MULTIFUNCTIONAL EXTRACTION CHANNEL DEVELOPMENT HEAVY ION RFQ (RADIO FREQUENCY QUADRUPOLE)*

E.Khabibullina#, R.Gavrilin, B. Chalykh, G. Kropachev, R. Kuibeda, S.Visotski, T. Kulevoy, A.Golubev, ITEP, Moscow, Russia
M. Comunian, LNL-INFN, Legnaro (PD), Italy
E.Khabibullina#, T. Kulevoy, NRNU "MEPhI", Moscow, Russia

Abstract

In the ITEP the Heavy Ion RFQ HIP-1 (heavy Ion Prototype) has to provide ion beams for two different experimental programs. The first one, aimed to irradiation resistance investigation of reactor construction materials, is successfully ongoing. Samples of new materials for reactors were irradiated by beams of iron, vanadium and titanium ions accelerated by the RFQ. The irradiated materials were investigated by both transmission electron microscope and atom-probe tomography. The second one is under development and it is aimed to investigation of ion beam interaction with plasma and metal vapour targets. For this program a wide range of beams (both gas ions and metal ones) accelerated in the RFQ can be used. Based on beam dynamics simulation the design of new RFQ output beam line enabling both experiments realization was developed. Details of beam dynamics simulation and output line design are presented and discussed in this paper.

INTRODUCTION

In the ITEP the Heavy Ion RFQ (Fig.1) provides irradiation resistance investigation of reactor construction materials. The HIP-1 is a heavy ion RFQ linac accelerating ion beams generated by either MEVVA ion source or duoplasmatron. It provides accelerated beam of ions from C^{+} to U^{4+} with energy of 101keV/n and several mA of current[1].

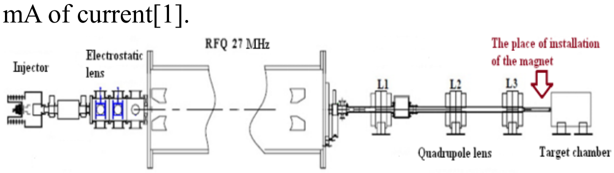

Figure 1: The Heavy Ion Prototype.

For project realization the special target chamber providing sample heating up to desired temperature from range of 20ºC to 700ºC was developed. A set of experimental works for reactor material resistance investigation were carried out already [2].

The experiments of heavy ion beam interaction with plasma and metal vapor target can't be carried out simultaneously with ones for reactor resistance investigation at the existing RFQ output beam line. The existing output beam channel of TIPr-1 can't be used for both targets, for reactor materials investigation and for plasma-beam interaction. The target for imitation experiments with reactor materials is nontransparent. The target for plasma and metal vapor interaction with ion beam is transpired but a considerable amount of intensity (more than 90%) is lost during beam passage through plasma target diaphragms.

According to theoretical models the plasma (ionized gas) has a higher stopping power for ion beam with energy of about 100 keV/n compare to both gas target and even metal one [3]. The design of new beam line is under development now. The results of simulation are presented and discussed.

PLASMA TARGET

The plasma target device generates plasma by an electric discharge igniting in two collinear quartz tubes, each of 5 mm in diameter and 78 mm long. The capacitor bank of ~3 μF provides the discharge at voltage up to 5 kV and produces the electrical current flowing in two opposite directions in both quartz tubes. Such a design for the plasma target enables suppression the well-known effect of the plasma lens caused by the magnetic field of the discharge current. The focusing effect of the first discharge tube is compensated for the defocusing effect of the second one. Symmetry of the discharge ensures by special inductivity coils, included into the discharge circuit, with two wires for the two current branches wind in the opposite directions (Fig.2).

An ultimate vacuum obtained in the target is $1.6 * 10^{-7}$ mbar. During experiments the target pressure may be varied by inlet valve in the range from 1 to 10 mbar. It allows plasma production with variation of both an electron density and a of ionization rate [4].

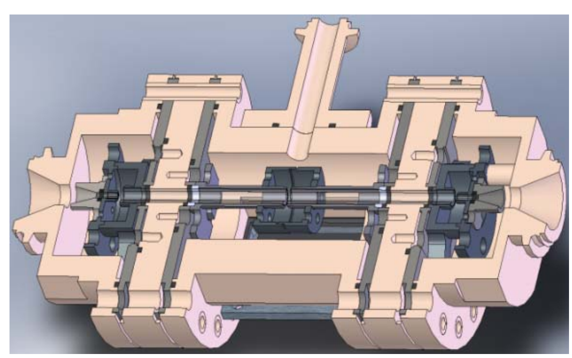

Figure 2: Cross-section view of the plasma target device.

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Therefore to enable two experiments realization with ion beam accelerated in ITEP, it is necessary to develop two correlated beam channels at the RFQ structure output for imitation experiments target and plasma target.

SIMULATION

The multifunctional RFQ output line for both targets was designed on the base of beam dynamic simulation carried out by TraceWin code [5]. The elements which can be transported throughout the channel and provide the required beam parameters at the targets were selected. Moreover, the system described has to fit the experimental hall. For beam transportation to the plasma target, the bending magnet constructed in frame of ADS program [6] for proton beam energy of 36 MeV (Fig.3) was selected thanks to its maximum magnetic field and bending radius. The magnet has magnetic field up to1.3 T, bending radius 670 mm and 30 mm aperture. The quadruple lenses have a 70 mm aperture and can provide up to 12 T/m maximum gradient. It provides the delivering of the ions with mass-to-charge ratio up to 20 to the plasma target.

Figure 3: The dispending magnet.

Since for reactor material irradiation the iron ion beam is used the straight line should be used for this experiment program. The Al^{2+} beam was chosen for experiments at the plasma target, because the maximum field in bending magnet can provide Al beam delivering to the plasma target. The beam initial parameters are determined by Twiss-parameters that were obtained as a result of Al^{2+} and Fe^{2+} ion beams simulation in RFQ channel with the use of Dynamion program [7].

Table 1: The Twiss-parameters

Magnitude	x	y	z
α	-0.238	0.057	0.106
β, mm/π•mrad	0.31	0.022	14.855
γ, π•mm•mrad	0.0248	0.0258	1.008

The simulation was carried out with 4 mA beam current and 10^6 particles in transportation channel. The cross-section of ion beam at the RFQ output is showed in Fig.4.

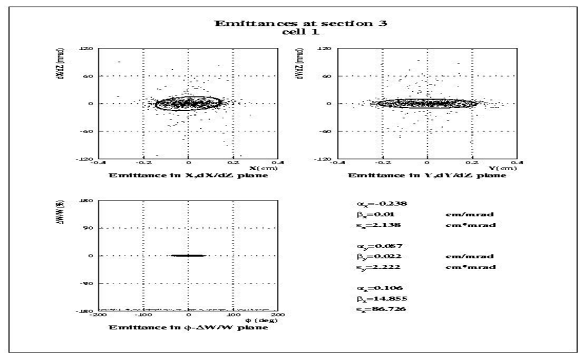

Figure 4: The beam phase characteristics of RFQ structure output.

At first stage, the simulation of existent channel for reactor material target at the HIP-1 output was performed with the quadrupole parameters that are used for ongoing experiments. The obtained results were compared to the experimental data for evaluation of afore-mentioned model and changes made during channel modernization.

Two beam focusing variations at the location of sample installation were considered during the simulation: the elliptical and the circular beam cross-section. The simulation showed the good agreement with the experimental parameters.

At the next step, the similar simulation but taking into account the bending magnet installation between last quadruple lens and the target was carried out. The magnet installation changes the location of the target. The gradient magnitudes were selected in such a way, as to achieve the same values of beam impact on the target, as without magnet installation. The result of simulation is shown in Fig. 5.

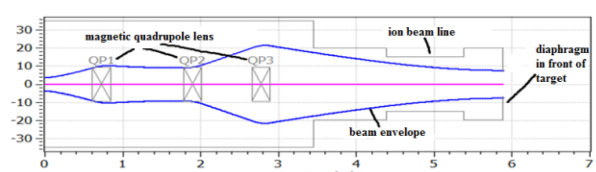

Figure 5: The beam dynamic simulation from RFQ output to target for irradiation resistance investigation of reactor construction materials with magnet ion guide

As the next stage the beam transport simulation to the plasma target was carried out for the channel with beam bending to 34°. During the simulation the line parameters optimisation to reach the maximum beam passed throughout two 1-mm diaphragms fixed on the input and output on plasma target were carried out. Beam loses will be inevitable, because the beam emittance is several times larger than target acceptance. For best focusing and beam passage through plasma target the magnet quadrupole triplet between bending magnet and target was used. The triplet consist of similar lens were installed at the HIP-1. It was found that more than 2% of beam accelerated in RFQ can be delivered to the detector after the plasma target. It means that the channel provides the beam transportation needed for the experimental works (Fig.6, Tab.2)

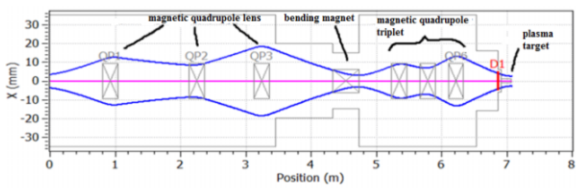

Figure 6: The beam dynamic simulation from RFQ output to plasma target.

Table 2: Channel parameters for transport of Al^{2+}ions

Parameter (units of measurement)	
DRIFT(mm)	613
QUAD, G (T/m)	**3.55**
DRIFT (mm)	935
QUAD, G (T/m)	**-3.9**
DRIFT (mm)	645
QUAD, G (T/m)	**3.95**
DRIFT (mm)	1491
BEND(°)	**34**
DRIFT (mm)	200
QUAD, G (T/m)	**6.4**
DRIFT (mm)	200
QUAD, G (T/m)	**-8.3**
DRIFT (mm)	200
QUAD, G (T/m)	**7.23**
DRIFT (mm)	773

CONCLUSIONS

As a result of this work the magnetic and focusing elements providing realization of two independent experiments at the HIP-1 output channel are selected. The construction is based on the bending magnet and triplet of quadruple lenses.

On the basis of beam dynamic simulation of Fe^{2+} ions in channel for experiments aimed to irradiation investigation of reactor construction materials and Al^{2+} ions in channel for experiments with plasma target in the approximation of ideal fields the channel was designed. The quadruple lenses gradients providing the necessary beam parameters on the targets are determined.

Thus, the base configuration of transport channel at HIP-1 linac was designed for two experiments realization on the plasma target and on metal vapour target (Fig.7).

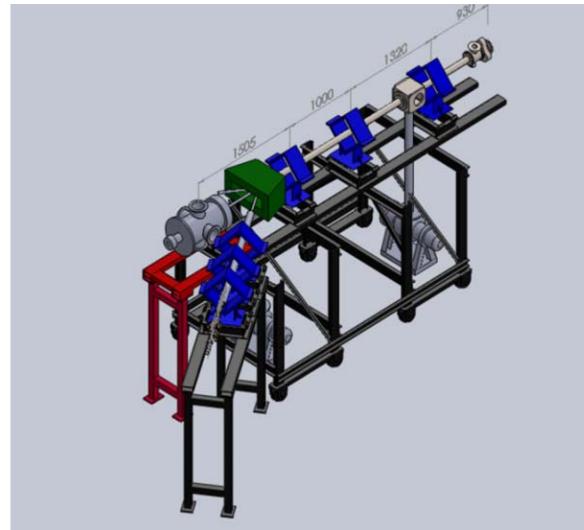

Figure 7: The general view of multifunction channel on the metal vapor target and on the plasma target at the HIP-1.

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