# BEAM DYNAMICS IN MATCHING CHANNEL OF ITEP-TWAC HEAVY ION INJECTOR I-3

N.N. Alexeev, S.L. Bereznitsky, V.I.Nikolaev, ITEP, Moscow, Russia


## *Abstract*

Longitudinal and transverse dynamics of many species ion beam generated in laser ion source and transported through matching channel and two gap 4MV resonator is considered. The channel properties studied by simulation and results of first experiments with ion beam transportation and acceleration are presented.


## INTRODUCTION

The ITEP-TWAC project is intended to initiate some providing ground for development and promotion of high intensity and high power heavy ion beam technology on the base of accelerator installations available at ITEP. Parameters of TWAC Facility [1] are challenging, but realisation of them depends on so far as constituent parts will be improved.

The Ion Injector I-3 is one of available at ITEP accelerator that was modified in the frame of TWAC project for utmost intensity of the accelerated beam.

Table 1. I-3 resonator parameters

| | |
|---|---|
| RF | 2.504 MHz |
| Number of acc. gaps | 2 |
| Voltage per gap | >2 MV |
| Length of drift tube | 1920 mm |
| Aperture | 70-90 mm |
| Length of first acc. gap | 250 mm |
| Length of second acc. gap | 230 mm |
| Range of Z/A | 0.2÷0.5 |
| Input beam energy | up to 50 kV |
| Transverse acceptance | Up to 2000 $\pi$ mm mrad |
| Buncher rf voltage | 10 kV |

Injector I-3 (Fig.1) is the single drift tube linac supposed for acceleration of heavy ion beam from laser ion source in a wide range of charge to mass ratio. Beam currents of 10-30 mA for some ion species ($C^{4+}$, $Al^{11+}$, et al.) observed in experiments at ITEP and TRINITY [2] with 5 J and 75 J lasers were used as the reference-point for injector optimisation.

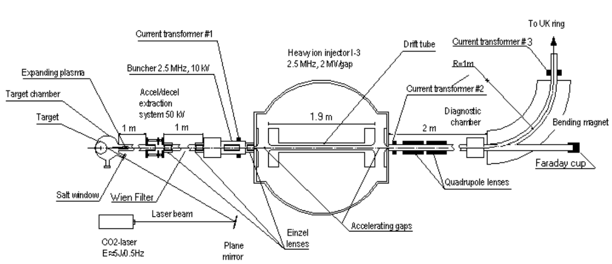


Fig.1. 3 Injector I-3 configuration.

Tank of the I-3 resonator with internal induction-coil has been taken as it was but the whole of components in linear accelerating channel was optimised on a base of beam dynamics simulation.

## 1 BEAM DYNAMICS SIMULATION

### *1.1 Longitudinal motion*

Kinetic energy of the input beam (~50 kV) at the entrance to resonator is low compared with accelerating potential in the first accelerating gap (~2 MV), so the particles getting into decelerating half of rf wave will be lost. The bunch is formed of particles in the accelerating half of rf wave in phase interval of 100-150 degrees as it's seen on Fig.2.

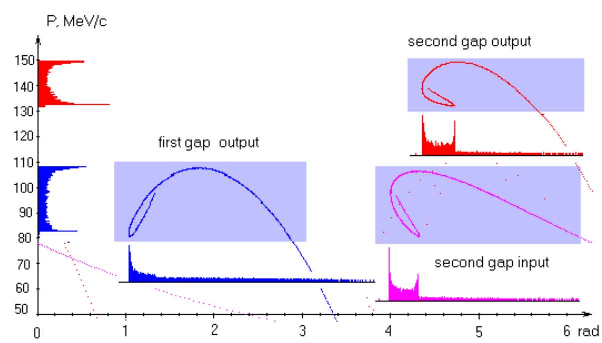


Fig.2. Accelerated $C^{4+}$-beam diagrams in rf_phase-momentum plane and particles distributions in momentum and rf phase (*without bunching*).

The range of ion species whose charge to mass ratio is suitable for accelerating in this structure with similar efficiency is wide, as may be seen on Fig.3. But effectiveness of this accelerator to be used as injector for synchrotron is low because the momentum spread of the output beam without bunching is excessively big, and beam-cutting with $\Delta p/p=\pm1\%$, that required for injection to synchrotron, doesn't exceed half of the whole accelerated beam. Beam bunching at the input of resonator results to increase the beam density in momentum, so the efficiency of longitudinal beam capture in injector has to be raised from 10-15% up to 50-60%. But, calculated value of beam capture can't be reached because of beam bunching causes a harmful effect for transverse motion of nonlinear space-charge forces increase (Fig.4).

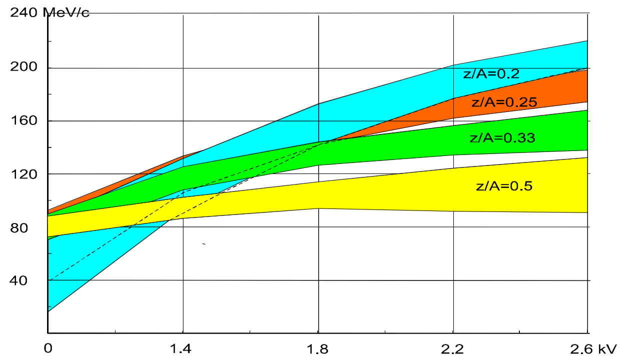


Fig.3. Accelerated beam diagrams in rf_voltage-momentum plane for different ion species.

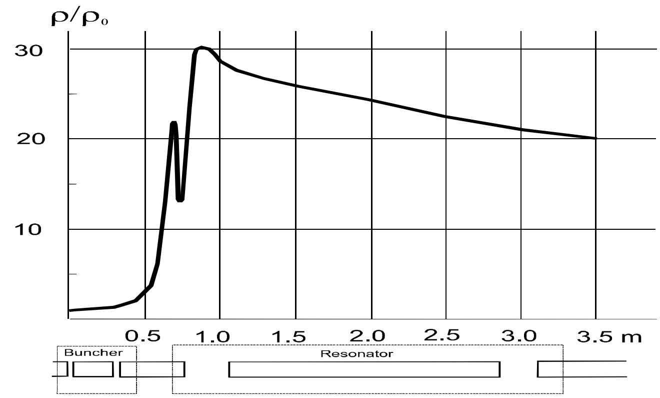


Fig.4. Dynamics of beam density at bunching and acceleration

## *1.2 Transverse motion*

The assumptions that we have made in simulation algorithm are the following:

the flow of a beam is laminar;

the beam cross section at any given position along the direction of travel does not change with time;

initial particle distribution in the transverse phase space is normal and axisymmetric.

To get maximum yield at the injector output, beam has to be treated in matching channel for separation of main ion species, bunching and focusing to minimise particle loss and get definite portrait of the beam phase space at the first accelerating gap.

Acceptance of the channel for considered ions and zero current is order of 2000 π mm mrad. The optimum value of transverse emittance of beam with nonzero current is order of 500 π mm mrad. The 30 mA beam in the 500 π mm mrad emittance is transported through the channel and accelerated without particles loss (Fig.5). Dynamics of beam loss in resonator at higher currents can bee seen in table 2.

Table 2. Dynamics of beam loss with beam current

| Input, mA | 50 | 60 | 70 | 90 | 120 | 160 | 200 |
|---|---|---|---|---|---|---|---|
| Output, mA | 49 | 51 | 48 | 40 | 33 | 24 | 20 |

Essential feature of a beam transverse dynamics in the channel and resonator consists in space charge forces increase at beam bunching. Beam bunching leads to decrease of the beam transfer capacity for resonator so that only the 15 mA beam may be transported with bunching factor of 5 and accelerated without particles loss by transverse motion.

Superfluous ion species create additional space charge forces and lower the transfer capacity of channel for a main ion component. Ions separation increase the transfer capacity of channel by factor of ~2. Results of $C^{4+}$ beam separation by Wien filter is shown on Fig.6. Deviation of the superfluous ion beam creates transverse space charge force affecting the main beam component. This effect has to be compensated by mismatching of electrostatic and magnetic field values in Wien filter.

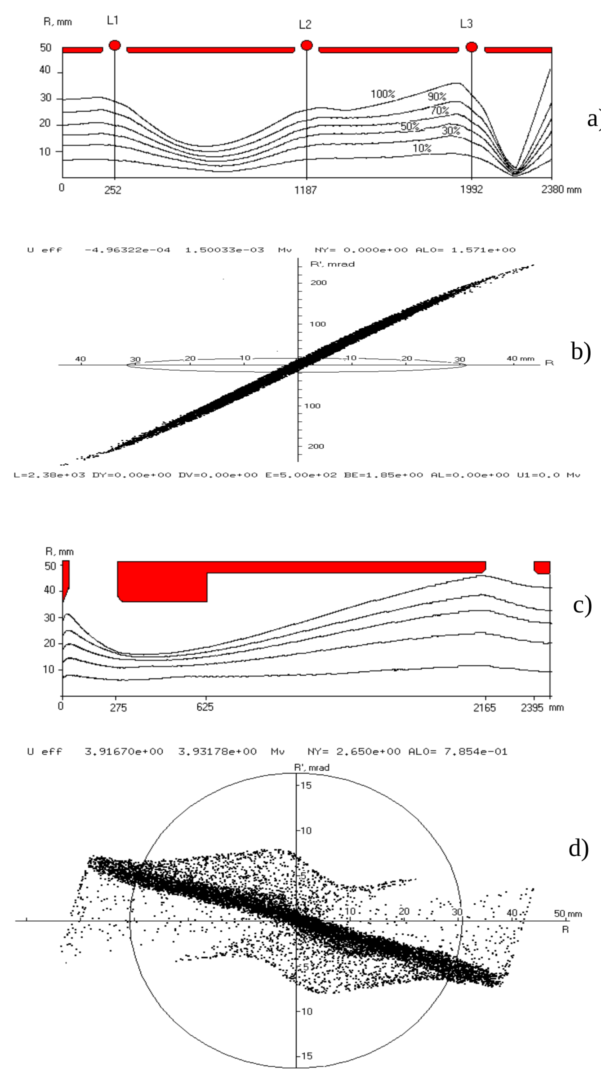


Fig.5. Beam transfer through matching channel and resonator a,b) beam envelope and emittance in matching channel; c,d) tha same in resonator.

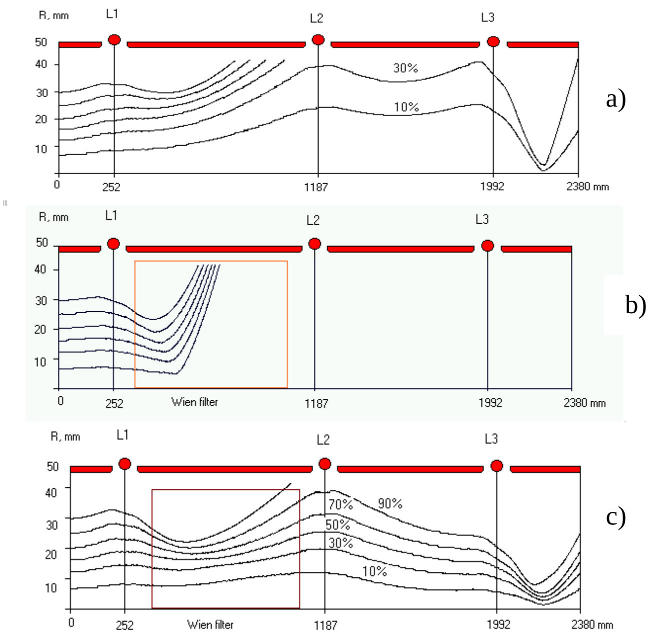


Fig.6. The beam envelope at separation by Wien filter (composition of $C^{5+}$- 10 mA, $C^{4+}$- 15 mA, $C^{3+}$- 10 mA; $C^{2+}$- 10 mA; a) no separation; 35% transmission b) removing fraction; 95% transmission with separation.

## 2 FIRST EXPRIMENTAL RESULTS

For generation of ion beam, we have used the laser ion source with $CO_2$-laser of 5J energy and carbon target. The ions with charge states up to (5+) have been observed with total current amplitude of 10-15 mA measured by transformer #1 at the input of resonator (Fig.1).

The beam composition was analysed by the $90^0$ bending magnet. Oscillograms of current transformer #3 for ions of different charge states without beam acceleration in resonator are shown on Fig.7. The average percentage of ions with different charge states is order of values adduced in [2], but dispersion of these values was big enough.

The Wien filter hasn't been installed, so we haven't possibility to separate ion species at the resonator input. The total current of accelerated beam measured in straight channel has been up to 5 mA. The choose of operational ion species has been done by means of tuning the bunching rf phase and the $90^0$ bending magnet current. The beam of $C^{4+}$ ions has been the best choice, as most stable and high current. Fig.8 shows oscillograms of the total input beam current and the accelerated current of $C^{4+}$ and $C^{5+}$ ions. The bunching has multiplied the current value by factor of 3-4. The observed 1.5-2 mA amplitude of the accelerated $C^{4+}$ beam current makes up the ~40% capture of the $C^{4+}$ fraction in the total ~10 mA beam current.

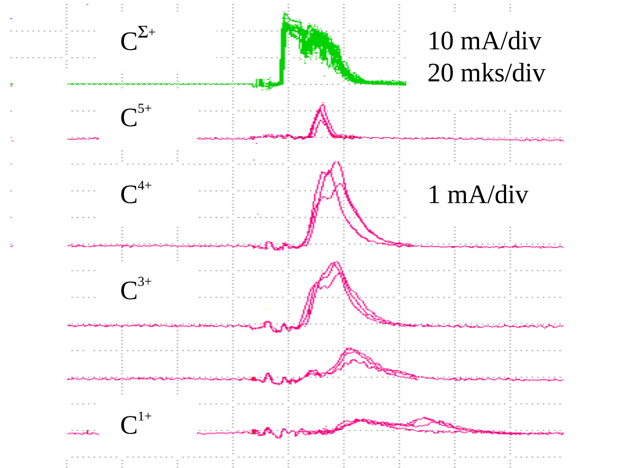


Fig.7. Oscillograms of carbon ions with different charge states.

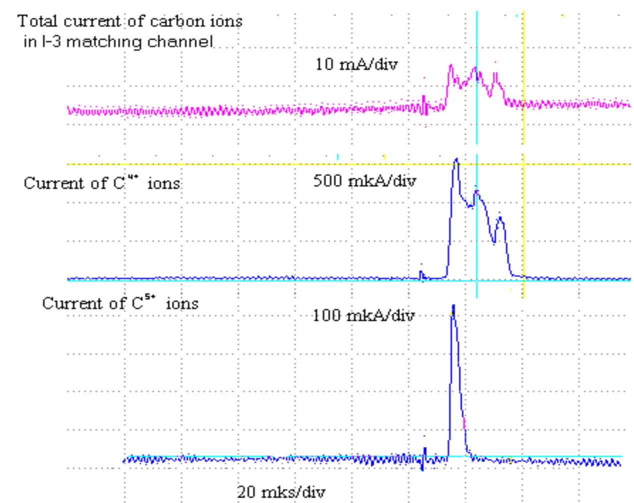


Fig.8. Oscillograms of the total input beam current and the accelerated $C^{4+}$ beam current.

## CONCLUSION

Configuration of the heavy ion linear injector I-3 with matching channel has been studied by simulation, constructed and tested at ITEP in the frame of TWAC-ITEP project. Calculated optimum transmission of this channel is estimated as 50% in the range of the 5-7 mA apportioned beam output current. Preliminary experimental result is the 1.5-2 mA current of accelerated $C^{4+}$ beam. We hope to increase the output ion current by means of space charge density decrease at the beginning of matching channel using Wien filter and optimizing the aperture of ion source output window.

## REFERENCES

[1] D.G.Koshkarev et al., “ITEP Accelerator Facility Upgrade”, XV Workshop on Charged Accelerator, Protvino, October 1996, v.2, p.319.

[2] S.Kondrashev et al., Rev. Sci. Instr., 71(3), 2000, pp.1409.