STUDY OF THE INR RAS LINAC PULSED DUOPLASMATRON

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Abstract

Results of numerical simulation and experimental study of hydrogen ion beam from a pulsed duoplasmatron with different plasma expansion cup geometry are presented. Intensive oscillations of hydrogen ion beam current with frequency of ~ 1 MHz and amplitude up to 70% from maximum value (~ 100 mA) of ion current were observed with plasma expansion cup of different shape. It was found by direct measurements that these oscillations are formed during plasma transport through the expansion cup. Noiseless mode of operation for the pulsed duoplasmatron has been obtained with a plasma expansion cup of new design. Results of measurements of current and emittance of the hydrogen ion beam are presented

INTRODUCTION

A duoplasmatron-type ion source initially developed at NIIEFA [1] is used for injector of linear accelerator of INR RAS. The ion source has pulsed mode of operation with repetition rate of 50 Hz, pulse duration of 200 μs and pulsed ion current of 50-120 mA. During several years we study the ion source with goal to improve its reliability and increase of brightness of ion beam produced [2]. Initially, ion beam formation system of the duoplasmatron consisted from cylindrical plasma expansion cup 60 mm in diameter and gridded extraction electrode. The grid of the extraction electrode has been made from tungsten-rhenium wires 0.1 mm in diameter [1]. Hydrogen ion beam with pulsed current up to 200 mA has been obtained with this beam formation system. However, significant sputtering of the wires of the grid by beam ions has been observed after long term operation of the ion source. Relative brakes of the wires occurred which reduce reliability of the ion source. Deformation of the grid was arisen also due to its heating by the ion beam.

Additionally, significant unavoidable emittance growth of the ion beam occurred in electric field of the grid cells. This is why several gridless ion beam formation systems were used after that. The gridless ion beam formation system had high reliability and produce formation of hydrogen ion beam with relatively small normalized emittance of 0.1 π cm mrad (for 67% of ion beam current) [2]. However, ion beam obtained with the gridless ion beam formation systems had “noise” (~ 1 MHz oscillating component) which reached in some cases 70% of average value of the ion beam pulsed current. The “noise” appearance was not controlled completely by parameters of the duoplasmatron discharge and extraction voltage. Some measurements were performed to determine the “noise” origination. Then a new ion beam formation system has been developed and tested. With this beam formation system the duoplasmatron produces “noiseless” hydrogen ion beam. Results obtained are outlined in the paper.

STUDY OF “NOISE” ORIGINATION

It was shown by direct measurements that oscillations of the ion beam current are arisen in a plasma expansion cup. Initially, total ion flux emitted from anode orifice to expansion cup has been measured. For that, a flat collector 38 mm in diameter was installed at distance of 16 mm from the anode orifice. The collector was biased by negative potential of ~ 200 V relative the anode to suppress electrons from plasma to come to the collector. The total ion flux current of 350-530 mA was recorded for the duoplasmatron discharge current of 30-50 A respectively. It was found that the ion flux current was noiseless, what means that the “noise” originated downstream the anode emission orifice. Then the ion beam current has been recorded immediately downstream the beam formation system by Faraday cup with suppression of secondary electrons and simultaneously ion beam current to the extraction electrode of the beam formation system has been recorded. It was found that oscillations already exist and that oscillations of ion beam current and of ion current to the extraction electrode are in the same phase. This result shows that oscillations of ion flux at emission plasma surface of the expansion cup are already existed. Thus, it was found that ion current oscillations arisen in the plasma expansion cup. A new ion beam formation system has been developed then with goal to eliminate the “noise” origination.

A NEW ION BEAM FORMATION SYSTEM

Extensive simulations of ion beam extraction from ion source and the ion beam transport in the proton injector were performed to optimize geometry of the ion beam formation system. Program code TRAK of Field Precision LLC [4] has been used for the simulations. The code makes possible simulation of a self-consistent emission plasma boundary of ion sources and ion beam transport with space-charge.

The new ion beam formation system designed is shown in Figure 1. A flat grid made of tungsten wires 0.1 mm in diameter is installed at output of the plasma expansion cup of the beam formation system. Diameter of the emission surface is 30 mm. A plasma electrode of the expansion cup has quasi-Pierce geometry (see Figure 1) with angle 23° relative to the emission grid surface for diameters between 30 and 40 mm. This allows to obtain flat surface of plasma with flat grid by respective choice of extraction voltage for given plasma ion flux and to minimize effective emittance growth connected with initial focusing of ions by curved emission plasma surface at the grid cells. The plasma electrode has angle 35° relative to the emission grid surface for diameters from 40 mm to 65 mm to ensure additional focusing of the ion beam in the extraction gap. The extraction gap has shape of cuted cone with angle relative to system axis of 45°. The ion beam extracted is focused downstream into the accelerating tube by application of varied potential to a focusing electrode (see Figure 1).

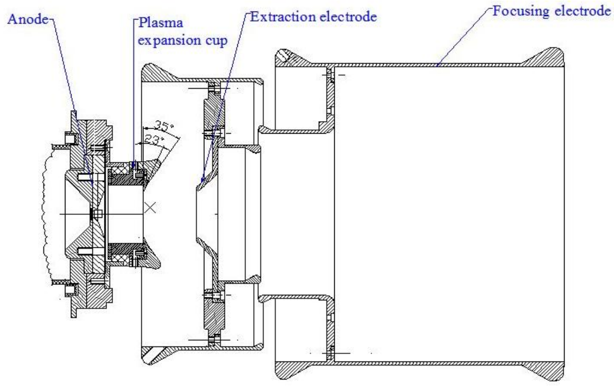


Figure 1: The ion beam formation system of the duoplasmatron.

It is worth noting that installed in the present ion beam formation system plasma electrode grid is sputtered and heated by ions in significantly less degree in comparison with system, where the grid is installed in the extraction electrode because of ions in plasma have average energy of order of 10 eV while accelerated in the extraction gap ions have more than three order of magnitude larger energy (20-40 keV).

Results of ion beam simulation with TRAK code for the ion beam formation system described are shown in Figures 2, 3.

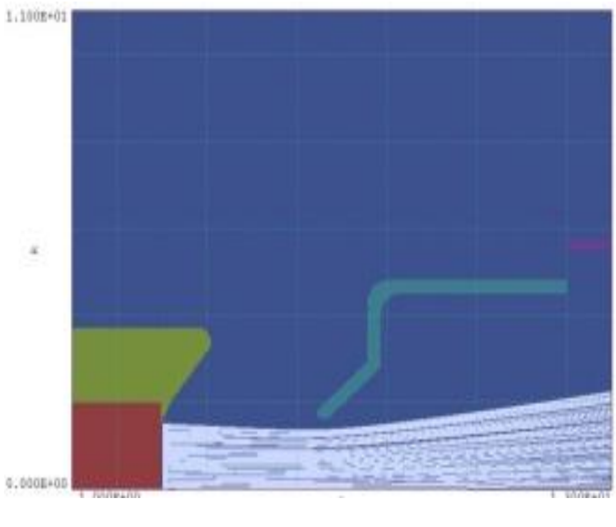


Figure 2: Results of an ion beam simulation with TRAK code. Ion beam trajectories in the beam formation system for extraction voltage of 25 kV and ion beam current of 100 mA.

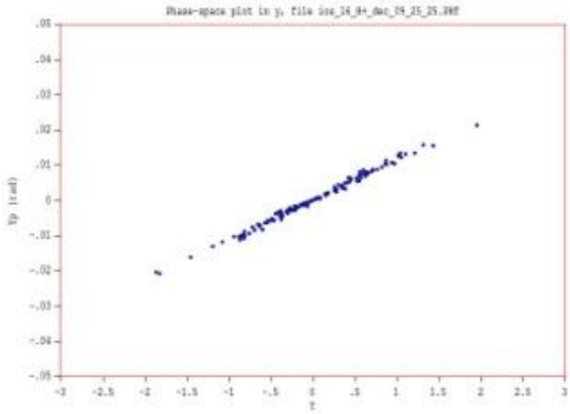


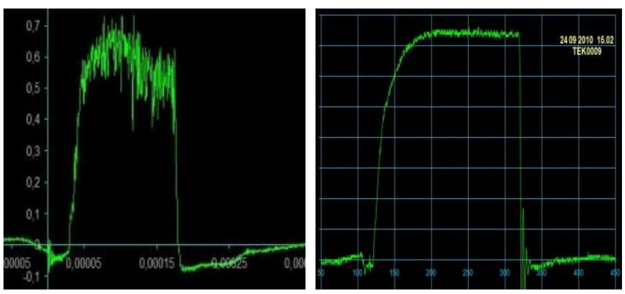
Figure 3: Results of an ion beam simulation with TRAK code. Phase space portrait of the ion beam at distance of 200 cm from the accelerating tube output.

The results show that with the given ion beam formation system aberration free ion beam extraction, acceleration and transport are achieved for an ion beam pulsed current of 100 mA. Thus the goal of the system numerical optimization is achieved.

RESULTS

The ion beam formation system described above has been incorporated into the duoplasmatron in October of 2009. The proton injector operated in five linear accelerator runs during 2009-2010 years with pulsed current at the injector output of 80 mA and repetition rate of 50 Hz. Total duration of the duoplasmatron operation since then was 1500 hrs without any failures. Evidence for sputtering or deformation of the plasma grid were not observed.

Hydrogen ion beam with pulsed current up to 180 mA has been obtained with the new ion beam formation system and recorded downstream the duoplasmatron by a Faraday cup with suppression of secondary electrons. Typical ion beam current at the injector output used for operation with linac was 80 mA. Oscillograms of the ion beam at the injector output with previous gridless ion beam formation system and with new one are shown in Figure 4a,b.



a b

Figure 4: Oscillograms of the ion beam at the injector output, a) gridless ion beam formation system b) new ion beam formation system

The ion current has been recorded by a beam current transformer at the injector output.

Emittance has been measured at the injector output for the hydrogen ion beam with energy of 400 keV. The emittance measuring device is described in [2] and is based on “slit-slit” method. Normalized emittance of the ion beam was measured to be 0.076 π cm mrad for 63% of the total current and 0.2 π cm mrad for 90% of the total ion beam current. Typical phase space portrait measured is shown in figures 5. Percent part of the ion beam inside the given phase-space area is shown in figure 6.

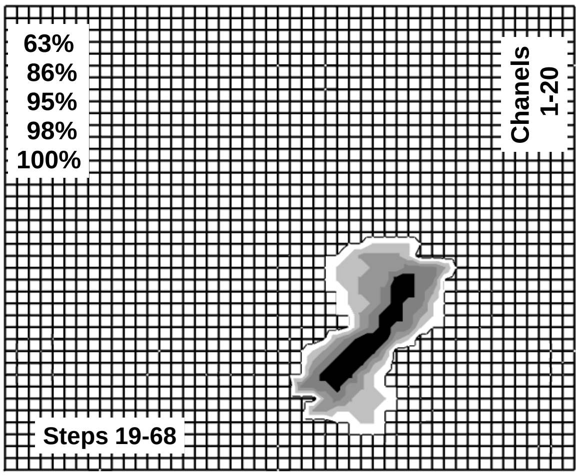


Figure 5: Phase-space portrait of the hydrogen ion beam at output of the proton injector. Ion beam energy is 400 keV, ion beam current is 85 mA. Horizontal scale is 2 mm/div and vertical scale is 2 mrad/div.

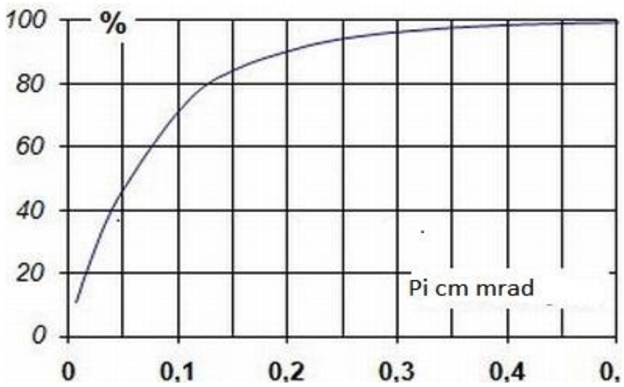


Figure 6. Percent part of the hydrogen ion beam (vertical) inside the given phase-space area (horizontal). 90% of total ion beam current is inside phase-space area of 0.2 π cm mrad.

CONCLUSION

It is shown in the present paper that oscillations of ion beam current from a duoplasmatron with typical frequencies of ~ 1 MHz which exist at some conditions are arisen in a plasma expansion cup of the duoplasmatron. Noiseless mode of the duoplasmatron operation has been obtained with the new ion beam formation system. Hydrogen ion beam with a typical pulsed ion beam current of 80 mA and normalized emittance of 0.2 π cm mrad for 90% of total ion beam current has been obtained. The duoplasmatron with these parameters of the hydrogen ion beam has been used in the INR RAS linear accelerator runs demonstrating high reliability and stability of the ion beam.

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