THE GAS CHARGE-EXCHANGE TARGET OF THE TANDEM ACCELERATOR WITH VACUUM INSULATION

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Abstract

To solve problems of boron neutron capture therapy in the BINP an electrostatic tandem accelerator with vacuum insulation on proton energy of 2.5 MeV and current of tens mA is developed. The experimental results on the study of distributing concentration of gas molecules emerged from the charge-exchange target to the vacuum volume are performed in the paper. The vacuum characteristics of the system on the pumping of different gases of the target both external turbo-molecular and internal cryogenic pumps are given. The experimental results on the estimation of stripping gas effect emerged from the target to the vacuum volume on electrical strength of 45 mm of high voltage vacuum gap are performed. The area of electrodes is about of 0.7 m^2.

INTRODUTION

The research of influence of a stripping target gas on electrical strength of high-voltage vacuum gaps is one of the important tasks for a proton accelerator - tandem with vacuum insulation (fig. 1), developed in the INP SD RAN [1].

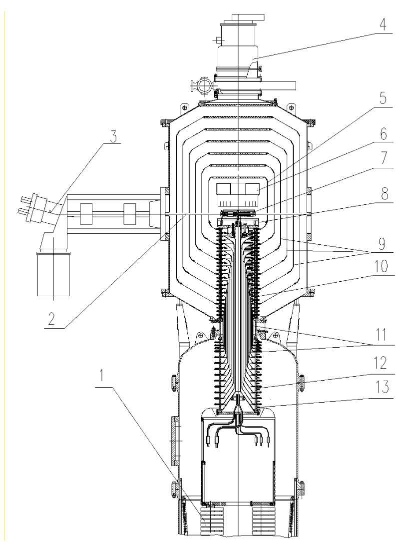

Fig.1: General view of the six-gap tandem with vacuum insulation.

The beam of hydrogen negative ions, injected by a source 3, passes through low-energy channel and is accelerated in a path 2 up to energy determined by potential of a high-voltage electrode 5. The rectifier 1 sets the high-voltage electrode potential. The proton beam is accelerated up to complete energy of 2.5 MeV after charge exchange on a gas stripper, which is taking place inside a high-voltage electrode. The gas is moved in tube 7 of a stripper through leak valve 8, which is also inside a high-voltage electrode. The distribution of an electrical field along accelerated path is determined by intermediate cylindrical electrodes - shields 9, located coaxial with a high-voltage electrode. Electrode potentials are set by a resistive divider 13, located both inside the top (10), and outside the bottom (12) parts of gas-filled feedthrough insulator. The internal coaxial cylinders 11 connect electrodes of the bottom (gas) and top (vacuum) parts of feedthrough insulator.

99 % stripping of negative ions of hydrogen is realized at a gas stripper flow rate in tens mTorr·l/s under tube target diameter of 10 mm and length of 400 mm [2]. The pumping speed of tandem vacuum volume by the external pump 4 is equal to 1500 l/s (in view of conductance of high-voltage and intermediate electrodes - shields louver covers). The average value of vacuum in the area of high-voltage gaps of a tandem does not exceed $5\cdot10^{-5}$ Torr and does not result in decrease of electrical strength of vacuum gaps [3].

The local increase of residual pressure in the area of beam passage for accelerating intervals is caused by a part of a target gas flow going into gaps through apertures in a high-voltage electrode, located on a path of a beam passage. The pump 6 (located inside a high-voltage electrode) is intended for reduction of residual pressure in the area of ion beam acceleration.

To estimate the top limit of residual pressure in the area of ion beam acceleration and to check up influence of pressure on the high-voltage characteristics of a tandem, it is necessary to know axial and radial distribution of gas density going into vacuum volume from target tube.

The work purpose is to determine the dependence of electrical strength of a high-voltage vacuum interval with electrodes of the large area from magnitude of residual pressure, which is basically determined by the gas flow going in vacuum volume from a stripper tube.

EXPERIMENTAL FACILITY

Target and high-voltage experiments were carried out on the prototype of a tandem (fig. 2), in which positive potential of the cascade generator submits on a high-voltage electrode 5 through feedthrough insulator 1. Cylindrical walls of vacuum volume 7 and high-voltage electrodes with the «intense» area 0.71 м^2 serve the electrodes of a 45-mm high-voltage coaxial vacuum gap. The apertures for beam passage in a cylindrical wall of a high-voltage electrode were absent.

For target experiments the carbon dioxide gas was chosen. The adjustment of gas flow was carried out by both leak valve 3, and change of pressure in vacuum-tight gas volume, in which the leak valve was. The gas moved in volume " from ground " through dielectric pipe. The axial-radial distribution of gas flow density was investigated without a high-voltage electrode. Distance from the ends of a stripper tube up to a wall of vacuum volume was equal to 75 mm, at an internal tube diameter of 10 mm and length of 400 mm.

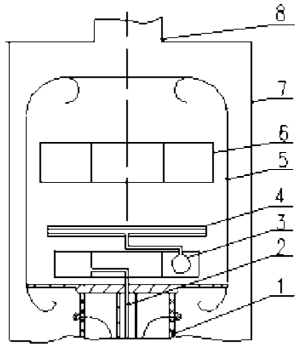

Fig.2: General view of tandem prototype.

The nitric trap 6 for increase of accuracy of measurements (significant excess of registered gas density in stream above residual - background gas pressure in vacuum volume of the prototype). For CO_2 molecules the trap cold surface works as a pump with pumping speed in tens thousand liters per second. The turbo-molecular pump through opening 8 carried out the vacuum volume pumping of the prototype.

For measurement of gas density distribution ionized vacuum gauge with an axial collector at volume of an anode grid less 1cm^3 was developed. The design of vacuum gauge drive allowed moving it in axial and radial directions without breaking of prototype vacuum density.

DISTRIBUTION OF GAS DENSITY GOING FROM STRIPPER TUBE.

Other things being equal the rate of a gas flow going in the vacuum volume, is determined by a diameter of a gas stripper tube, which is depended on magnitude of an accelerated current [4].

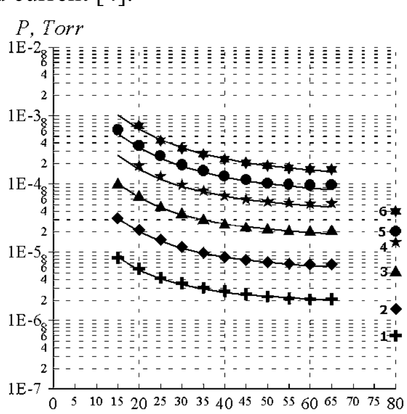

Fig.3: Axial distribution of gas density in stream for various gas flows.

Fig. 3 shows the experimentally received dependences of gas density distribution (local pressure) on an axis of a stream for a line of gas target flows, where Z - distance from the tube end up to the center of the vacuum gauge. The measurement of residual pressure in vacuum volume for all gas flows was carried out on distance of 100 mm from a flow axis and 10 mm from a wall of vacuum volume.

The curves on the diagram 3 correspond to flows: 1 - 2.6 mTorr·l/s, 2 - 6 mTorr·l/s, 3 - 21 mTorr·l/s, 4 - 55 mTorr·l/s, 5 - 100 mTorr·l/s, 6 - 170 mTorr·l/s. Points in the right part of figure correspond to values of residual pressure in vacuum volume. The appropriate symbols of points on curves show the measured values of axial density of a considered flow.

Axial distribution dependence of gas density for a dot source is submitted as

$$P(Z) = \frac{A}{Z^2} + B,$$

where A and B - constants taken for approximation (continuous lines) of received experimental data on each flow.

Because of the predictable large mistake of measurements (essential change of gas density on distance about the size of the vacuum gauge) experiments for Z < 15 mm were not carried out.

In view of the received experimental results the top border of expected pressure on an axis of a stream in area of the first high-voltage gap of an tandem accelerator is expected not higher than in $2 \cdot 10^{-4}$ Torr (at a target gas flow of 100 mTorr·l/s).

Fig. 4 shows the diagram for a flow in 100 mTorr·l/s, where R - distance from an axis of a stream up to the center of the vacuum gauge. Radial distribution of gas density in planes located perpendicularly to a flow axis in the distance from the target tube end of a 20, 30, 40 and 50 mm are accordingly shown by curves 1, 2, 3, 4.

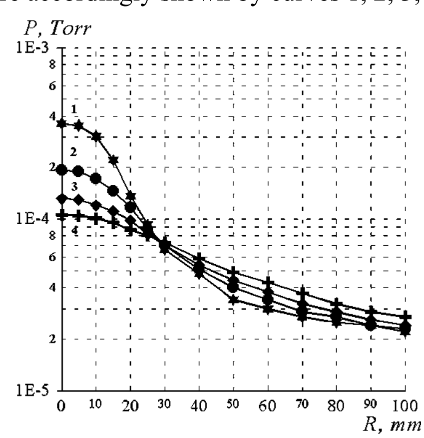

Fig.4: Radial distribution of gas density in stream.

It is noticed, that for the above mentioned gas flows the residual pressure along an stream axis on radius ≈ 30mm does not vary in the measured range of distances and decreases with growth of radius up to background value faster, than pressure on an axis with growth of distance from the tube end.

ELECTRICAL STRENGH OF A HIGH-VOLTAGE GAP.

In 66-mm high-voltage accelerating gaps of a tandem the average value of intensity of an electrical field makes 33 kV/cm [1]. The rating of residual pressure magnitude on an axis of a beam in the field of high-voltage gaps above mentioned, does not guarantee absence in them of the gas discharge (area of the left branch of a Pashen curve [3]). The high-voltage experiments on research of residual pressure influence in a vacuum interval on its electrical strength (in view of the ratings which were made) were carried out at intensity of an electrical field in a gap up to 66 kV/cm and vacuum up to $4{\cdot}10^{-4}$ Topp.

Three possible variants of targets gas pumping offered in [2], have determined a set of researched gases for high-voltage experiments: argon, nitrogen and carbonic gas.

The magnitude of residual pressure in a high-voltage gap with electrodes of the large area was determined by an adjustable flow of researched gas going through both tube ends of a target.

The sort of researched gas did not influence the results of the carried out high-voltage experiments. Vacuum breakdowns in a gap did not reduce its electrical strength. Typical training curve is shown in a fig. 5, where N - number of successive vacuum breakdown, and E - value of intensity of a field on a surface of a high-voltage electrode, at which breakdown of an interval has occurred.

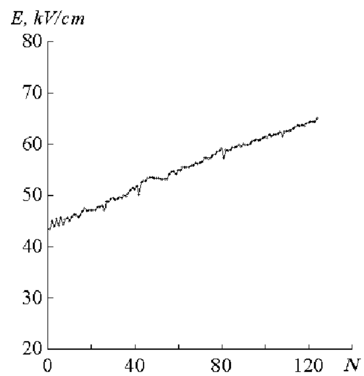

Fig.5: High-voltage gap training curve.

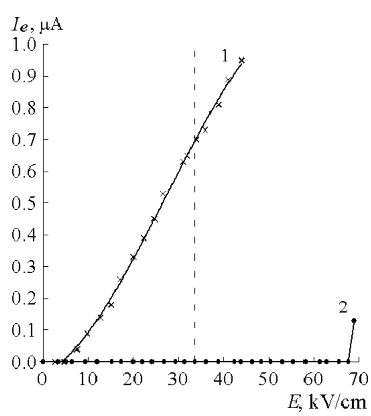

Fig.6: Dependence of field-emission current on intensity of electrical field in high-voltage gap by training start and finish.

Fig. 6 shows the typical diagrams of dependence of a field emission current (Ie) at the beginning (1) and end (2) of trainings from intensity of an electrical field in a high-voltage gap. The value of working intensity for high-voltage gaps of a tandem - 33 kV/cm is shown by a shaped line. Reduction of magnitude of a field emission current in a researched gap practically up to a zero level (compare with [1]) became possible at the expense of increase of high-voltage training time.

CONCLUSION

1. For high-voltage coaxial 45-mm vacuum gap at increase of residual pressure up to $4{\cdot}10^{-4}$ Torr, determined by molecules N_2, Ar, CO_2, influence of residual gas pressure on electrical strength of a gap is not revealed, down to double excess of value, chosen for gaps of a developed tandem.
2. The values of field emission currents in vacuum gaps after training in an atmosphere of the investigated gases down to pressure $4{\cdot}10^{-4}$ Torr are small and do not require the increases of capacity of a voltage active divider for accelerating gaps of a tandem.
3. The measured distribution of gas density along a stream axis is well described by dependence $A/Z^2 + B$. At a flow of target gas in 100 mTorr·l/s expected residual pressure on a stream axis in area of the first high-voltage gap of a developed tandem will be not higher than $2{\cdot}10^{-4}$ Torr. At reduction of vacuum conductivity entrance and exit apertures for a beam in a high-voltage electrode and, in view of results of high-voltage experiments, target gas pumping by the external pump is possible through louver cover of electrodes - shields without loss of electrical strength of gaps of a developed tandem. The final choice of target gas (and pumping variant of it) will take into consideration the results of the ahead analysis of processes occurring at interaction of a hydrogen negative ion beam with target gas.

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