Electrical strength of the high-voltage gaps of the tandem accelerator with vacuum insulation

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Abstract- **New type of accelerator - electrostatic tandem accelerator with vacuum insulation – was proposed and constructed for boron neutron capture therapy (BNCT). The accelerator has a high acceleration rate of charged particles, which gives hope for its stable operation without breakdowns at high currents. Specialties of the accelerator are large surface area of the accelerating electrodes (41 m^2) and large stored energy (tens of joules). The results of experiments, carried out on the high-voltage stand and the tandem accelerator, are presented. The influence of breakdowns on the electrical strength of the high-voltage accelerator elements are studied. This investigation allows increasing proton energy up to 2.3 MeV and current up to 5 mA.**

I. INTRODUTION

In the BINP, the prototype of epithermal neutrons source in an innovative high-current tandem accelerator with vacuum insulation has been proposed [1] and constructed [2]. It is attractive to be accommodated in oncological clinics for carrying out boron neutron capture therapy of malignant tumors.

In the high-voltage vacuum components of the installation, electrons of auto emission and discharge origin, which are the basic elements of the parasitic "dark" current [3] and are accelerated in a vacuum gaps.

II. Design of the accelerator

Fig. 1 shows the accelerator. Coming from the source *1* [4] negative hydrogen ion beam with 23 keV energy and 5 mA current is rotated in a magnetic field at an angle of 15 degrees, focused by a pair of magnetic lenses *2*, injected into the accelerator and accelerated up to 1 MeV. In the gas (argon) stripping target *7*, which is installed inside the high-voltage electrode *5*, negative hydrogen ions are converted into protons. Then protons by the same 1 MV potential are accelerated to 2 MeV energy. The potential for the high-voltage *5* and five intermediate electrodes of the accelerator *6* is supplied by a high-voltage source *10* (most of the source is not shown) through the feedthrough insulator *9*, wherein the resistive divider is set. Evacuation of gas is performed by turbo molecular pumps *8* mounted at the ion source and at the exit of the accelerator, and a cryogenic pump *4* via blinds in the electrodes.

Vacuum part of the high-voltage feed-through insulator (Fig. 2) is collected from 24 annular glass insulators with a diameter of 400 mm and a height of 35 mm, vacuum tightly strapped with intermediate electrodes through the rubber seals. The gas part of the insulator situated in a tank of a high voltage rectifier is composed of 14 ceramic rings with a diameter of 400 mm and a height of 60 mm, glued with their electrodes.

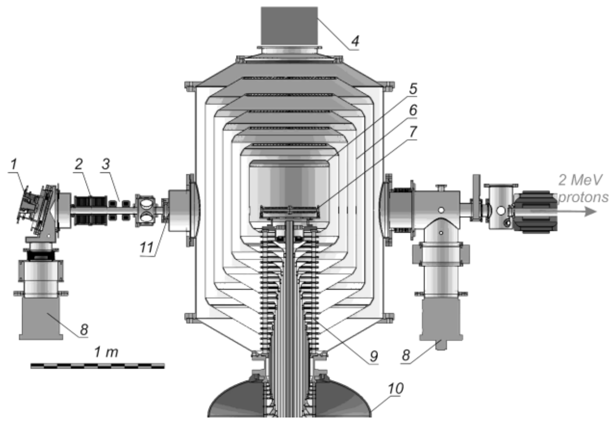

Fig. 1. Tandem accelerator with vacuum insulation: *1* - source of negative hydrogen ions, *2* - magnetic lenses, *3* - correctors, *4* - cryogenic pump, *5* - high voltage electrode, *6* - intermediate electrodes, *7* - the gas stripping target, *8* - turbo molecular pump, *9* - feedthrough insulator, *10* - high-voltage power supply, *11* - inlet diaphragm.

The inner part of the feedthrough insulator is filled with SF_6 gas at a pressure of 0.3 MPa, the high-voltage rectifier tank of 0.6 MPa. Maximum gradient along the surfaces of the insulators on the vacuum side is 12 kV/cm, on the sulfur hex side — 14 kV/cm, peak fields of the gaps in the gas region — 95 kV/cm.

The accelerator is characterized by fast acceleration of charged particles (25 kV/cm), large distance between ion beam and insulator (on which electrodes are mounted), large stored energy in the accelerating vacuum gaps (up to 26 J) and strong input electrostatic lens. The high-voltage strength of centimeter vacuum gaps with large stored energy (up to 50 J) was investigated [5]. On the accelerator it was investigated the high-voltage strength of centimetre vacuum gaps with large stored energy, proposed and realized the way of consistent training of accelerating gaps and obtained the required voltage of 1 MV [6]. The behavior of dark currents was studied and then they were reduced to an acceptable level by long staying under voltage [7]. An auto-emission current was detected, the cause of its

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occurrence was established, and changes in the design of the accelerator to prevent it were made [7].

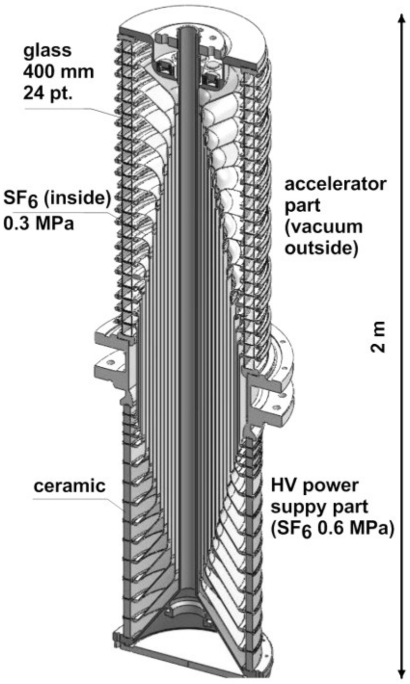

Fig. 2. Scheme of the high-voltage feedthrough insulator.

III. Experimental results

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.

Each vacuum accelerating gap (at the same time with corresponding gas gaps, glass and ceramic insulators) was tested a voltage of 200 kV.

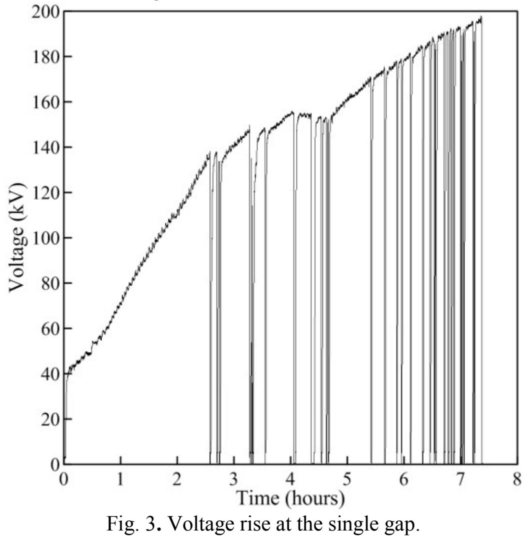

Fig. 3**.** Voltage rise at the single gap.

Fig. 3 shows the voltage rise at one of accelerating gaps owing to the gap_by_gap aging. One can 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 0.6 MPa pressure of SF_6 gas inside the tank of the high-voltage rectifier, and the pressure inside the feedthrough insulator was 0.3 MPa. Fig. 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.

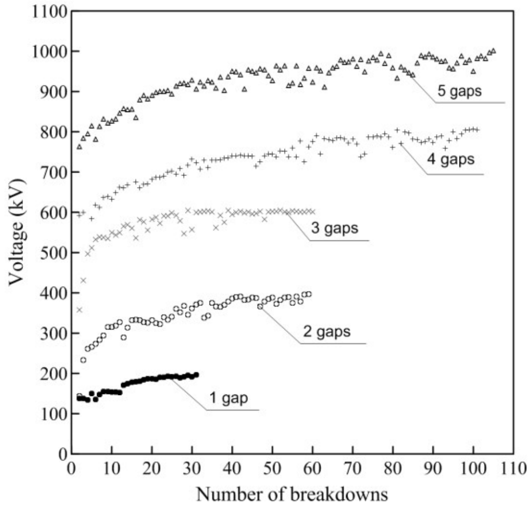

Fig. 4. Dependence of the breakdown voltage on the number of breakdowns.

The voltage of 1 MV was obtained at the accelerator, and the dynamics of reaching the operation without breakdowns is shown in Fig. 5. The maximal time of the withstanding voltage without breakdowns was more than 3 hours.

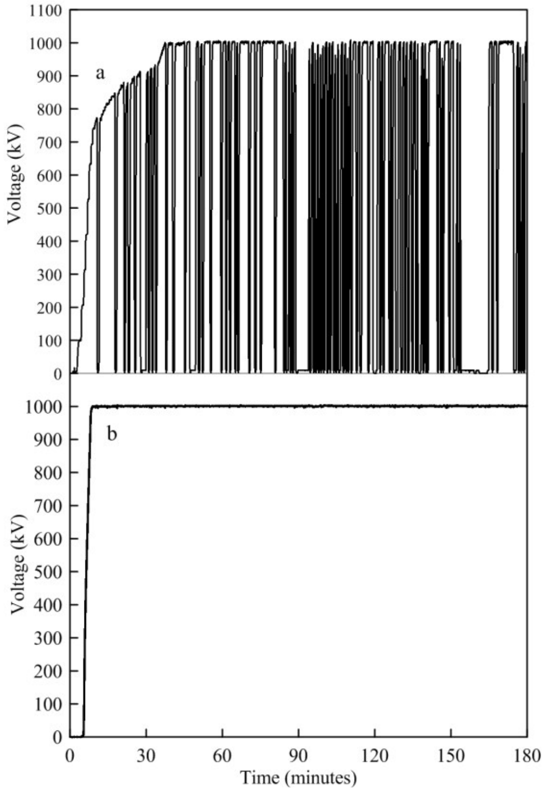

Fig. 5. Dynamics of reaching the operating voltage of the mode without breakdowns: (a) beginning and (b) end.

Working electric field strength in the electrode gap is about 30 kV/cm at energy 2.3 MeV tandem accelerator with vacuum insulation. Maximum gradient along the feedthrough insulator surfaces on the vacuum side is ~ 14 kV/cm, on the gas side is ~ 16 kV/cm. Dark currents of different nature must inevitably occur in the accelerating gaps that can lead to breakdowns and loss of electrical strength.

To increase the required energy of the proton beam accelerator implemented voltage rise to 1.15 MV (Fig. 6), followed by breakdowns. By reduction of the residual pressure, dark current and X-ray radiation shows that the training is a process that requires time to enter the mode without breakdowns.

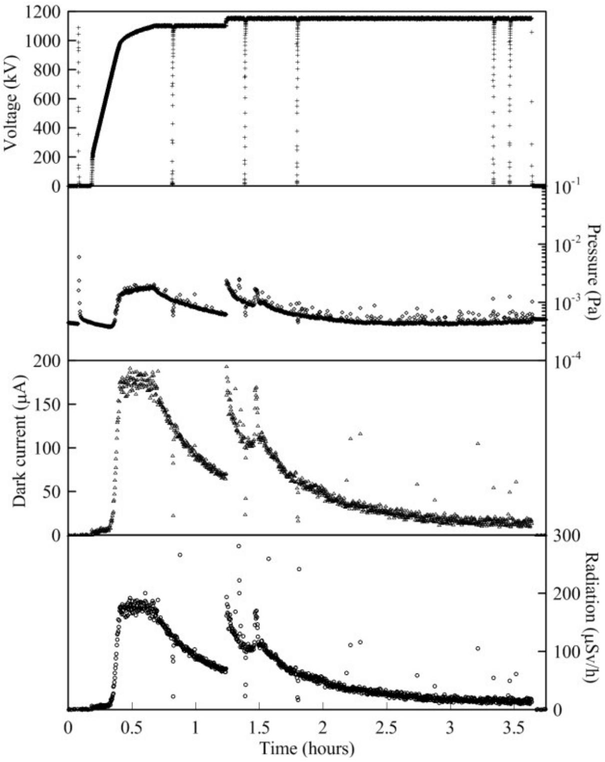

Fig. 6. The time dependence of the voltage, pressure, dark current and X-ray radiation.

The resistive divider located around the gas part of the feedthrough insulator, through the electrodes of the gas part of the insulator, metal thin-walled tubes of varying lengths and diameters, arranged coaxially inside the insulator and the electrodes of the vacuum part insulator evenly distributes the high voltage on an intermediate accelerating electrodes. The potential distribution on the electrodes of the vacuum part insulator, is not electrically connected with the coaxial tubes is set by resistors located inside the vacuum part of the feedthrough insulator.

Dark currents in the accelerating gaps can significantly affect uniform distribution of the potential along the accelerating channel, and accordingly, on the beam transportation. There is a need to set the potential on the electrodes directly from the rectifier, and not through the divider.

The first step to solving this problem is to increase the height of the individual insulators from 35 mm to 73 mm, i.e., leave in the upper vacuum part of the feedthrough insulator only the electrodes, are electrically connected with electrodes of the lower gas part by the internal coaxial tubes (Fig. 7).

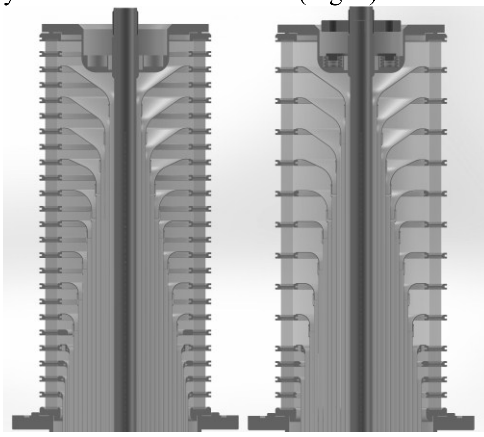

Fig. 7. Cross section of the existing and proposed vacuum upper part of the feed through insulator.

It was necessary to ensure the work of insulators without breakdowns. This requires experiments to study the reliable operation of the 73 mm insulators and a diameter of ~ 400 mm as the individual elements at voltage of 100 kV.

Experiments were carried out to study reliable operation of individual ceramic insulators height 73 mm with smooth and ribbed configuration of the vacuum surface (Fig. 8).

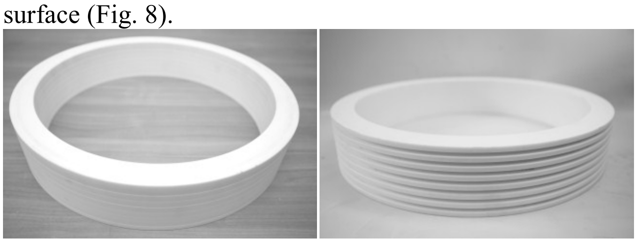

Fig. 8. Ceramic insulators: smooth and ribbed.

The Fig. 9 shows that the operating mode without breakdowns at a voltage of 100 kV reached at both insulators, but training of insulator with a ribbed surface held faster than the insulator with a smooth surface.

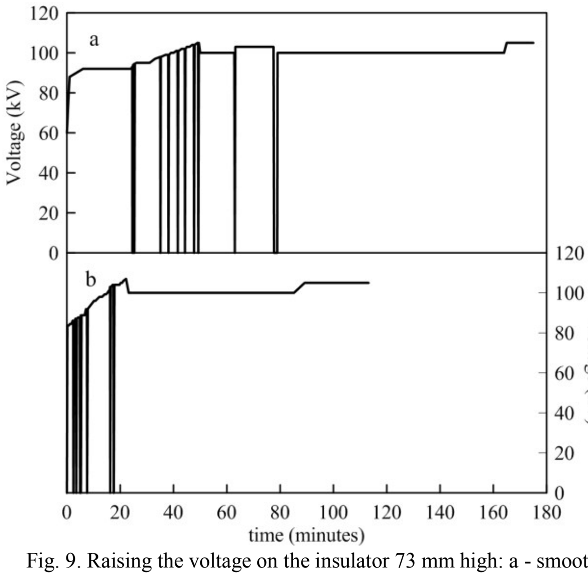

Fig. 9. Raising the voltage on the insulator 73 mm high: a - smooth, b - ribbed.

Vacuum conditions in both experiments were approximately the same.

Conclusions

Source of epithermal neutrons based on the tandem accelerator with vacuum insulation for the development of boron neutron capture therapy was created in BINP. In result of the experiments it was achieved voltage 1.15 MV and were found ways to increase electrical strength of the accelerator.

The use of offered isolators significantly simplify the assembly process. This will give the opportunity to set the potential to accelerated electrodes directly from the sections of high voltage power supply. This will eliminate the possibility of redistribution of stresses in the gaps and significantly improve the quality of the beam transport.

The data obtained will allow to modernize the accelerator for maximum reliability and will reduce its height by 1.5 times. This will increase the possibility of placing a new neutron source based on tandem accelerator with vacuum insulation in hospitals.

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