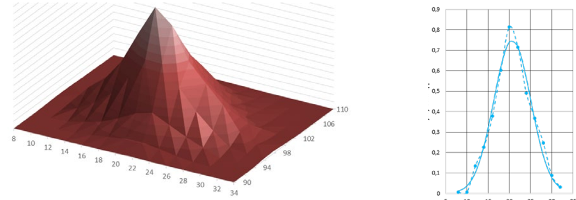

Figure 10: The example of the two-dimensional tomography measurement (left) and chord measurement, passing through the peak current (right).

CONCLUSION

The Budker Institute of Nuclear Physics operates a vacuum insulated tandem accelerator, in which transporting the proton beam with high power density – it can reach few tens of kW/cm^2. To provide stable transportation of the beam from the exit of tandem-accelerator up to lithium neutron generating target there were proposed and implemented 9 diagnostics of proton beam size.

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