New Feedthrough Insulator of the Compact Tandem-Accelerator with Vacuum Insulation

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***Abstract*— The source of epithermal neutrons based on the tandem accelerator with vacuum insulation and a lithium target was created at the Budker Institute of Nuclear Physics for the development of the technique of boron-neutron capture therapy of malignant tumors (BNCT). A stationary proton beam with energy of 2 MeV was obtained, neutrons were generated, and studies of the effect of neutron radiation on cell cultures and laboratory animals were carried out. An increase in the proton energy to 2.3 MeV and equipping the beam shaping assembly will make it possible to obtain a neutron flux that satisfies the BNCT requirements the most. The report describes and discusses a new feedthrough insulator of the accelerator at the voltage of 1.15 MV, characterized by a doubled height of single insulator rings, the absence of a resistive divider inside the insulator. The proposed changes will improve the reliability of the accelerator, provide greater stability of the accelerating electric field from the influence of dark currents in accelerating gaps and reduce the height of the facility. The new feedthrough insulator is manufactured and installed in the accelerator. The voltage of 1.26 MV was received. The report presents the results of these experiments using the new feedthrough insulator.**

Keywords—feedthrough insulator, tandem-accelerator with vacuum insulation

I. Introduction

The prototype of a source of epithermal neutrons based on a vacuum-insulated tandem accelerator and a lithium target for placement in oncological clinics and conducting boron-neutron capture therapy of malignant tumors was proposed [1] and created [2] in the Budker Institute of Nuclear Physics. A stationary proton beam with energy of 2 MeV was obtained, neutron generation was carried out, and studies of the effect of neutron radiation on cell cultures and laboratory animals were carried out. An increase in the proton energy to 2.3 MeV and equipping the accelerator with a beam shaping assembly will make it possible to obtain a neutron flux that satisfies the BNCT requirements the most. The purpose of the work was to obtain a voltage of 1.15 MV, which is required to increase the proton energy to 2.3 MeV.

II. Accelerator Design

Figure 1 shows the tandem accelerator with vacuum insulation. A beam of negative hydrogen ions is injected into the accelerator and accelerated to 1 MeV. The negative hydrogen ions are converted into protons in the gas (argon) stripping target *7*, which is installed inside the high-voltage electrode *1*. Then, protons with the same potential of 1 MV are accelerated to an energy of 2 MeV [3]. Gas is pumped with a turbo molecular pump *10* installed at the output of the accelerator and a cryogenic pump *4* through the jalousies *3* in the electrodes.

The voltage from the high-voltage rectifier *2* is fed to the central electrode of accelerator *1* through the sectionalized disassemble feedthrough insulator. The electrodes of one potential of the lower (gas) *8* and upper (vacuum) *9* parts of the feedthrough insulator are connected with a system of internal coaxial cylinders *11*. Cylinders have different length and diameter. The potential distribution over the intermediate electrodes *6* was determined by the resistive divider, which was located outside of the lower part of the feedthrough insulator. Resistive divider located inside the vacuum part of the feedthrough insulator determined the potential distribution over the electrodes, which were not connected directly to inner coaxial tubes of the feedthrough insulator.

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It was shown that the electric strength did not decrease with increasing insulator height and the voltage by 2 times [5].

Fig. 2. Breakage and heat of the divider part, located inside the feedthrough insulator.

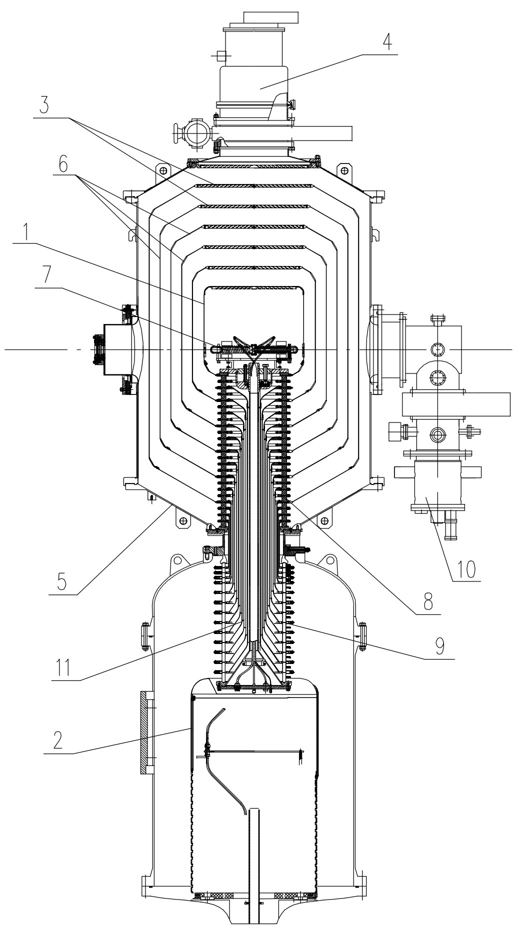

Fig. 1. General cross-section view of the electrostatic 6-gap tandem-accelerator with vacuum insulation: 1 - high-voltage electrode of the tandem-accelerator; 2 - high-voltage electrode of direct voltage source; 3 - jalousies of electrodes; 4 - cryogenic pump; 5 - vacuum tank; 6 - intermediate electrodes of the tandem-accelerator; 7 - gas stripping target; 8 - vacuum part of feedthrough insulator; 9 - gas part of feedthrough insulator; 10 - turbo molecular pump; 11 - internal coaxial cylinders.

The appearance of dark current, as a result of voltage rise and gas desorption from the electrodes surfaces [4], and the deposition of the beam current to the electrodes led to a disruption of the uniform voltage distribution in the accelerating gaps. As a result, the reliability of the feedthrough insulator operation has decreased. The sag of the internal resistors was being due to the limited space inside the feedthrough insulator and the heat released. Resistors stopped working (Fig. 2). Replacement of resistors was possible only with complete disassembly of the feedthrough insulator.

It was necessary to remove electrodes, which did not have direct contact with the internal cylinders of the feedthrough insulator to solve the problem. If the electrodes will not remove, it will have a floating potential. The feedthrough insulator height is not to be changed due to the design features of the accelerator. Therefore, two single insulators were replaced per single double-height insulator. It allowed removing the resistors from inside the feedthrough insulator. The possibility of using single double-height insulator was studied on a specially created high-voltage gas-vacuum stand.

The feedthrough insulator was modernized, according to the obtained experimental data. Glass insulators with a height of 35 mm were replaced with insulators of smooth ceramics 73 mm in height (taking into account the compensation of the thickness of the electrode to be removed). Only electrodes in the upper vacuum part of the feedthrough insulator were left (Fig. 3), connected directly to the electrodes of the gas lower part by internal coaxial tubes.

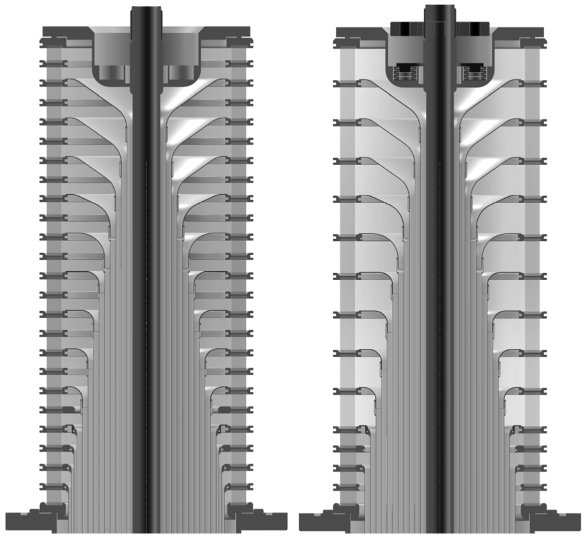

Fig. 3. The previous (glass) and the existing (ceramic) version of the upper vacuum part of the feedthrough insulator.

The new resistive divider was made, which was located completely outside the lower gas part of the feedthrough insulator (Figure 4, right). The insulator of the lower gas part remained the same. The total height of the feedthrough insulator was unchanged.

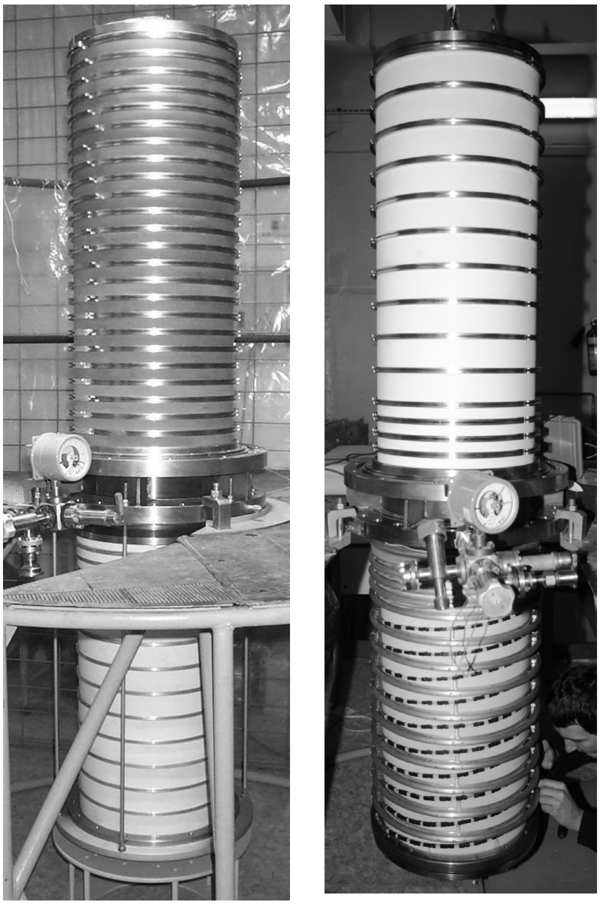

Fig. 4. Previous (left) and new (right) version of a feedthrough insulator with an external divider.

III. RESULTS OF EXPERIMENTS

The purpose of the experiments was to determine the reliability of the feedthrough insulator operation at a voltage of 1.15 MV.

New feedthrough insulator was installed and standard training of the accelerator was conducted after opening into the atmosphere. The voltage of 1 MV was achieved without any difference in the procedure used earlier. It means that the removal of the intermediate electrodes and the replacement of two single insulators (35 mm) by one double-height insulator (73 mm) does not lead to any limitations in achieving the required voltage or reducing the reliability of the feedthrough insulator operation.

During the period of four months of operation of the installation, there was no situation related to disturbances in the work of the feedthrough insulator, which would lead to disassembly and elimination of malfunctions.

Thus, it has been experimentally established that the use of single insulator rings of double height and the refusal to use a resistive divider inside the feedthrough insulator are justified. The voltage of 1 MV has been obtained and the reliability of the insulator operation was increased.

The series of experiments have been carried out. The aim was to obtain at the accelerator the voltage of 1.15 MV. Experience with the accelerator has shown, to work without breakdowns at the required voltage, it is necessary, at least, previously to exceed it by 5%.

Fifteen breakdowns occurred during the training for 2 hours in the first series. Figure 5 shows the first breakdown occurred at the voltage of 1060 kV, the maximum voltage reached 1175 kV.

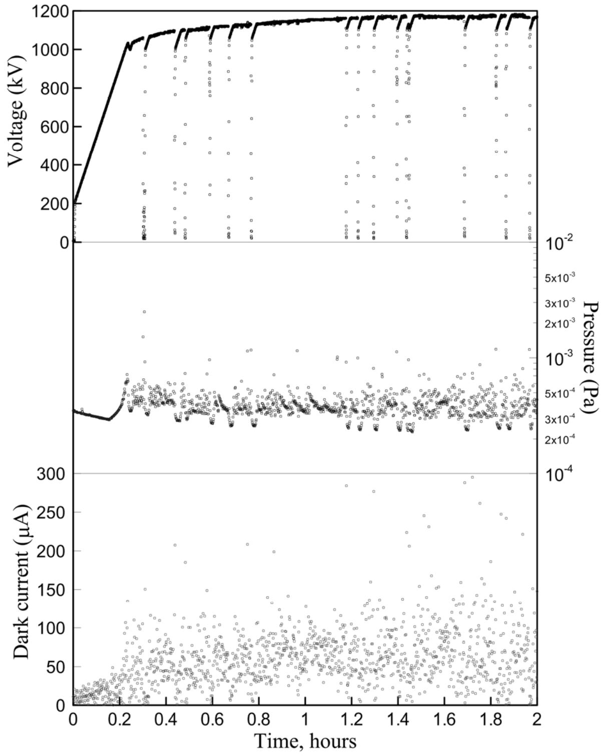

Fig. 5. Graphs of voltage (U), residual pressure (P), dark current (Idark) dependence the accelerator when the voltage rises.

It was possible to increase the voltage to 1210 kV for 1 hour (Fig. 6) after 2 hours of training in the second series of experiments. Only one breakdown passed for the same time.

The voltage of 1260 kV was achieved in the third series of experiments. It should be noted that the average electric field strength along the vacuum surface of the insulator was 14.3 kV/cm. It is almost 1.5 times the value of the electrical strength, which is used for the reliable operation of our industrial accelerators.

The voltage of 1260 kV was lowered to the working voltage of 1150 kV and a mode was achieved without breakdowns (Fig. 7). At the same time, the electric field strength on the vacuum surface of the feedthrough insulator was 13.2 kV/cm. In addition, the reduction of dark current and X-rays dose rate to the minimum values was continued. The reason was the voltage fixation and the reduction of gas desorption from the electrode surfaces.

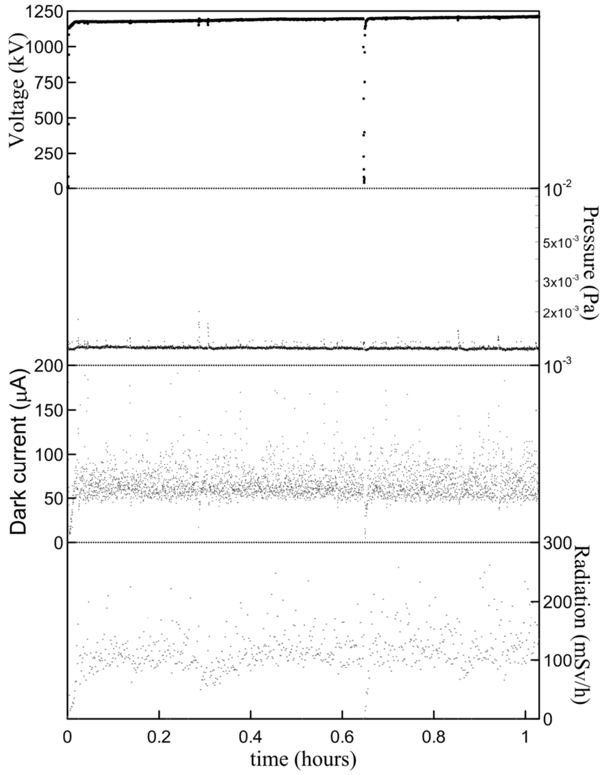

Fig. 6. Graphs of voltage (U), residual pressure (P), dark current (Idark) and X-rays dose rate (D) of the accelerator as the voltage rises.

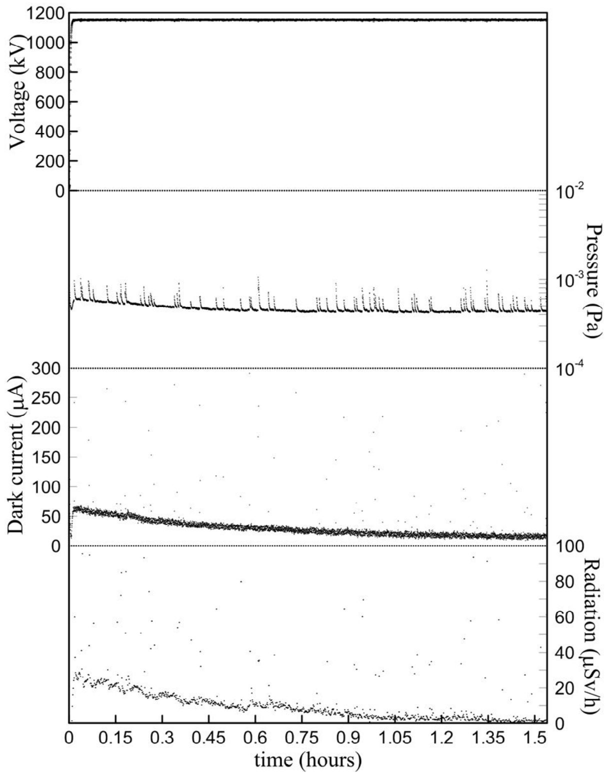

Fig. 7. Graphs of voltage (U), residual pressure (P), dark current (Idark) and X-rays dose rate (D) of the accelerator at a tide of 1150 kV.

CONCLUSION

The source of epithermal neutrons based on a tandem accelerator with vacuum isolation and a lithium target functions at the Budker Institute of Nuclear Physics. To improve the reliability of the installation, the modernization of the feedthrough insulator has been proposed and implemented. In the vacuum part of the feedthrough insulator, the glass ring insulators were replaced with ceramic smooth insulators of doubled heights. Intermediate electrodes, galvanic unrelated to internal coaxial tubes were removed. The new resister divider was manufactured and installed on the lower outer gas part of the feedthrough insulator.

As a result of the pilot studies, it has been established that an upgraded feedthrough insulator provides greater reliability compared to the previous one. Thus, an increase in the height of single insulators by a factor of two does not lead to a decrease in the reliability of the accelerator work.

The tandem-accelerator with vacuum isolation is equipped with a new upgraded feedthrough insulator. The stably voltage of 1.15 MV, required to produce the proton beam energy of 2.3 MeV, is obtained.

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