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NUCLEAR EXPERIMENTAL TECHNIQUES

A Voltage Buildup at High-Voltage Vacuum Gaps of a Tandem Accelerator with Vacuum Insulation

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Abstract—A new type of accelerator, namely, an electrostatic tandem accelerator with vacuum insulation, being distinguished by a high acceleration rate of charged particles and a large surface area of accelerating electrodes, was proposed, manufactured, and put into operation to obtain a proton beam with a 2-MeV energy and a direct current up to 10 mA. The influence of breakdowns on the electric strength of high-voltage components of the accelerator is studied in the work.

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For performing boron–neutron-capturing therapy of malignant tumors in conditions of cancer oncological clinics, an epithermal neutron source based on a new type of accelerator (electrostatic tandem accelerator with vacuum insulation) was proposed [1]. The general appearance of the accelerator is shown in Fig. 1. The injected negative ions of hydrogen are accelerated up to 1 MeV by the potential, applied to the high-voltage electrode, transformed into protons in a gas stripping target, and then protons are accelerated up to 2 MeV by the same potential. The gas of the stripping target is pumped out by cryogenic and turbo-molecular pumps via a jalousie system, located in the upper part of electrodes–screens. The potentials are applied to the high-voltage electrode and intermediate electrodes–screens from the high-voltage source through the SF6-filled bushing insulator, where an ohmic divider is placed.

The created accelerator is characterized by a large area of electrodes (41 m^2). Due to the absence of data on the high-voltage strength of similar systems, at first the electric intensity at the single-gap (45 mm) prototype with a high-voltage electrode area of 0.7 m^2 was determined and it was 60 kV/cm [2]. This result served as a basis for selecting the electric field intensity in interelectrode gaps of the created accelerator (25 kV/cm). In addition to vacuum gaps, the bushing insulator also determines the high-voltage strength of the accelerator. When the insulator was designed, the result of work [3] was taken into account, namely that the high-voltage strength over the surface of insulators in the form of rings, operated in the SF_6 medium under a pressure of over 3 atm, is over 100 kV/cm. It is also known from practice that the first surface vacuum breakdowns of insulators with a height of several centimeters occur at an intensity of ~10 kV/cm. As a result, in the gas part of the designed bushing insulator (*9* in Fig. 1), the intensity of the electric field over the surface of ceramic rings was 15 kV/cm and in the vacuum part of the insulator (*8*) it was 12 kV/cm over the surface of glass rings. One can see that the experimental data did not completely confirm the selection of the electric intensity in the interelectrode gaps and over the outer surface of the glass rings of the vacuum part of the bushing insulator.

The design electric intensity in the interelectrode gaps and over the surface of the insulator can be achieved by the high-voltage breakdown aging. This work is devoted to the study of the effect of breakdowns on the electric strength of the high-voltage components of the accelerator for obtaining the required voltage at the accelerator.

Due to the novelty of the design of the tandem accelerator, i.e., large area of electrodes and complex design of the bushing insulator, it was proposed to perform the breakdown aging in two stages. At first, the voltage was raised at separate gaps, and then the gaps were connected in series and the complete voltage buildup was carried out. Before the voltage was raised, the vacuum tank of the accelerator was heated up to a temperature of 110°C by heaters located on the outer surface of the tank.

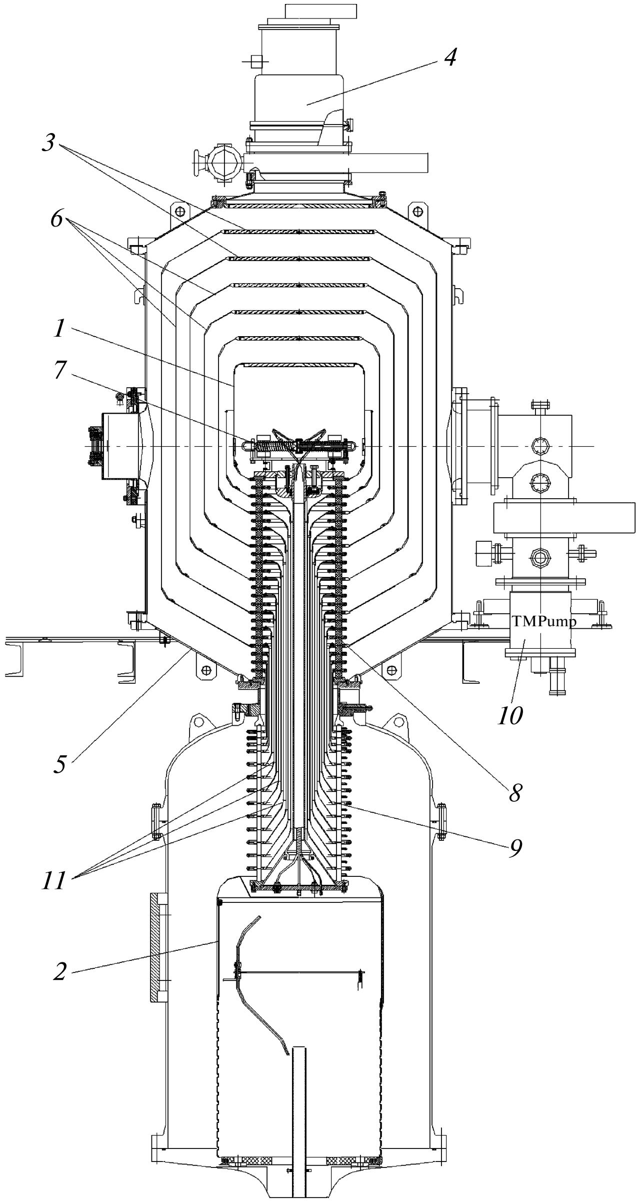

Fig. 1. General appearance of the six-gap tandem accelerator with the vacuum insulation: (*1*) high-voltage electrode of the tandem accelerator; (*2*) high-voltage electrode of the voltage source; (*3*) jalousie of the electrodes–screens; (*4*) cryogenic pump; (*5*) vacuum tank of the accelerator; (*6*) intermediate electrodes–screens; (*7*) gas stripping target; (*8*) vacuum part of the bushing insulator; (*9*) gas part of the bushing insulator; (*10*) turbo-molecular pump; and (*11*) internal coaxial cylinders.

For testing both separate and serially connected gaps, a special work tool (Fig. 2) in the form of two bars moving throughout the height was designed and manufactured. The bars were attached to the insulator between the high-voltage electrode and the wall of the tank of the high-voltage rectifier. Bar *1* had the common potential with the rectifier, and bar *2* had it with the earth. Each vacuum accelerating gap (together

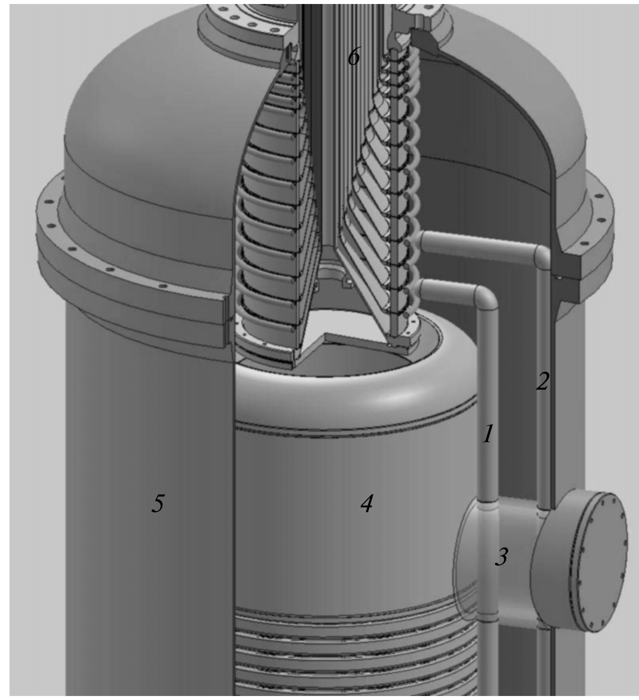

Fig. 2. Work tool for the single and serial connection of the gaps: (*1*) bar with a high potential; (*2*) earth bar; (*3*) insulator; (*4*) high-voltage electrode of the rectifier; (*5*) tank of the rectifier; and (*6*) gas part of the bushing insulator.

with corresponding gas gaps, glass and ceramic insulators) was tested for a voltage of up to 200 kV.

Figure 3 shows the voltage buildup at one of accelerating gaps owing to the gap-by-gap aging. One can

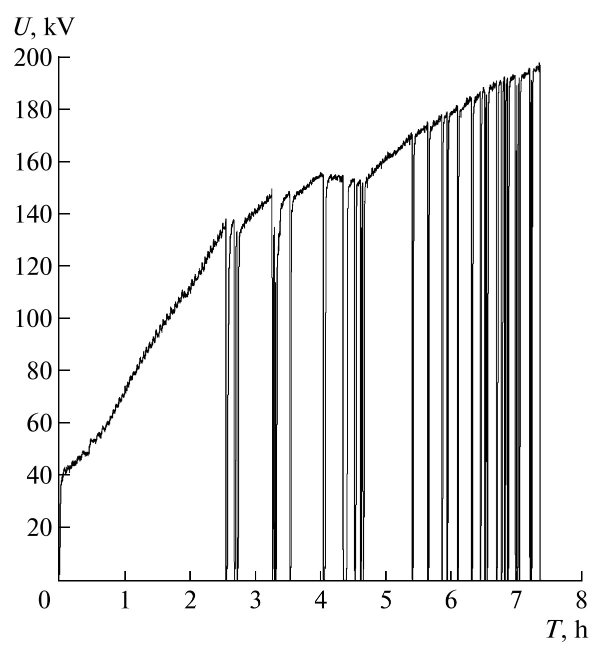

Fig. 3. Voltage buildup at the single gap.

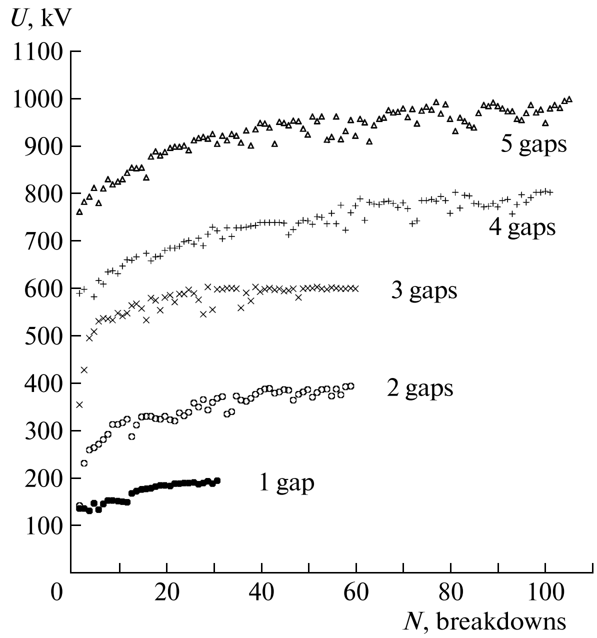

Fig. 4. Dependence of the breakdown voltage on the number of breakdowns.

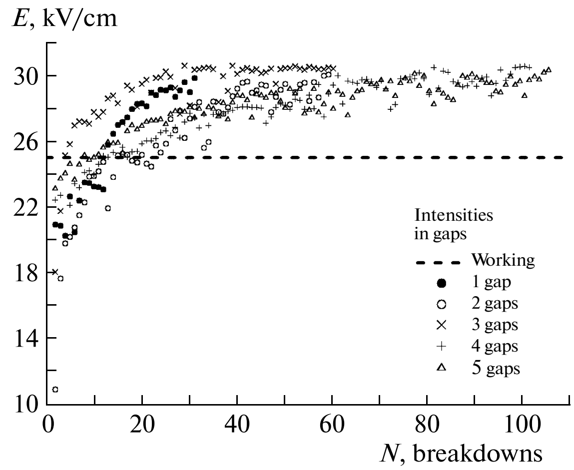

Fig. 5. Dependence of the intensity in the gaps on the number of breakdowns.

see that the first breakdown occurred at 140 kV, corresponding to an electric intensity over the glass insulator surface of ~10 kV/cm.

The tests with gaps, which were connected in series, were performed under a 6-atm pressure of SF6 gas inside the tank of the high-voltage rectifier, and the pressure inside the bushing insulator was 3 atm. Figure 4 shows the dependences of the breakdown voltage on the number of breakdowns for one, two, three, four, and five serially connected gaps. One can see from the graphs that, as the number of gaps goes up, the breakdown voltage of the accelerator increases, and a 1-MV voltage was reached at five gaps. Intensities of ~30 kV/cm (Fig. 5), which were reached for a short time in the experiments, are 20% higher than the working intensity (designated by the dotted curve in the graph).

After high-voltage strength tests of all components of separate accelerating gaps, the complete voltage was applied to the accelerator, and the aging curve of one of the first experiments is shown in Fig. 6a. The first breakdown occurred at a voltage of 770 kV, corresponding to a 20-kV/cm electric intensity in the gaps. The voltage buildup and breakdowns were accompanied by changing the residual pressure in the vacuum tank. A 1-MV voltage was obtained at the accelerator, and the dynamics of reaching the operation without breakdowns is shown in Fig. 6. The maximal time of the voltage withstanding without breakdowns was over 2 h.

Thus, the influence of breakdowns on the electric strength of high-voltage vacuum accelerating gaps was studied at the tandem accelerator with the vacuum insulation of electrodes. The gap-by-gap aging of all the gaps was performed. It is confirmed that the vacuum breakdowns do not reduce the high-voltage strength of the tandem accelerator. As a result of the

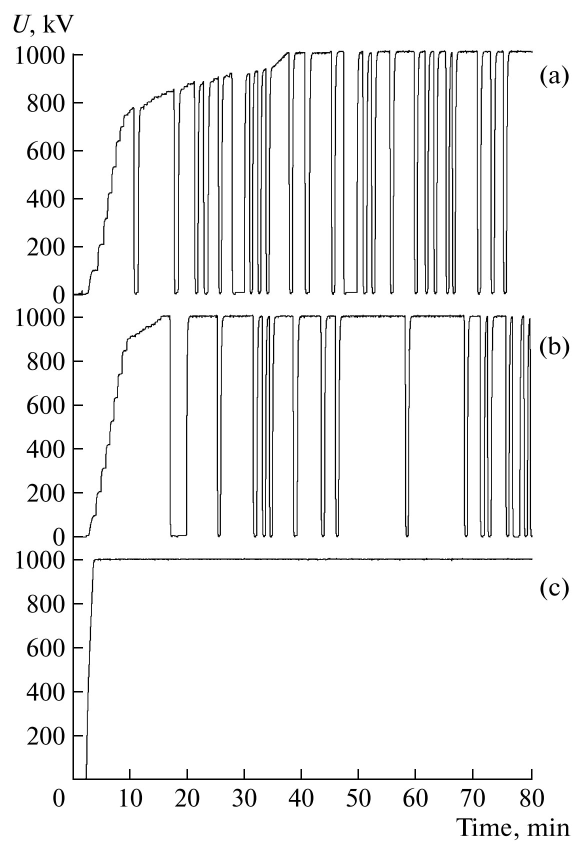

Fig. 6. Dynamics of reaching the operating voltage of the mode without breakdowns: (a) beginning, (b) middle, and (c) end of aging.

performed experiments, the required voltage (1 MV) was reached and the stable operation of the accelerator without breakdowns was ensured within several hours.

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