DEVELOPMENT OF A NUCLEAR DIAGNOSING PROTON BEAM FOR A COLLECTIVE ION ACCELERATOR

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A nuclear method for determination of energy and intensity of a proton beam is proposed to use for investigation of collective ion acceleration by space charge waves arisen in an intense relativistic electron beam (REB) at its temporal and spatial modulation. It is proposed to register the proton beam by using nuclear reactions $^{11}B(p,\alpha)^{8}Be$, $^{9}Be(p,\alpha)^{6}Li$ at the proton beam assistance to produce alpha particles, which should be detected with solid state detectors.

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INTRODUCTION

Conventional electrothechnical measurements of parameters of accelerated ions in a collective ion accelerator [1-3] based on temporal and spatial modulation of a pulsed intense relativistic electron beam, are impeded because of a high level of electromagnetic background noise. Besides, standard methods for diagnostics of protons (magnetic analyzer, track detectors, flight-time method) applied in [1] did not allow registering accelerated protons within obtained MeV energy range. Nuclear physics methods are expedient in such circumstances. We have considered several schemes for nuclear reactions usage, which occur at a chosen target bombardment by a proton beam, as well as some realizable methods for nuclear reaction products registration. The conclusion is made regarding which one of these methods is appropriate for registration of a proton beam obtained and for measurement of its parameters.

EXPERIMENTAL SET-UP AND METHODS

In Fig.1 the scheme of an experimental prototype of collective ion accelerator based on a plasma virtual cathode for REB temporal modulation and an external periodic magnetic field for REB spatial modulation is shown. The accelerator consists of the following main systems: a Marx generator (MG), a magnetically-insulated diode (1), a power supply and control system of MG's parameters, a vacuum system, a system of external magnetic field formation (EMFF) by an air-cored solenoid (2), MG's and EMFF's starting system with synchronizing devices and a monitoring system of the accelerator (ASCS is the accelerator starting and control system).

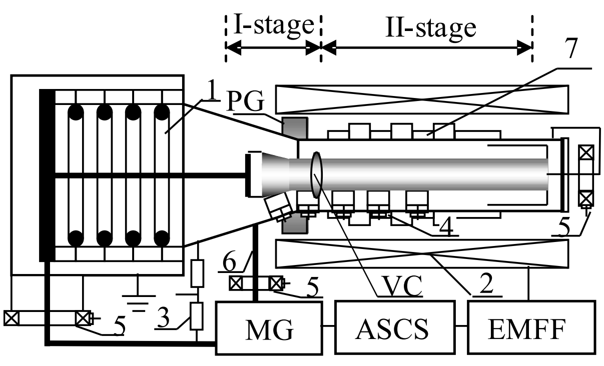

Fig.1. Schematic of collective ion accelerator

A fundamental part of the collective ion accelerator studied is a high-current REB accelerator "Agate", which is capable to produce an intense electron beam with energy 280 keV and current 4.4 kA of pulse duration 0.8 μs. Such acceleration allows obtaining speed-ups bunches with energy of protons up to 800 keV. Therefore, it is necessary to use nuclear-physical methods for registration of the protons of such energy at a high level of electromagnetic background noise.

The registration of protons with energy E>160 keV was realized by means of $^{11}B(p,\alpha)^{8}Be$ reaction. In this case, the proton beam arrives to a B_4C target, which is capable of maintaining high thermal loads. A solid-state detector of α-particles made of cellulose nitrate in a form of truncated cone was placed at an angle (θ≈135°) and a subtended angle of 2 radians.

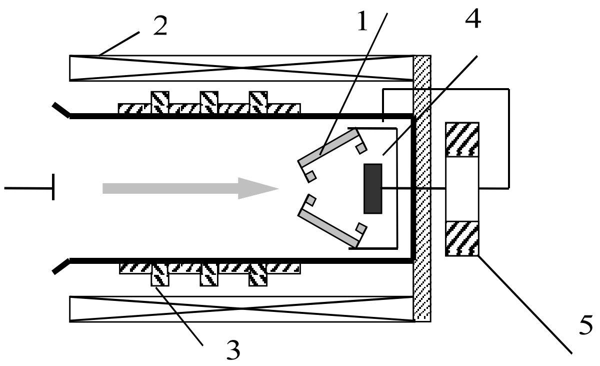

Fig.2. Registration unit: 1 – cellulose; 2 – solenoid; 3 – Al-Fe rings; 4 – target B_4C; 5 – magnetic sensor current

After a certain number of "shots" had been performed, the cellulose was extracted from the vacuum and underwent an etching in 10% solution of sodium hydroxide at a temperature of 60°C during 2 minutes. A number of registered particles was determined by a microscope – "MBB-1".

The first resonance of the reaction $^{11}B(p,\alpha)^{8}Be$ is realized at an energy 162.8 keV with a width of 5.3 keV, the second resonance of this reaction occurs at 675 keV with the width of 150 keV [4].

In this connection, an α-particle energy spectrum (and the spectrum for protons as well) can be measured with a sufficiently large error (~30%).

For registering the accelerated protons with a specific energy a nuclear reaction $^{14}N(p,\gamma)^{15}O$ was used.

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The first resonance of this reaction occurs at 277 keV with the half-width of 1.6 keV, while the second resonance – at 1064 keV with the width 4.8 keV. So, there exists a resonance at 700 keV with the width of 100 keV. Note that the period of ^{15}O half-life is 2.03 min.

Therefore, an exposure time of a TiN target was usually 4…5 min. Having been irradiated, the target TiN was placed into a low-background installation for measurements of its activity. An emission was detected with energy 511 keV and also positrons were registered with maximum energy 1.683 MeV.

RESULTS AND DISCUSSION

There were used nuclear reactions with α-particle yields which were registered by the solid-state detectors.

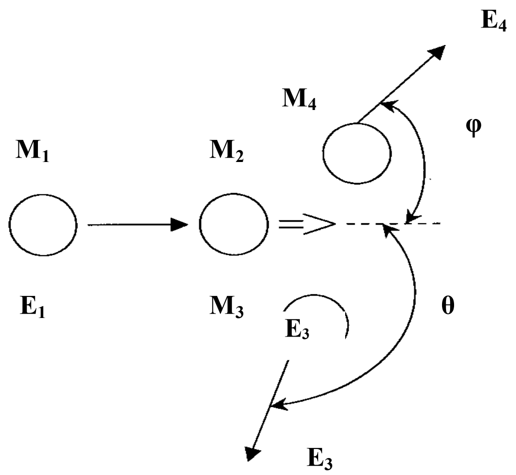

Fig.3. Diagram of the nuclear reaction: M_1, E_1 – mass and energy of the impinging particle; M_2 – the rest mass particle; M_3, E_3 – mass and energy of the departing particle; M_4, E_4 – mass and energy of residual nucleus

An energy of a particle M_3 (in our case, α-particles) is equal to (see Fig.3):

$$E_3^{1/2}=A\pm(A^2+B)^{1/2}, \quad (1)$$

where

$$A=[((M_1M_3E_1))^{1/2}/((M_3+M_4))]*\cos(\theta); \quad (2)$$

$$B=((M_4*Q)+E_1(M_4-M_1))/(M_3+M_4); \quad (3)$$

Q is the reaction energy.

In our case, the reaction energy for $^{11}B(p,\alpha)^8Be$, $^9Be(p,\alpha)^6Li$ and $^{19}Fe(p,\alpha\gamma)^{16}O$ reaction is equal to 8.586, 2.12, and 8.114 MeV, respectively. The maximum reaction cross-section of $^{11}B(p,\alpha)^8Be$ reaction is realized for an α_1–group. In this case, the reaction energy is equal to 5.686 MeV. This fact was used for energy calculation of the α-particles recorded. For the reaction $^{19}Fe(p,\alpha\gamma)^{16}O$ the maximum output is also realized for the α_1–group, but the reaction energy is equal to 1.974 MeV.

This method made it possible to measure the intensity of protons with an energy up to 600 keV at a level of 10^6 protons in 20 minutes of irradiation for the reaction $^{11}B(p,\alpha)^8Be$ and 10^8 protons in 5 minutes of irradiation for the reaction $^{14}N(p,\gamma)^{15}O$ (Fig.2). There exist other possible reactions: a target CaF_2 $^{19}Fe(p,\alpha\gamma)^{16}O$ resonance at 340 keV with the width 3 keV, an isotopic target $Ti^{15}N$ resonance at 429 keV with the width 0.9 keV (the limit of registration being 10^7 protons in 20 minutes of irradiation). In this case, the protons with the known resonance energy are detected.

For registration of the protons within an energy range 200…400 keV it is possible to use a nuclear reaction $^9Be(p,\alpha)^6Li$ [5]. The reaction cross-section for $^{11}B(p,\alpha)^8Be$ reaction at 162,8 keV is 10 mbn, while that one for the $^9Be(p,\alpha)^6Li$ reaction at 350 keV is 300 mbn. This fact allows obtaining a significant improvement in conditions for accelerated protons detection.

Let us underline that with the use of this reaction, acceptable conditions for spectral measurement of protons at energy of α-particle registered by a solid-state detector are realized (Fig.4).

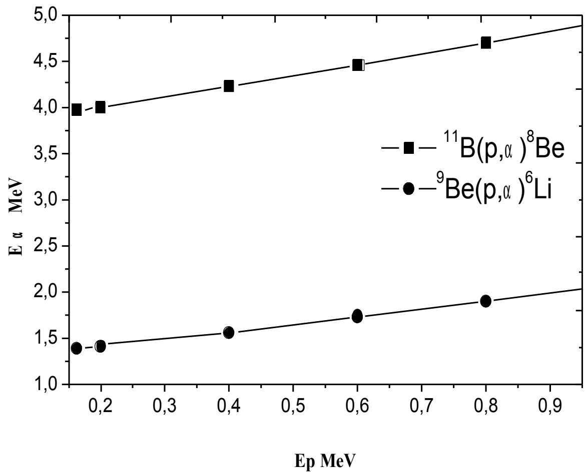

Fig.4. Dependence of α-particles energy on proton energy

The usage of the $^{11}B(p,\alpha)^8Be$ reaction results in more substantial change of a departing α-particle energy and, consequently, its path through cellulose is also changed (Fig.5).

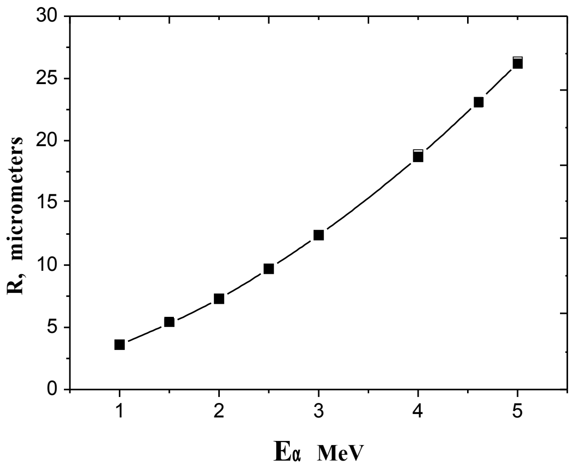

Fig.5. Dependence of run α-particles in cellulose on energy

Therefore, the path and track diameter measurements make it possible to determine a proton spectrum at a collective ion accelerator. For obtaining the data about accelerated particle distribution in the collective accelerator it is also possible to use films of different thickness for decreasing the proton energy at the B_4C target with subsequent calculation of the spectrum of protons by a method of regularization.

CONCLUSIONS

1. The use of solid-state detectors on a basis of cellulose for α-particles registration obtained in nuclear reactions, which are excited by protons, makes it possible to detect an energy and intensity of accelerated protons in collective ion accelerator.

2. The methods for energy measurements of accelerated protons in a collective ion accelerator are developed on a basis of α-particle diameter track measurements with the use of resonance nuclear reactions.

3. For an increase in a "signal/noise" ratio the use of the nuclear reaction ^{9}Be(p, α)^{6}Li is more preferable due to a high speed of α-particle track etching with the energy of 1…2 MeV.

4. The nuclear reaction ^{9}Be(p, α)^{6}Li is preferable for increasing of ratio "signal/noise".

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ИСПОЛЬЗОВАНИЕ ЯДЕРНЫХ РЕАКЦИЙ ДЛЯ РЕГИСТРАЦИИ ИМПУЛЬСНЫХ ПУЧКОВ ЗАРЯЖЕННЫХ ЧАСТИЦ

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Предложено использовать ядерно-физический метод определения энергии и интенсивности протонного пучка при исследовании коллективного ускорении ионов волнами плотности пространственного заряда, возникающих в интенсивном релятивистском электронном пучке при его модуляции во времени и в пространстве. Протонный пучок предполагается регистрировать с использованием ядерных реакций ^{11}B(p,α)^{8}Be, ^{9}Be(p,α)^{6}Li при наличии протонного пучка для получения альфа-частиц, которые должны фиксироваться твердотельными детекторами.

ВИКОРИСТАННЯ ЯДЕРНИХ РЕАКЦІЙ ДЛЯ РЕЄСТРАЦІЇ ІМПУЛЬСНИХ ПУЧКІВ ЗАРЯДЖЕНИХ ЧАСТОК

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Запропоновано використати ядерно-фізичний метод визначення енергії та інтенсивності протонного пучка при дослідженні колективного прискорення іонів хвилями густини просторового заряду, які виникають в інтенсивному релятивістському електронному пучку при його модуляції в часі та у просторі. Протонний пучок припускається реєструвати з використанням ядерних реакцій ^{11}B(p,α)^{8}Be, ^{9}Be(p,α)^{6}Li при наявності протонного пучка для отримання альфа-часток, які повинні фіксуватися твердотільними детекторами.