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# UPGRADE OF HEAVY ION INJECTOR FOR ITEP-TWAC FACILITY

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*Abstract*

A new scheme of heavy ion injector I-3 designed for improvement of accelerated beam parameters has been proposed for ITEP-TWAC Facility. It is based on the usage of two quarter-wave double gap resonators operated on 5 MHz with accelerating voltage of 3 MV per gap. Existing 2.5 MHz double gap resonator will be retuned for operational frequency of 5 MHz and new additional one will be built. The new injector optimized for acceleration of heavy ions with A/Z in the range of 3-10 will allow accelerating any ions from C to U with beam current up to10 mA. Results of both electrodynamics and beam dynamics simulations of the accelerating structures are presented.

## INTRODUCTION

The ITEP-TWAC existing injection complex [1] including two injectors: I-2 and I-3 generating proton and ion beams has been fully consistent with multipurpose usage of accelerator (see Fig. 1).

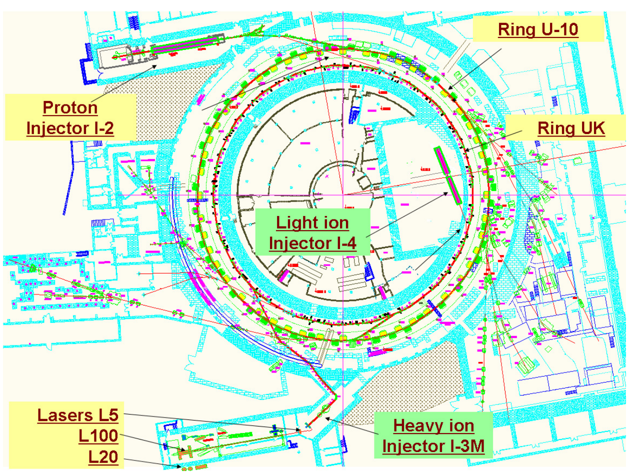


Figure 1: Layout of ITEP-TWAC Injection complex.

But, low energy (4Z MeV) and low accelerating frequency (2.5 MHz) of injector I-3 significantly limited parameters of pre-accelerated beams for effective acceleration in synchrotron UK.

Modernization of the I-3 is aimed not only improvement of beam parameters but also expanding of multipurpose machine flexibility for using it in different applications.

Based on the beam parameters generated in laser ion source (LIS) [2,3] new ion injection complex will include two ion injectors: linear accelerator I-4 designed for acceleration of light ions with A/Z≤3 up to the energy of 7 MeV/u [4], and upgraded accelerator I-3 modified to I-3M for acceleration of heavy ions A/Z≥3 up to the energy of 12Z MV. Section RFQ of linac I-4 has been constructed [5] and it undergoes tests now. Light ion will be accelerated in this section with beam current up to 100 mA at transmission factor of 95%.

Upgrade of injector I-3 will allow increasing of accelerated beam energy (up to 12Z MV) as well as beam intensity (up to $10^{11}$ n/p) for any type of ions from C to U generated in LIS. Pre-acceleration of heavy ions will be performed in four gap accelerating structure I-3M composed of modified I-3 resonator tuned from 2.5 MHz to 5 MHz and additional one operating on the same frequency. Resonators configuration is optimized for acceleration of ions with A/Z=(3÷10) at accelerating voltage of 3 MV per gap. Edge focusing of the beam in first accelerating gap is optimized for maximum beam transmission factor.

Parameters of some ion components accelerated in I-3M are given in Table 1. Charge states of ions and beam intensity presented in the table are calculated for the beam parameters at the output of LIS with the 100 J $CO_2$ laser [3] and really achievable transmission ~50%.

Table 1: Acceleration of Different Ions in I-3M

| | 10($U^{24+}$) | A/Z | 6($Ag^{19+}$) | 4($Fe^{16+}$) | 3($Ni^{18+}$) |
|---|---|---|---|---|---|
| $U_{ion}$, eV | 600 | 736 | 512 | 506 | 624 |
| m/Z, MeV | 9315 | 7452 | 5589 | 3726 | 2794 |
| P/Z, MeV/c | 440 | 411 | 357 | 283 | 240 |
| E, MeV/u | 1.0 | 1.4 | 1.9 | 2.6 | 3.4 |
| N, p/p | 6.0x$10^9$ | 6.0x$10^9$ | 8.0x$10^9$ | 9.0x$10^9$ | 8.5x$10^9$ |

## ELECTRODYNAMICS SIMULATION OF THE RESONATORS

The new injector I-3M (see Fig. 2) will consist of two spiral quarter wave resonators. Existing 2.5 MHz spiral two gap resonator will be retuned to 5 MHz and a new one will be constructed. Simulation of the resonators has been carried out by means of CST Studio code [6]. Additional test simulation by the code has been fulfilled for existing resonator I-3, which actual dimensions are well known. Results of the simulation are in very good agreement with rf parameters of existing 2.5 MHz resonator. The test simulation allowed creation of an accurate model for 5 MHz QWR.

Resonator configuration has been modified to get operating resonance frequency, to minimize E-field gradient which limits maximum voltage at accelerating gap, and to minimize transverse field in accelerating gap.

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The width of accelerating gap and length of drift tubes in both resonators provides close to the maximum energy gain for particles with A/Z = (3÷10).

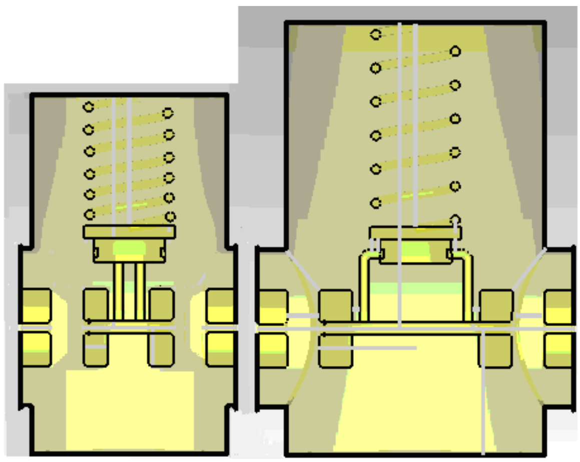

Figure 2: Scheme of I-3M acceleration structure.

Some preliminary parameters of the modified injector I-3M simulated by CST code are given on Table 2.

Table 2: Parameters of I-3M Resonators

| Parameter | First | Second |
|---|---|---|
| Tank height, mm | 2500 | 2970 |
| Tank diameter, mm | 1500 | 1985 |
| Spiral diameter, mm | 700 | 700 |
| Length of solenoid, mm | 1000 | 1500 |
| Number of turns in solenoid | 6 | 6 |
| Length of drift tube, mm | 500 | 1400 |
| Width of acc. gap, mm | 250 | 250 |
| Resonance frequency, MHz | 5 | 5 |
| Voltage at the gap, MV | 3 | 3 |
| Energy gain, MeV | 6 | 6 |
| Quality factor | 5800 | 5960 |
| Power dissipation, kW | 3600 | 3500 |

## OPTIMIZATION OF DRIFT TUBE GEOMETRY

Dependence of electric field gradient from geometrical parameters of the drift tubes has been obtained by POISSON and CST codes in order to get maximum voltage at the accelerating gap. Results of the simulations for the gap voltage $V_g$ = 2 MV from both electrode diameter and radius of its surface rounding are shown in Fig. 3.

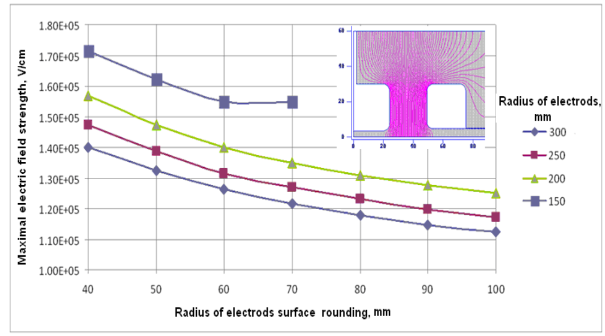


Figure 3: Dependence of E-field gradient from radii of electrode surfaces.

As can be seen from Fig. 3 larger both drift tube and curvature radius allows having lower surface electric field. From this point of view it would be preferable to have both large tube and curvature radius. From one side the larger tube increases capacitance of the channel and hence rf power losses. On other hand, larger curvature radius reducing capacitance allows improving rf efficiency of the resonator. So, optimization of the tube geometry is very important for maximum accelerating field in the gap.

Supposedly, nominal gap voltage in two resonators of the new injector I-3M will be equal 3 MV. Since maximum surface electric field shown in Fig. 2 should be multiplied by factor of 1.5 and it will not exceed 17 MV/m for the case when tube radius $R_{tube}$ = 300 mm and curvature radius $r_{tube}$ = 100 mm. For the moment optimization of the resonator geometry is being continued having the goal to get best rf efficiency.

## CONSTRUCTION OF THE RESONATORS

As it was shown in Fig. 2 acceleration structure of the I-3M injector composes of two resonators. The second resonator will be rebuilt from existing one, operating presently on 2.5 MHz, in which the number of solenoid turns will be reduced as well as the length of drift tube. The geometry of the drift tubes will also be modified to lower E-field gradient for gap voltage $V_g$ = 3 MV.

First resonator with a shortened drift tube has to be designed and built. It is supposed to reduce transverse dimensions of the tank according to optimal βλ/2 as well as its height keeping drift tube geometry similar to those of second resonator in order to have the same gap voltage.

Design of the rf system has been presently begun. Two versions are being considered. First of them supposes self exciting of one of the resonators and matching resonant frequency of another one to its resonant frequency keeping proper phase difference between them.

Such approach may be possible solution taking into account that parameters of the resonators will be similar each other. Another version foresees classical scheme, with master generator and independent tuning resonant frequencies and phases of the resonators.

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## BEAM DYNAMICS OPTIMIZATION

Efficiency of ion beams acceleration in I-3M depends on focusing fields in the first acceleration gap and on optimization of beam matching conditions for longitudinal and transverse motion of particles at the inlet of acceleration structure. Longitudinal matching is provided by tuning of amplitude and phase of RF buncher voltage for getting minimal energy spread in accelerated beam. Optimal beam bunching gives transmission factor 55% for the beam with momentum spread of ±1% and it doesn't depend on beam current.

Transverse acceptance of accelerating structure is determined by the focusing properties of the first accelerating gap and it depend on the current of accelerated beam. Setting of beam transverse focusing is performed by forming the optimal function of accelerating field by proper aligning the position of the screen grid at the entrance of accelerating gap. . Beam dynamics simulation for beam aperture of 70 mm and for the beam current up to 30 mA, gives optimized transverse acceptance of 500 π mm mrad (see Fig. 4).

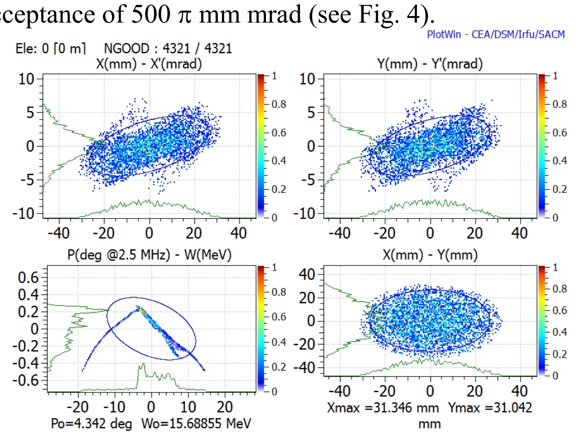


Figure 4: Results of beam dynamics simulation at the output of first resonator for the beam current of 30 mA.

Beam envelope in the first resonator obtained by simulations is shown in Fig. 5.

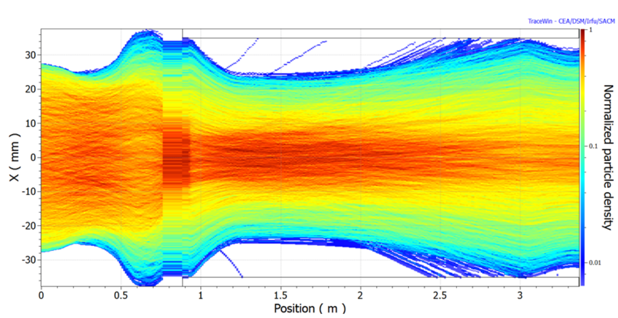


Figure 5: Beam envelope in the first resonator for the beam current of 30 mA.

The increase in the beam current above 30 mA leads to increasing losses of particles due to swelling of the transverse beam size called Coulomb defocusing forces. Dependence of output beam current on input one is shown on Fig. 6.

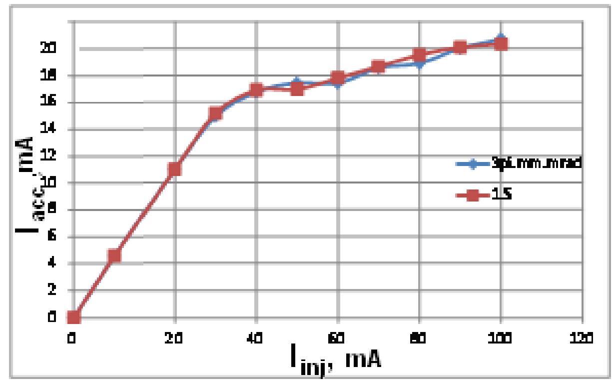


Figure 6: Dependence of input and output beam current for the first resonator.

## CONCLUSION

The planned modernization of heavy ion injector I-3 for ITEP-TWAC Facility will allow to essentially improve all main parameters of accelerated ion beams and, accordingly, to raise efficiency of ion beams acceleration in synchrotron UK.

Proposed accelerating structure of heavy ion injector I-3M with four accelerating gaps and extremely high accelerating voltage on the gap (up to 3 MV) allows getting the high acceleration rate (~3Z MeV/m) for particles with A/Z in the range from 3 to 10.

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[6] https://www.cst.com/support/