MAGNETRON PROTON SOURCE

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Abstract

The design and preliminary experimental results for magnetron proton source with a cold cathode are presented. To produce nonuniform magnetic field at the emission aperture the permanent circular NdFeB magnets with opposed polarity placed outside the ceramic chamber of source have been used. 110 mA impulse beam current with the energy of 100 keV at 1Hz frequency and 25 µs pulse duration has been received. Normalized emittance equals to 0.8 π mm·mrad .

INTRODUCTION

The most important question of linear accelerator LU-30 with the radio-frequency quadrupole focusing (RFQ) reliability operation is the operational integrity of its injection system. The injection system includes an ion gun with a protons source and an extraction system of ions from the plasma and focusing lenses. From the injection system the beam enters in the initial part of accelerator (RFQ linac). The beam capture, formation and acceleration to 2 MeV happen in the RFQ. At the present time the source of duoplazmotron type with a cold-cathode developed by V.V. Nizhegorodsev over 35 years ago is applied as the source of protons [1]. The long-standing practice of using the source with a non-glow cathode showed its high reliability and cathodes long service life. This source has proven good performance for many years of its operation. Proton beam phase characteristics generated by this source meet the linear accelerator LU-30 source requirements. It provides the beam necessary quality requirements, but its construction is critical in many parameters and it is difficult in adjustment and operation.

During the LU-30 operation it was investigated that the breakdowns frequency in the RFQ linac is not less, but often more than the breakdowns frequency in the main part of the LU-30 accelerator with the spatially periodic quadrupole focalization followed by the RFQ linac. It should be noted that the electrical field strength on the RFQ linac electrodes is 225 kV/cm and on the electrodes of the main part of accelerator it is 380 kV/cm. The RFQ linac electric strength reduction process increases in time due to the high content of impurities in the generated ion beam. This is explained by the contamination of the RFQ linac electrodes by the work products used in the construction of a proton source in which PTFE, organic glass and vacuum rubber are widely applied. Contamination process is irreversible and removing impurities by the cleanup is not possible. The only way out of the situation is the RFQ linac electrodes replacement and application of a new proton or ion source H-minus source.

It should be noted that there are two ways to increase the proton source emission ability and to receive plasma with high density at the design stage: either to increase the number of particles bombarding the emission surface or to increase the emission surface. When designing the source V.V. Nizhegorodtsev chose the first approach. As a result the hydrogen supply in discharge chamber source is done impulsively at relatively high pressure, which causes significant gas inleakage into the accelerator. In pulsed mode of source work with high pulse repetition rate (16.7 Hz) the vacuum pumps of high efficiency are required to provide source electric strength and to prevent beam scattering on residual gas which reduces phase density.

At the present time IHEP is developing a proton source of magnetron type with simpler and more reliable design. In the developed protons source of magnetron type with inverted cathode the surface area emitting electrons is increased substantially, and the application of the above mentioned materials is limited. As a prototype the ion source with a cold magnetron cathode and magnetic plasma contraction developed in the Sukhumi Physics-Technical Institute was selected [2,3].

SOURCE CONSTRUCTION

The main elements of the magnetron protons source with a cold cathode and magnetic contraction of plasma are shown in Fig. 1. The discharge source chamber is installed in a longitudinal magnetic field and it can be divided into three areas: auxiliary discharge area (magnetron cathode area), general discharge area (the main anode and magnetic plasma contraction area) and plasma expansion area (expander with conical insert) [2].

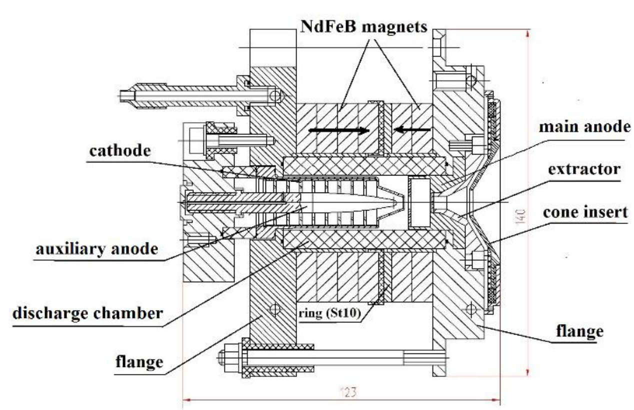

Figure 1: Magnetron proton source.

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The glow discharge between the cold magnetron cathode and the excitation copper anode with a conical end is ignited in the area of auxiliary discharge. The cylindrical inverted magnetron cathode made of stainless steel and divided into several chambers by the diaphragms is used to increase the emission surface, which allows stabilizing the source operation. Hydrogen is fed through the hole in the anode. To increase the density of plasma outflowing from the cold cathode area into the main discharge area the magnetron cathode end is made in the form of a truncated cone. The permanent NdFeB magnets in the form of cylindrical rings 8 mm thick with inner and outer diameters of 40 mm and 80 mm respectively were used to create the magnetic field. Four rings create a magnetic field in the magnetron cathode area. Two other rings with opposite polarity create a strong inhomogeneous magnetic field in the general discharge area which contracts discharge at the emission holes. The ring of 5 mm in thickness made of steel St.10 is placed between the magnets with opposite polarity. It increases the magnetic field on-axis both in the magnetron cathode area of (0.18 T maximum field) and in the area of the magnetic plasma contraction (0.48 T maximum field). Unlike the constructions described in [2,3] the permanent magnets are placed outside the source discharge chamber. This allows to significantly improve the technological effectiveness of design in the source manufacture and its assembling, as well as to decrease the discharge chamber capacity to reduce the hydrogen supply rate and increase gas efficiency. The discharge chamber case is made of ceramics VC 94-1. The indium seal was used for vacuum sealing of the source chamber with end flanges. Channels for water cooling were drilled in both flanges to operate the source in buster mode with the frequency of 16.7 Hz. Main anode is made of copper with 1.2 mm aperture. Plasma penetrates into the cone expander made of iron through the hole in the anode. The magnetic flow is closed through the expander, iron ring and frontal flanges. In addition to the magnetic field formation the expander also serves to remove heat from the main anode. The cone insert with an aperture of 10 mm is set into the expander. The distance from the hole in the anode to face plane of conical insert is 14 mm. The conical insert is isolated from the expander and it is at the floating potential. The source cathode was hooked up to the discharge modulator with negative polarity. Main and excitation anodes were hooked up to the modulator with positive polarity on two parallel circuits through the ballast resistance. Electric power supply scheme is similar to that described in [2]. By changing the values of the ballast resistors resistances it is possible to regulate main and auxiliary discharges currents ratios. The magnitude and pulse duration of ion current extracted from the source were mainly defined by the current in main discharge circuit which depended on the magnetron cathode discharge parameters.

For the ions extraction from plasma and the primary beam forming the three-electrode ion-optical system (IOS) of acceleration and deceleration was applied. It included an emission electrode (expander with conical insert), an extraction electrode and a decelerate electrode. The source and the plasma electrode were at pulse potential of +100 kV. The extraction electrode was at the potential of -20 kV in relation to the plasma electrode, the decelerate electrode (flange) was grounded. The extraction electrode aperture diameter was 14 mm. Full ion current extracted from the source was measured using the Faraday cylinder. The last one was a cylinder with the inlet of 44 mm and the length of 70 mm made of graphite and located on the beam axis at the distance of 270 mm from the source flange. In order to eliminate the influence of ion-electron emission the grid from thin wire was mounted in front of the Faraday's cylinder. It was at negative potential. To measure the proton beam component the beam-bending magnet which deflected the beam on the graphite current-collector was used. A grid of thin wire with negative potential was also installed in front of it. The beam emittance was measured using the lamella current-collector which was located at the distance of 550 mm from the source flange. It was a lattice consisting of 96 wires 1 mm thick each and with 1 mm gap between them. A split with the width of 0.2 mm which cut the beam streamlet and moved across the axis using a stepper motor was fixed at the distance of 90 mm from the decelerate electrode.

EXPERIMENTAL RESULTS

The hydrogen ion source with a cold magnetron cathode and plasma magnetic contraction in the emission holes field initial testings were carried out for extraction and beam forming IOS similar to the IOS for LU-30 injection system. The experiments were conducted in the pulsed mode with the frequency of 1 Hz and pulse duration of 25 μs. The discharge ignited and steadily burned at the voltage of 400-450 V. Maximum current of ancillary emergency discharge in the magnetron cathode area could reach 100 A. The maximum current of main discharge was 200 A at the modulator voltage of 700 V. In these experiments the ion beam current did not exceed 10 mA. For this reason the extraction system of ions from plasma was changed for the magnetron source. The performed studies helped to find out the two most critical questions which influenced on the value of current extracted from the source.

First of all this is the location of the conical insert into the expander. Its position along the axis defines plasma density in the beam extraction area. It is known [4] that in order to get the beam with low divergence the ion current density arriving to the plasma boundary must be equal to the beam current density, calculated basing on the law 3/2:

$$0.4en_+(2kT_e/M)^{1/2} = 1/(9\pi)\cdot(2e/M)^{1/2}\cdot U_0^{3/2}/d^2,$$

where n_+ is ion concentration, T_e is electron temperature, M is ions mass, e - electron charge, U_0-extraction voltage (120 kV), d - length of extraction gap (distance from the conical insert to the extraction electrode).

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To reduce the beam divergence angle the gap length between the conical insert and the extraction electrode was reduced from 40 mm to 24 mm. The research on the influence of shape (a cone angle), conical insert size (diameter) and its position on the beam axis (which was determined by the distance from the hole in main anode to the end surface of cone insert) on the value of the extraction current was carried out. For large distances (>25 mm) the value of extracted current was 10-20 mA and it did not depend on the extraction voltage. When the distance was decreased to18 mm the current increased to 50 mA and its value increased a few with extraction voltage decreasing. These data indicated significant divergence of plasma in expander, fall-off its density and penetration of extracting field inside the conical insert. As a result plasma extraction happened before the hole in the insert and the magnitude of the extracted current was small. The maximum value of the total current (protons, ions H_2^+, H_3^+) extracted from the source was received when the distance from the main anode hole to the conical insert end surface was 14 mm and the aperture diameter of the insert was 10 mm. It was 150 mA. Proton beam component value deflected by the magnetic field reached 110 Ma. The fraction of proton beam component was 73%. Further distance reduction to the hole in the anode could not be done from the constructive point of view. The presence of the annular slot between the expander cone and the insert allowed to throw off part of gas entering from the source to the expander and stabilize the source operation. The normalized emittance measured value at beam current 110 mA was 0.8 π mm mrad. Beam emittance at current 110 mA is shown in Figure 2. Herewith the beam proton component current was 85 Ma, i.e. the protons fraction was around 77%.

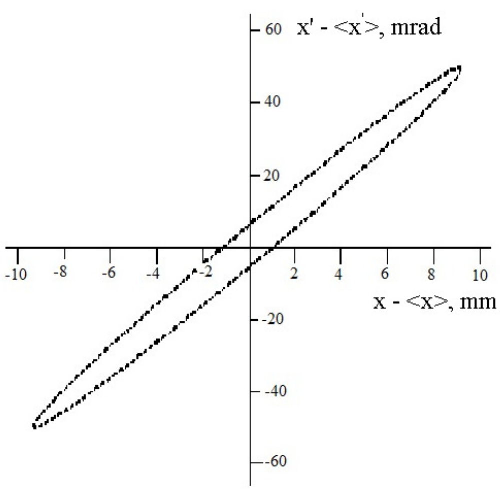

Figure 2: Measured distribution of particles in phase space of a 110 mA total beam (77% proton fraction) at 100 kV.

The study of the magnetron source performance will be continued. To extract more intense beams other source parameters optimization is to be carried out, in particular the optimization of the shape and size of the extractor which determines the distribution of the magnetic field contracting plasma near the emission hole. The research works on the source in buster mode with high pulse repetition rate (16.7 Hz) have been started.

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