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DEVELOPMENT OF THE ION BEAMS HIPR-1 TRANSPORT CHANNEL FOR ION ENERGY LOSSES MEASUREMENT IN PLASMA TARGET*

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Abstract

The research of the processes occurring during the interaction of heavy ions with plasma is carried out on the Heavy Ion RFQ HIPr-1 (Heavy Ion Prototype) in the ITEP. The HIPr-1 is a heavy ion RFQ linac that accelerates ion beams generated by either a MEVVA ion source or a duoplasmatron. It provides accelerated beam of ions from C^{+} to U^{4+} with energy of 101 keV/u and up to 3 mA of current. Gas-discharge plasma target, which was produced in ITEP, is used for the measurement of ion energy losses in the ionized matter. The diaphragms at the entrance and the exit of the plasma target provide the necessary vacuum into the transport channel (which is 10^{-6} mbar), while the gas pressure in the target equals to 1-10 mbar. The design of the beam transport channel for performing experiments to determine the energy losses in plasma was developed based on the beam dynamics simulation. According to the obtained results the first successful tests on the HIPr-1 were held.

INTRODUCTION

Investigation of ion stopping in an ionized matter is important for obtaining new knowledge in high energy density in matter and plasma physics. Especially interesting is the investigation of the interaction of heavy ions with low energy range from 40 to 500 keV/u with strongly ionized low temperature hydrogen plasma [1,2]. Work on the determining of the ions energy losses in a plasma is carried out into heavy ion RFQ linac Heavy Ion Prototype (HIPr-1) [3] at ITEP. HIPr-1 accelerates heavy ion beams in the pulsed mode with pulse length of 450 µs and repetition rate up to one pulse for four seconds. HIPr-1 layout is shown in Fig. 1. A metal ion beam is generated using the metal vapor vacuum arc ion source (MEVVA). To generate a gas ion beam the duoplasmatron ion source is used [4]. In RFQ structure the beam is accelerated up to 101 keV per nucleon total energy (5.6 MeV for Fe). The RFQ structure was produced for accelerating of heavy ions with the mass to charge ratio ~60 [5].

Transport channel includes three magnetic quadrupole lenses and two observation chambers.

Below are the results of the development of the transportation channel and the launch of an experimental bench based on HIPr-1.

PLASMA TARGET

Plasma target (PT) was developed at ITEP [6], plasma inside PT ignited by electrical discharge in two coaxial quartz tubes (see Fig. 2). The capacitor bank with charging voltage range from 2 to 5 kV produces the discharge of hydrogen with maximal current up to 3 kA. As laser interferometry measurement [7] shows the linear free electron density of plasma is in the range from $3.3*10^{17}$ to $1.3*10^{18}$ cm^{-2}. For the plasma temperature measurement will be applied spectrometric method.

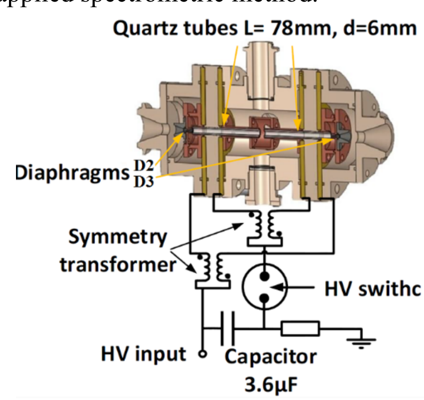

Figure 2: Plasma target.

The plasma target was installed between the third quadrupole lens and the observation chamber.

For plasma generation the initial hydrogen pressure should be from 1 to 10 mbar in PT. In order to guarantee required vacuum magnitude 10^{-6} mbar in the transport channel in front and back of the plasma target a set of four diaphragms was used. In Fig. 3 the diaphragms locations, the vacuum system and the beam diagnostic system are shown.

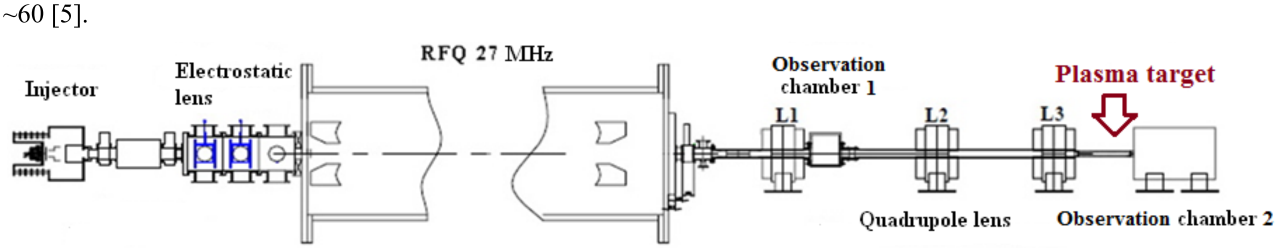

Figure 1: Layout of the HIPr-1.

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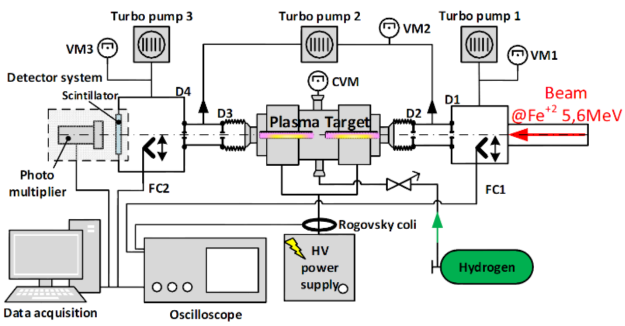

Figure 3: Vacuum system and diagnostic equipment, D1-4 – diaphragms of differential pumping system Ø = 1-3mm, VM1-3 – vacuum meters, CVM – gas independent vacuum-meter, FC1-2 – Faraday cups.

Vacuum system of PT consisted of three turbomolecular pumps. Vacuum-meters (VM) controlled volumes divided by diaphragms. VM1 was installed in observation chamber 1 before D1. When in observation chamber 1 vacuum is more than $5 \cdot 10^{-5}$ mbar, there are RF-discharges inside the RFQ. Two Faraday Cups were used for current measurement: FC1 - before the PT, FC2 - after the PT in the observation chamber.

BEAM DYNAMIC SIMULATION

Beam dynamic simulation was carried out for Fe^{2+} with energy of 5.6 MeV and beam current of 3 mA. Output phase-space ellipses of the RFQ obtained earlier by Dynamion [8] were used as input parameters of the channel. The norm.emittances were equal to $\varepsilon_x = 0.062\ \pi \cdot$mm$\cdot$mrad, $\varepsilon_y = 0.065\ \pi \cdot$mm$\cdot$mrad (Fig. 4).

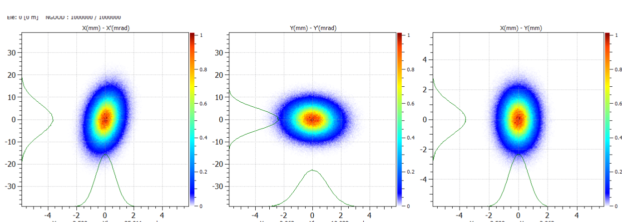

Figure 4: Input phase-space ellipses of the transport channel.

The following characteristics of the magnetic quadrupole lenses, installed in the transport channel at HIPr-1 (see Fig. 5), were used: effective length – 240 mm, distance between poles - 76 mm. In accordance with passport data the magnetic field gradient is 8 T/m at current equal to 37 A [9]. Operational experience demonstrates that lenses can be exploited for a long time without overheating at currents in coil corresponding to a magnetic field gradient of 9 T/m. This value was accepted as a limit for the simulation.

The peculiarity of developing channel construction was a set of the diaphragms, which located at the entrance and the exit of the PT. The main parameters of diaphragms are presented in Table 1. The transverse beam size into the channel exceed the diameters of the diaphragms. It was necessary to create a weakly-converging beam with a crossover at the centre of the target for a better beam passing through the PT.

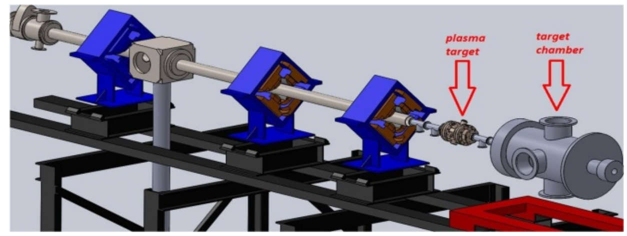

Figure 5: The general view of the channel with the PT at the HIPr-1.

Table 1: Parameters of the Diaphragms

Set	Parameter	D1	D2	D3	D4
1st	Diameter (mm)	3	2	2.5	2.8
	Length (mm)	0.5	10		10
2nd	Diameter (mm)	3	1		2.8
	Length (mm)	0.5	10	10	10

As a result of simulation the gradients of magnetic quadrupole lenses were selected: -7.5; 7.3; -6.8 T/m. After passing through four diaphragms, the beam current was reduced to 54 μA. The beam's emittance at the entrance of the target was several times greater than the acceptance of the tube with diaphragms. This led to a cutoff of the beam and large number of particles losses. Figure 6 and 7 show the beam multiparticle envelopes into the channel and the phase space ellipses at output of PT.

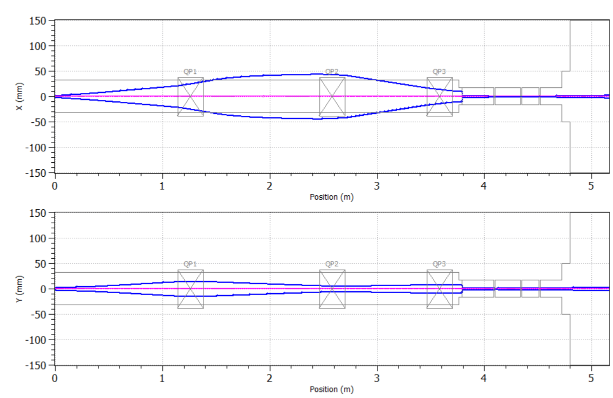

Figure 6: Multiparticle envelopes in x and y directions.

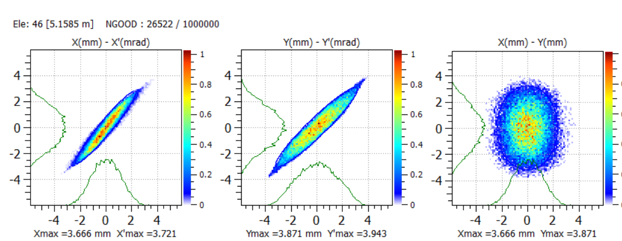

Figure 7: Output phase-space ellipses of PT.

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EXPERIMENTAL WORKS

Adjustment of the Vacuum System

Preliminary tests with PT were carried out with the parameters obtained by simulation. Using the first set of diaphragms (from Table 1), the current was 40 µA after D4 without gas in PT. In the case of gas injection inside the PT for a pressure of 3 mbar in the PT, there are RF-discharges inside the RFQ ($6 \cdot 10^{-5}$ mbar on VM1). So it was decided to replace the first set with another one of narrower and longer diaphragms. The parameters of the diaphragms were selected manually to provide the necessary vacuum level. It was necessary to define the best balance between required vacuum and beam current value passed through PT. The main characteristics of the second set is presented in Table 1. The final set of diaphragms allow making measure in plasma with cold gas pressure up to 2 mbar. Maximal measured beam current (between D3 and D4 diaphragms) in this geometry was about 35 µA. In compare with other diaphragms sets, it gives a sufficiently high level of the signal on the detector. Operating with this set without gas inside the PT the beam current after passing through it was equal to 30 µA. During letting-to-gas the current into observation chamber was getting less.

Measurement of Losses in Plasma

For ion energy losses measurement the detector system was used. The system consists a fast Al_2O_3 based sapphire scintillator and Photomultiplier Hamamatsu R760. Time-of-flight method (TOF) was used during the experiment. The method is about defining of time delaying dT (temporal shift) of microbunches peaks in relation to accelerator radiofrequency signal (see Fig. 8). The time resolution of registration system 0.8 ns. Unfortunately, the level of RF-noise and plasma discharge-noise was practically the same as the level of the beam current. The correction of microbunches peak value positions in local regions of signal with insufficient signal-to-noise ratio and curve fitting of dT distribution in plasma discharge area have been implemented in Matlab.

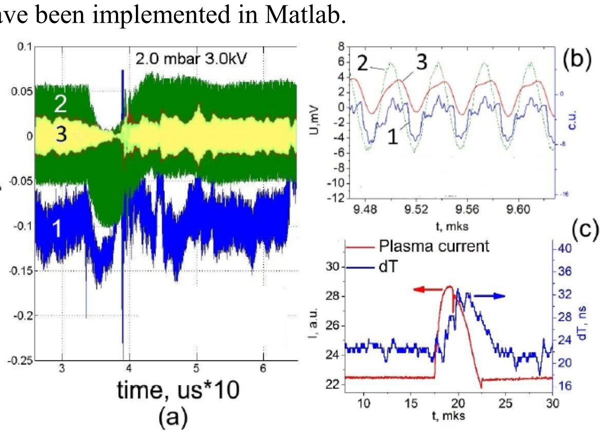

Figure 8: (a,b) 1 - raw photomultiplier signal, 2 – accelerator RF signal, 3 - Fourier correction of row signal. (c) – plasma current (left) and microbunch shift dT (right) compared in time.

CONCLUSION

The ion beam transport channel was designed for investigation of ion stopping in an ionized matter. Based on the beam dynamics simulation and manual adjustment the parameters of the ion-optical elements for beam focusing to plasma target have been selected. The experimental bench at the heavy ion RFQ linac (HIPr-1) was assembled. Work on the matching of vacuum system was carried out, which allowed determining the parameters of the diaphragms at the entrance and exit of the plasma target. The first principal results were obtained, proving the working efficiency of this installation. Works for induced-noise protection of photomultiplier and oscilloscope is under developing.

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