

UPGRADES OF A VACUUM INSULATED TANDEM ACCELERATOR FOR OBTAINING REQUIRED VOLTAGE WITHOUT BREAKDOWNS

I. Sorokin[†], Ia. Kolesnikov, A. Makarov, I. Schudlo, S. Taskaev,
Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia and
Novosibirsk State University, Novosibirsk, Russia

Abstract

Epithermal neutron source based on an electrostatic tandem accelerator of a new type - Vacuum Insulation Tandem Accelerator, and lithium neutron target has been proposed and developed at BINP for Boron Neutron Capture Therapy - promising method for treatment of tumors. 2 MeV proton beam was obtained in the accelerator, the neutron generation carried out with bombardment of lithium target by protons, successful experiments on irradiation of cell cultures incubated in boron medium have been carried out, human glioblastoma grafted mice were cured. It is necessary to increase proton energy from 2 to 2.3 MeV to form a neutron beam suitable for the treatment of deep-seated tumors and to provide the high-voltage strength of the accelerator at a potential of 1.2 MV in order to suppress dark currents to an acceptably small value. Two upgrades to obtain the required potential were consistently implemented. At first, the glass rings of the feedthrough insulator were replaced by smooth ceramic ones doubled in height which made it possible to refuse placing the resistive divider inside. Then the smooth ceramic rings were replaced by the new ceramic rings with a ribbed outer surface. Modernization made it possible to obtain the required voltage of 1.15 MV in the accelerator without breakdowns. The report describes in detail the modernizations carried out, presents the results of the studies.

INTRODUCTION

The source of epithermal neutrons based on a tandem accelerator with vacuum isolation and a lithium target [1] for the development of boron neutron capture therapy [2] of malignant tumors was proposed and created at the BINP. A stationary proton beam with energy of 2 MeV was obtained, neutrons were generated, and the effect of neutron radiation on cell cultures [3] and laboratory animals [4] was studied. An increase in proton energy up to 2.3 MeV [5] is required for a neutron beam suitable for the treatment of deep-seated tumors. The purpose of this work was to modernize a feedthrough insulator to increase a high-voltage strength of the accelerator when receiving a voltage of 1.2 MV.

ACCELERATOR DESIGN

Figure 1 shows a vacuum-insulated tandem accelerator. A beam of negative hydrogen ions is injected into the accelerator and accelerated to 1 MeV. In the gas (argon) stripping target 7, which has installed inside the high-voltage

electrode 1, negative hydrogen ions are converted into protons. Then, protons are accelerated to energy of 2 MeV by the same potential of 1 MV [5]. Gas is pumped by a turbomolecular pump 10 installed at the output of the accelerator and a cryogenic pump 4 through a jalousies 3 in the electrodes.

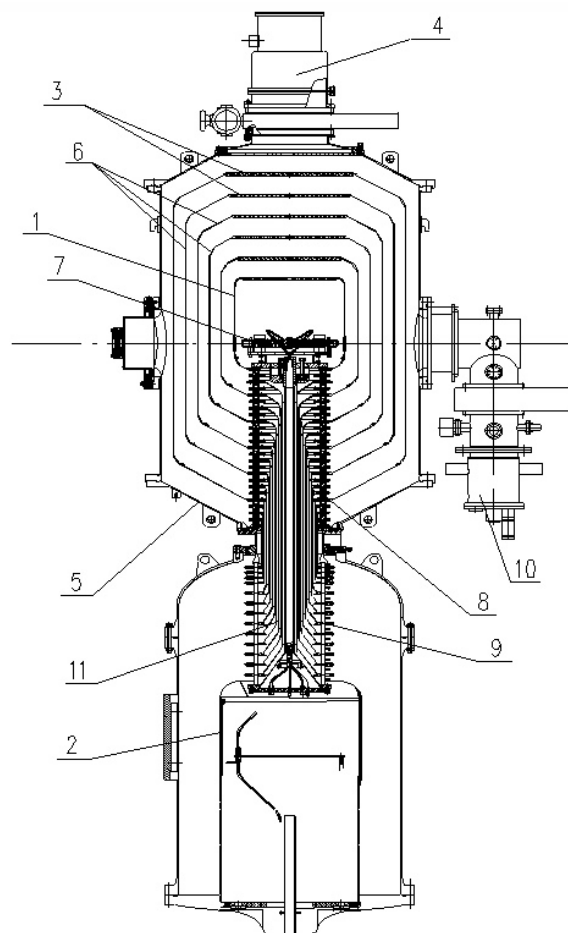


Figure 1: General cross-section view of the electrostatic 6-gap accelerator-tandem with vacuum insulation: 1 - high-voltage electrode of the accelerator-tandem; 2 - high-voltage electrode of high-voltage rectifier; 3 - jalousies of electrodes; 4 - cryogenic pump; 5 - vacuum tank of the accelerator; 6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

One of the basic elements of the vacuum-insulated tandem accelerator is a sectionalized disassemble feedthrough insulator through which the voltage from the high-voltage rectifier 2 is fed to the central electrode of accelerator 1.

[†]I.N.Sorokin@inp.nsk.su

Electrodes of same potential of the lower (gas) 9 and upper (vacuum) 8 parts of the feedthrough insulator are connected by a system of internal coaxial cylinders 11 of different length and diameter. The distribution of the potential over the intermediate electrodes 6 was determined by the new resistive voltage divider, which after replacing single glass rings with a height of 35 mm with ceramic rings with a smooth surface with a height of 35 mm and 70 mm, is completely located outside the lower gas part of the feedthrough insulator. The previous resistive voltage divider was originally located inside the upper and outside the lower part of the feedthrough insulator. The insulator of the lower gas part remained the same. The total height of the feedthrough insulator has not changed.

After a series of experiments, the purpose of which was to obtain a voltage at the accelerator of 1.15 MV with an upgraded feedthrough insulator made of smooth ceramics, the accelerator was disassembled. Large number visible traces of discharges were found over the entire surface of smooth ceramics (Fig. 2).

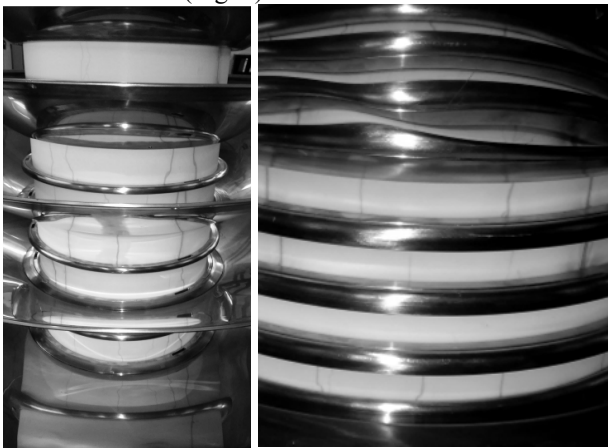


Figure 2: Smooth ceramic surface after training (left, right) with breakdown traces.

The appearance of breakdown traces is the result of a training during which the electric field strength on the ceramic surface was ~ 15 kV/cm.

Experience with accelerators showed that for it to work without breakdowns, it is necessary that the electric field strength on the surface of ceramic accelerator tubes be ~ 10 kV/cm. In our case, the voltage was exceeded by 1.5 times, while the accelerator was stable at a voltage of 1.15 MV (~ 13.7 kV/cm). However, traces of discharges may be the cause of subsequent breakdowns in the future.

There are two options for solving this problem. First, it is necessary to increase the height of individual insulators by 1.5 times, which will lead to an increase in the dimensions of the accelerator. The second option is to change the surface shape of the vacuum part of the ceramic rings

Studies of insulators with different geometry of the outer surface showed that a ribbed surface with radii of ribs and depressions from 0.5 to 1 mm provides an increase in electrical strength up to 1.5 times compared to a smooth surface. With the same height of the insulators, the surface length of the ribbed insulator is $\pi/2$ times longer than that of a smooth insulator. The developed processing

technology for inorganic insulators allows the realization of ribbed surface geometry.

Based on the obtained experimental data [6], we upgraded the feedthrough insulator. Ceramic insulators with a ribbed outer vacuum surface were made (Fig. 3), which replaced smooth ceramic insulators with a height of 35 mm and 73 mm. The radius of the ribs and troughs has chosen 1 mm, based on the previously obtained results.

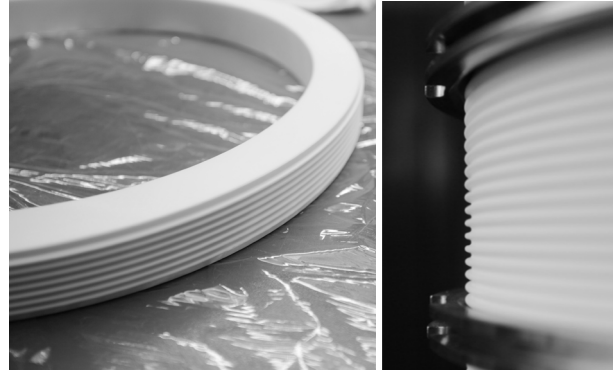


Figure 3: Ribbed ceramic surface 35 mm insulator (left) and 70 mm insulator (right) before training.

The height of the new individual ribbed ceramic insulators has not changed. The total height of the feedthrough insulator remained the same.

EXPERIMENTAL RESULTS

The new feedthrough insulator with an outer ribbed vacuum surface of ceramic rings has installed. After opening to the atmosphere standard training has performed. The voltage of 1 MV was obtained over a time that was 2 times less and with a smaller number of breakdowns than at the feedthrough insulator with a smooth ceramic surface (Fig. 4).

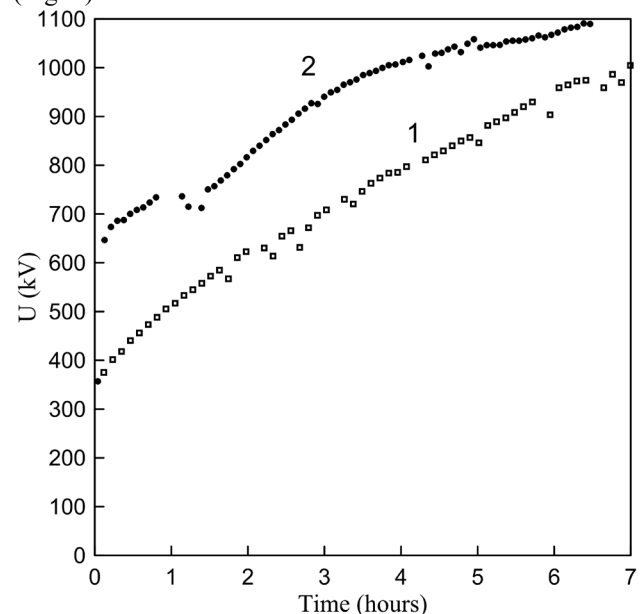


Figure 4: Graphs of the first increase in voltage at the accelerator after modernization: 1 - smooth ceramic, 2 - ribbed ceramic.

In the third series of experiments, the voltage of 1200 kV has reached (Fig. 5). Note that the average electric field strength on an insulator with a smooth surface was ~ 14 kV/cm, and on an insulator with a ribbed vacuum surface, taking into account an increase in its length by $\pi/2$, it was ~ 9 kV/cm. Its value is given in literary sources as a value providing the required electric strength.

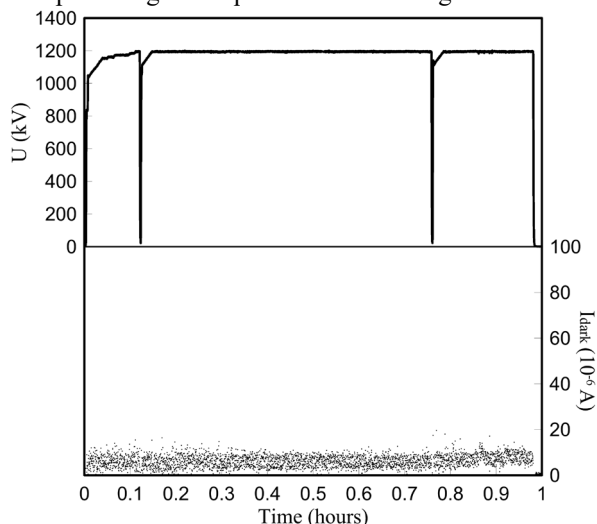


Figure 5: Graphs of the voltage U and dark current I_{dark} at the accelerator versus time.

After receiving 1200 kV, the voltage was reduced to a working 1150 kV and the mode without breakdowns was reached (Fig. 6). In this case, the average electric field strength on the vacuum surface of the feedthrough insulator was ~ 8.3 kV/cm, taking into account increase in its length by $\pi/2$. Also, decrease in the dark current value and the level of the X-rays dose to minimum values was observed.

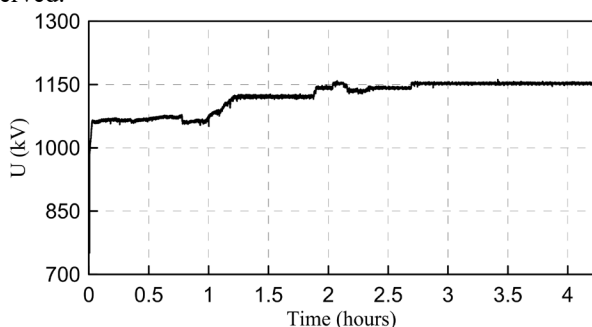


Figure 6: Graph of the voltage dependence of the accelerator when increasing and standing at a voltage of 1150 kV.

After several months of operation of the accelerator, during which there was no situation associated with violations in the operation of the feedthrough insulator, traces of breakdowns have not found on the ribbed vacuum surface of the feedthrough insulator (Fig. 7).

Thus, it has established experimentally that the use of single insulating rings of double height with a ribbed vacuum surface and the refusal to use part of the resistive voltage divider inside the feedthrough insulator is justified - the voltage of 1.15 MV has obtained and the working reliability of the feedthrough insulator is increased.



Figure 7: Ribbed ceramic surface (left, right) after training without breakdown traces.

CONCLUSION

An epithermal neutrons source based on the vacuum insulated tandem accelerator and a lithium target is operating at BINP. A modernization of the feedthrough insulator is proposed and implemented. Ceramic insulators with a ribbed surface replace ceramic ring insulators with a smooth surface. It has found that the upgraded feedthrough insulator provides greater reliability compared to the previous one. The required voltage of 1.15 MV was obtained in the vacuum insulated tandem accelerator after the upgrade. The operating mode without high-voltage breakdowns was maintained, which is important for using a neutron source in therapy and for other applications.

ACKNOWLEDGMENT

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