STATUS OF HITS INJECTOR

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Abstract

Ion injector for cancer therapy facility HITS was designed and assembled at BINP. Injector is based on electrostatic tandem accelerator with 1.25 MV at the high voltage terminal. The negative ion beams are injected into tandem and charge exchanged in the vapor-magnesium target with vacuum heat insulation. The results of injector tests and working with carbon ion beam are presented.

INTRODUCTION

In the BINP the facility for ion therapy of cancer based on the synchrotron with electron cooling is developed. Facility generates the therapeutic beam of carbon ions with energy up to 430 MeV/u [1, 2].

The tandem electrostatic accelerator with 1.25 MV at the high voltage terminal is used as the injector. The source of sputtering type is used for the generation of negative carbon ions C^- beam. The 10 keV beam of negative ions is transported along the low energy transport channel into the tandem accelerator. After acceleration in the first accelerating tube, negative ions charge exchange while passing the vapor-magnesium target and accelerated again at the same voltage in the second accelerating tube. Then carbon ions C^{+3} with the energy 0.417 MeV/u are injected through the transport channel into the booster synchrotron.

TANDEM ACCELERATOR

The electrostatic tandem accelerator is designed on the base of the ELV-type industrial accelerators developed in BINP [3]. The tandem assembled in a vessel with the following overall dimensions: a height is H = 3.64 m, a diameter is D = 1.346 m. The vessel can be operated at pressure up to P = 1.0 MPa (10 bar) of SF_6.

The tandem accelerating system consists of two ELV accelerating tubes located vertically at the vessel axis and the magnesium vapor charge exchange target between them. Operating vacuum p= $1\cdot10^{-6}$ Torr in the accelerating tubes is provided by two vacuum systems placed at ground potential up and down of the vessel.

The source of high potential is the ELV type cascade voltage generator with magnetic link located in the bottom part of vessel. The alternate magnetic flux is produced by the primary winding (35 turns of double copper pipe) coiled on the cone frame. The winding is shielded by stainless steel thin strips. The shield protects the winding turns against high voltage breakdowns from the rectifying column.

The power supply voltage with the frequency 400 Hz is provided by the transistor frequency inverter. The high voltage column consists of 38 rectifying sections connected in series. Each section consists of the coil (3000 turns), rectifying circuit doubling voltage and supports for putting sections one onto another. The column outer diameter is 750 mm. The distribution of voltage among the accelerating tube sections is provided by the resistive divider.

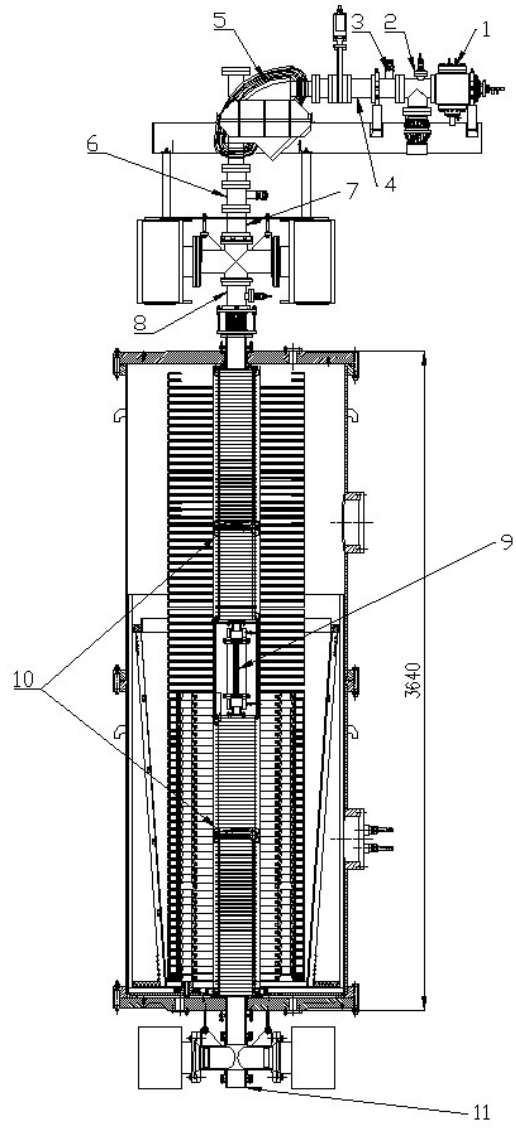

Figure 1: Injector layout: 1 – source of negative carbon ions C^- (10 keV); 2, 8 – electrostatic lenses; 3, 6 – electrostatic correctors; 5 – 90^0 bending magnet; 4, 7, 11 – Faraday cups; 9 – charge-exchange target; 10 - accelerating tubes.

In the high voltage electrode the charge exchange magnesium vapor target, the target power supply, the power supply winding for electronics, control and measurement electronics connected via the optical wires are installed. The upper accelerating tube is surrounded by the false column made with the use of the outer shields of rectifying sections. The voltage is divided among the false column shields with the resistive divider.

NEGATIVE CARBON IONS SOURCE

The sputtering type ion source of the negative carbon ions is used. The ion source is being successfully operated in the AMS facility developed in BINP (Fig.2) [4].

The main components of the source are: a vacuum stainless steel volume, a water cooled cathode where the sputtered carbon tablet is placed, an ionizer producing the flow of cesium ions to the cathode and cesium evaporator. The operation gas pressure after bake-out is 10^{-7} Torr.

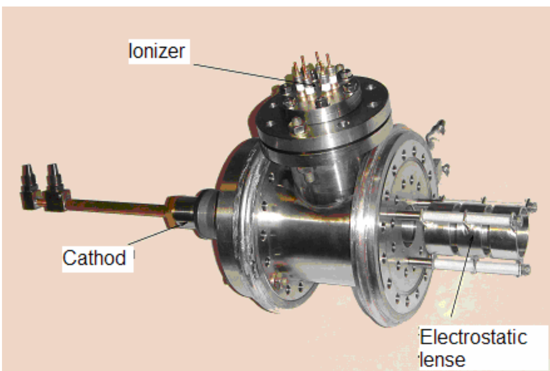

Figure 2: Prototype of the sputter source.

The ionizer working surface is a vacuum fusion tantalum spherical cup of 22 mm in diameter. The heater is laid at the opposite surface of ionizer along the spiral in two layers with connection in parallel. In order to reduce the heat loss, the heater is covered by the triple thermal shield made from the 20 μm tantalum foil. The ionizer surface temperature exceeds 1100 ^{0}C. The tube ceramic insulator is made from Beryllium oxide capable to operate at temperatures exceeding 2000 ^{0}C.

Ion source spectrum at low current measured after bending magnet is shown in Fig.3.

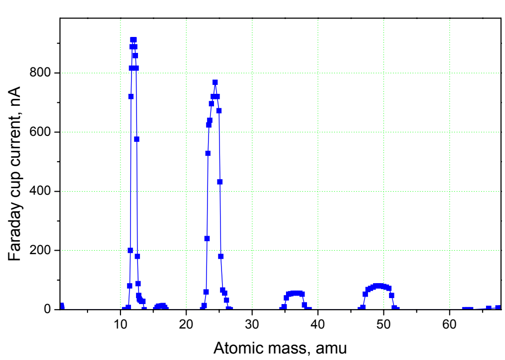

Figure 3: Spectrum of ion source.

The lens-sensor scheme was used for transverse emittance measurements. The measured emittance is 3.5 cm·mrad.

At present, the modified design of ion source is developed (Fig. 4). A new cesium container and mechanism of changing cathode position will increase the ion source working time without reassembly. Energy of ion source will be increased up to 30 keV.

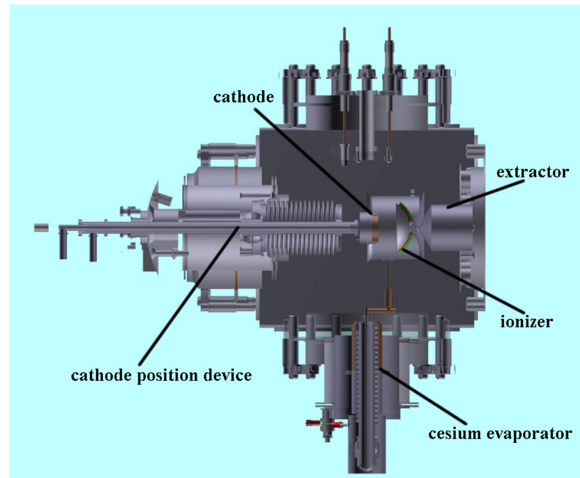

Figure 4: Layout of the new design negative ion source.

ION SOURCE-TANDEM LOW ENERGY TRANSPORT CHANNEL

The beam of carbon negative ions is transported to the tandem accelerator through the low energy transport channel (See Fig.1). The electrostatic lens installed after the ion source defines the beam size in the channel. The second lens provides matching of ion beam with the accelerating tube of tandem accelerator. The input electric field of the accelerating tube forms the effective focusing lens thus leading to the beam over focusing and limits the beam transition through the charge exchange target.

The C-shaped 90° dipole magnet with n = 0.5 bends ion beam in vertical plane and separates heavy clusters. Two pairs of electrostatic correctors allow correct the beam trajectory independently in two coordinates. The Faraday cups and beam position monitors control beam current, beam size and position.

VAPOR-MAGNESIUM CHARGE-EXCHANGE TARGET

The use of the vapor-magnesium charge exchange target provides the high vacuum in the accelerating tubes. The magnesium vapors are condensed in special containers at room temperature at the both sides of the charge exchange target.

The design of vapor-magnesium target developed for AMS facility has been accepted [5]. However, first experiments show inability of this design application in the atmosphere of sulfur hexafluoride. At the working temperature of target 500 ^{0}C the reaction with asbestos, glass cloth and stainless steel was observed. The heat insulation is destroyed and target body is corroded that leads to leak opens and losing of vacuum in accelerator.

The new design of charge exchange target was proposed and successfully applied. For prevention of chemical reaction the hot part of the target has been placed inside a vacuum shield. The pumping of target is realized through the accelerating tubes. The heat radiation of target is screened by the number of layers from stainless steel foil (See Fig. 5). The maximal temperature on the external surface of target is 150^{0}C.

The target charge-exchange channel of 300 mm long and 6 mm in diameter is surrounded with the shell-container with the solid magnesium. When heating the container, the magnesium vapors reach the charge exchange channel through three holes of 1 mm in diameter in the middle of the charge exchange tube. Amount of magnesium in the container is sufficient for continuous operation of up to 1000 hours. The target power consumption in the stationary mode is 80 W.

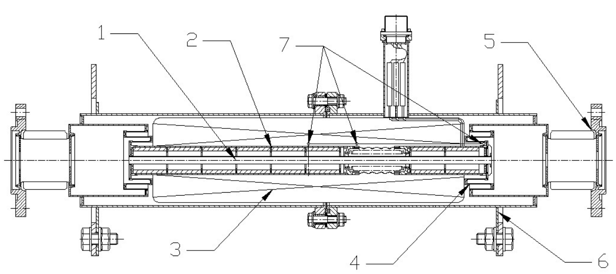

Figure5: Charge-exchange target. 1 - charge-exchange tube, 2 – container with magnesium, 3 – heat insulating layers, 4 - labyrinth, 5 - flange unit with the bellows, 6 - current inputs, 7 – control thermocouples.

EXPERIMENTAL DATA

The design of ion source prototype limits energy of ion beam not above 10 keV. Such low energy of ion beam not allows achieving the good matching of injected beam and input of accelerating tube.

With increasing of the accelerating voltage the average charge state of ion beam passed through charge-exchange target is increased. However, the experiments with different accelerating voltages show that the output current not increased according theory predictions. This phenomenon stipulated by degradation of matching conditions with increasing of accelerating voltage. The Fig. 4 shows the ratio of tandem output current I_{output} to input current I_{input} depends on temperature of charge-exchange target at different accelerating voltage.

For providing of good beam matching the increasing of ion source energy up to 30 keV is necessary.

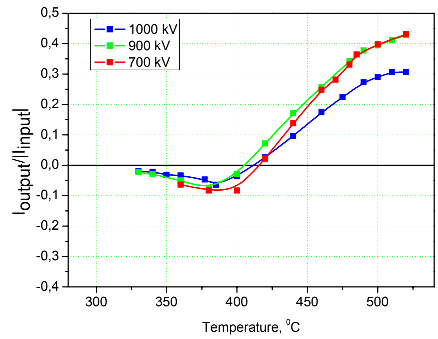

Figure 6: Charge-exchange of carbon ions depends on target temperature.

CONCLUSION

The ion injector based on tandem accelerator was designed, assembled and commissioned in the BINP. The high voltage up to 1.25 MV with stability 10^{-3} is achieved without breakdowns during long time operation with beam. New design of the vapor-magnesium charge exchange target with the vacuum heat insulation shows stable and reliable work. The measurements of transmission coefficient show necessity increasing of the ion source energy up to 30 keV. The new ion source is designed and under construction.

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