TANDEM PROTON ACCELERATOR AS INJECTOR FOR TRAPP

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To inject protons to the TRAPP (synchrotron for therapy of cancer) a tandem accelerator has been constructed. Its parameters are: protons energy is 1.4 MeV, current is 3 mA, pulse duration is 2 μs, frequency is up to 1 Hz. Negative hydrogen ions are extracted through the slit from a magnetron discharge on the heated surface of the LaB6 cathode. The beam of negative ions with an initial energy of 25 kV accelerates up to the half energy in the first accelerating tube, than recharges into protons in gas nitrogen target in a tube at a potential of 700 kV. After that, the proton beam doubles its energy in the second accelerating tube. Operating and control of the tandem are by means of computer.
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1 INTRODUCTION

Synchrotron for cancer therapy has been created in BINP to treat a tumor by means of a low intensity proton beam. It has a possibility of slow output, scanning and altering of the beam energy during a cycle. Main design parameters of the accelerator are:

– energy of protons up to 300 MeV,
– intensity 10^9 proton per pulse,
– frequency 1 Hz.

All these parameters have been obtained on the installation except an output current that is now only $3{\cdot}10^8$ particles per pulse. To get the beam current required it has been decided to double the energy of injection up to 1.4 MeV. For this, a tandem accelerator was constructed using developments manufactured and successfully tested for the VLEPP program. Tandem parameters are:

– energy of protons 1.4 MeV,
– proton current 3 mA,
– pulse duration 2 μs.

These parameters provide an injection into the synchrotron of about $1.2{\cdot}10^{10}$ particles.

One can note following advantages of the accepted scheme: high voltage is only a half of full beam energy and an ion source has a zero potential. Recharge of negative hydrogen ions is supposed to perform in a nitrogen gas stream in a recharge tube.

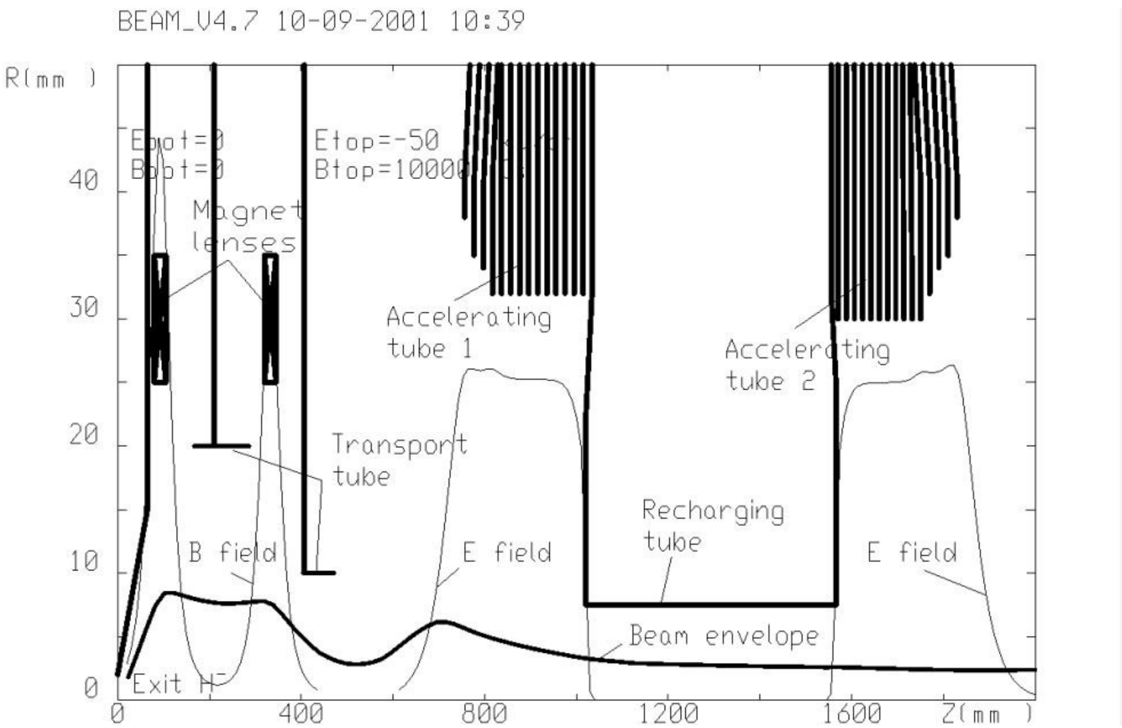

Fig. 1. Tandem optics.

2 TANDEM

2.1 Tandem optics

In Fig. 1 an electron optics is shown. Beam of negative hydrogen ions is extracted from the ion source and in the transport tube it is matched to the input of an accelerating tube (AT1) by means of two magnetic lenses. In the first AT it gains a half of its energy, is recharged in the gas target and is accelerated up to its full energy as a proton beam in the second accelerating tube (AT2). By altering currents through lenses one can adjust beam diameter as well as an angle of the beam divergence. In Fig. 1 an ion beam envelope is presented as well. The scheme of tandem accelerator is shown in Fig. 2.

In the tank of T-like form (1) with inner diameter 470 mm the following parts are placed:

(2) – DC source – cascade rectifier of 20 kHz frequency;
(3) – recharging tube;
(4) – accelerating tube for negative hydrogen ions;
(5) – accelerating tube for protons.

A source of H^- (6) is connected by transportation channel (7) with magnetic lenses (8) with AT1 of H^-. A gas is injected through pulsed magnetic valves (9). To control H^- current a dismounted sectional pickup is placed at the input of AT1 (10). Pumping is made by three pumps NMD-0.1 (11). Adjustment of H^- trajectories is effected by electrode system (12).

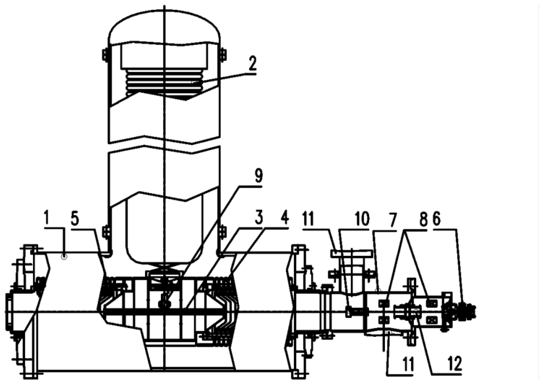

Fig. 2. Tandem scheme.

2.2 High voltage source

High voltage source – cascade rectifier operating at 20 kHz frequency - consists of 40 cascades, has the diameter 320 mm, and is placed into the tank with the inner diameter 470 mm and 8 atmospheres of SF_6. An ultrasound generator supplies it. With no-load the rectifier supplies a voltage of 1 MV. The average current of the rectifier is less than 1.5 mA.

2.3 H^- source

To obtain H^- a planar ion source with horizontal magnetic field and hot LaB_6-based cathode is used. Two permanent magnets placed on the magnetic yoke create the constant magnetic field.

After hydrogen injection into the ion source chamber when the pressure in it reaches a certain value, a pulsed voltage initiates a magnetron discharge. A current of the discharge depends on the cathode temperature and less on the magnetic field magnitude, discharge voltage or the pressure in the chamber. Typical value of voltage for discharge combustion is about 300-500 V and 1-20 A for current.

Since the time of one turn in the synchrotron is 1 μs, source discharge is burned up for only 4 μs and the extractor for only 2 μs. Extracting pulse with 25 kV of amplitude withdraws H^- through the slit 0.8 mm of width, length of 6 mm and 1 mm of thickness. The slit is perpendicular to the magnetic field. To adjust H^- beam angle due to extraction through the perpendicular magnetic field a reversal magnetic one is used. The supply of the discharge and gas valve is by the unit under - 25 kV of potential. The supply of extractor is by a high-voltage source with partly discharging capacitance and a pulsed transformer.

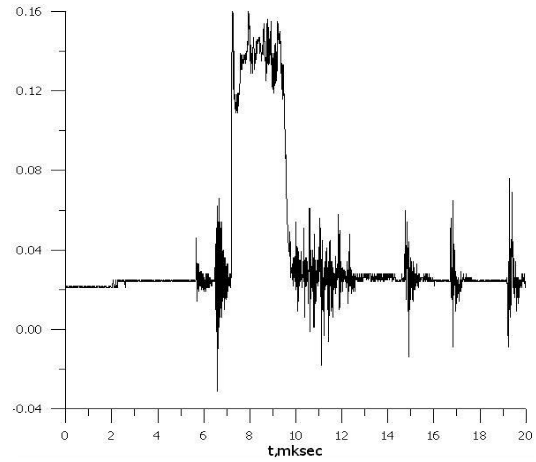

Fig. 3. Protons current.

2.4 Transportation channel

A ribbon beam being extracted from the ion source and expanded becomes a quasi-cylindrical one by means of the first magnetic lens. Than, it is focused by the second magnetic lens, passing through the tube with low gas conduction which separates ion source and tandem itself, and comes to the accelerating tube of H^-. At the exit of the separating tube there is the removable sectioned pickup, which allows one to measure H^- current and to estimate the beam position. Between two magnetic lenses there is the electrostatic adjusting device, which consists of 8 plates and allows one to make parallel transfer of the beam and to adjust the beam angle of divergence to aim the AT1 entrance.

2.5 Recharging device

Recharging of H^- takes place in the tube of 500 mm long and 15 mm in diameter in a nitrogen flow injected through a pulse valve at the middle of the recharging tube. The injection takes place about 300 μs before turning up the extractor. The supply of the valve, which has +750 kV of potential, is through transformer with gas insulation, controlling of the valve is performed by light guiders. Calculated dependence of the beam charge composition from the gas target thickness is presented in [2]. To recharge 90-98% of H^- into protons, the thickness of target $2\div3\cdot10^{16}$ molecules/cm^2 is enough. When the valve is cut off, negative ions are, at first, accelerated, than decelerated and we have at the exit of tandem the H^- current equal to proton one. At a low gas flow ions turn into neutrals and the current becomes undetectable.

2.6 Accelerating tubes

Two accelerating sectioned tubes are made from 16 ceramic rings of UF46 each. The outer diameter of ring is 210 mm, its height is 20 mm. The length of operating insulator is 320 mm. Tubes have been manufactured by means of thermo-diffusion welding at a time. The resistor divider provides the electrode potential distribution along the tube. The protection against an over-voltage during short cuts is provided by spark gaps. Outside the tubes a gas insulation by SF_6 under 8 atmospheres is placed. The divider with overall protection has 320 mm in diameter and a distance to the tank wall is 75 mm. During tests both tubes were pre-burned up to 800 kV.

3 RESULTS

1. The proton current of 2.5 mA at an energy of 1.MeV, with the 3 mA H^- current at the entrance of the transportation tube, has been obtained. Typical pulse is shown in Fig. 3. Real optics parameters are very close to the design ones.
2. Maximal H^- current of 3.8 mA has been obtained at the entrance of the first accelerating tube, but H^- source needs an alignment.

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