INJECTOR OF HIGH-CURRENT MULTICHARGE HEAVY IONS BEAM FOR THE TWAC PROJECT

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Abstract

The work on conversion of ITEP proton synchrotron to installation for heavy ion fusion experiments is now under realization. The constructed installation (TWAC) will accumulate high power heavy ion beams. In frame of the project a new injector capable to accelerate the Co^{25+} ions from the laser ion source up to energy 1.6 MeV/u is required. The 81 MHz RFQ has been designed to satisfy the specific requirements of the installation. The RFQ is based on developed in ITEP "four-ladder" structure. The structure allows constructing of the compact RFQ with low operation frequency. The RFQ based on this structure has more reliable mode separation in comparison with conventional "four-vane" RFQ keeping high RF efficiency. The dynamics in RFQ has been optimized for acceleration of intense heavy ion beam, consisting of mixture of ions with different charge states. The dynamics simulation has been carried out using new developed in ITEP code "DYNAMION". The results of simulation for the real charge spectrum of the ion beam from laser source are presented. The beam dynamics and basic parameters of the RFQ structure are discussed.

1. INTRODUCTION

The TWAC (TeraWatt Accumulator) project [1] at Moscow's Institute of Theoretical and Experimental Physics (ITEP) aims to produce intense heavy ion beams (100kJ/100ns) for a number of research programs connected with of heavy ion fusion physics (HIF). In the frame of this project the existing in ITEP accelerating installations - the UK 13 Tm booster ring, the U-10 34 Tm synchrotron and transfer lines - will be adopted for highly charged ions of atomic mass 40-60. It is supposed that laser ion source $_{59}Co^{25+}$ is considered as main candidate ion. The beam will be produced by a laser source, accelerated in the injector up to 1.6 MV/u, then transferred into the UK booster ring. After acceleration up to 0.7 GeV/u, a 250 ns bunch will be transferred in a single turn to the U-10 synchrotron through a stripping foil and will be storaged in synchrotron ring without acceleration.

To achieve of the design TWAC parameters the beam of the Co^{25+} ions with current not less than 20 mA and small emittance and pulse spread is required. Obtaining of such a beam is a sophisticated problem, the cost of the ions will be very high and their losses have to be prevented. Consequently the injector for the TWAC project must operate by such a way that the beam quality will not deteriorate between ion source and booster ring.

The existing in ITEP two gaps resonator U-3 will be in use as the injector on the first step of the installation commissioning. The beam can be accelerated in this resonator up to energy 1.6 MeV/u, however pulse spread of the particles at its output will be very large and cause the particle losses in the transfer line between the injector and the UK ring to a great extent.

The linear accelerator with RFQ structure is only one choice to have the beam with required parameters. Much work has been carried out at ITEP during several years for the development of the RFQ structures to accelerate intense heavy ion beams. The structure for high intensity RFQ must allow to preserve the injected beam brightness, therefore the field distribution should be free from dipole components. Moreover, the structure must be easily tunable, and a reliable stabilization of the operational mode should be provided. One of the new structures proposed in ITEP was chosen for the TWAC injector. This structure is the version of the so-called "4-ladder RFQ", based on a 90^0-apart-stem geometry [2].

2. BEAM DYNAMICS

The initial parameters of the injector design are listed in Table 1.

Table 1: Beam parameters.

Charge to mass ratio	1:3
Input energy, MeV/u	0.02
Output energy, MeV/u	1.6
Pulse repetition, Hz	1
Pulse duration, ms	0.1
Current of Co^{25+} ions, mA	20
Total current, mA	70
Acceptance, cmmrad	0.2
Transmission of Co^{25+} ions	≥85%

The beam at the output of the laser source is a mixture of ions with different charge states. Charge spectrum of the Co ions presently is still a question and charge spectrum of the Al ions experimentally measured at laser source output has been taken for simulations. It is clear that the parameters of RFQ depends very much of the using or not ions separation at its input. The RFQ can be designed with considerably lower current limit if only one kind of ions is accelerated. It is clear that in this case RFQ could work at higher operation frequency.

However, preliminary calculations shown, that there is no point of the beam separation at the input of the RFQ due to significant degradation of the beam parameters in the magnetic elements of the LEBT. This circumstance is due to heavy ions with energy corresponding RFQ input have relative high transverse velocities (β_x/β_z= 0.05÷0.1). This fact causes remarkable coupling between degrees of freedom of the particles motion, which can not be neglected.

The alternative is the direct injection of the laser source beam into RFQ without any magnetic elements in LEBT. It allows to keep beam parameters, however the mixture of ions with different charge states will be accelerated in RFQ and effects of presence in the beam ions with different charges should be investigated.

It is clear also that the abandonment of the beam separation at the RFQ input results in increasing of the mean beam current more than once in comparison with acceleration ions of the basic charge. This circumstance has an radical impact on the RFQ parameters choice and it should be designed with significantly higher current limit.

To provide high efficiency beam transportation using existing magnetic elements in between RFQ and the booster ring the pulse spread of the beam at RFQ output should be as small as possible and this should be taking into account in RFQ design.

Development and optimization of the injector design were carried out by recently elaborated in ITEP a simulation code "DYNAMION". The main objective to develop this code was to increase a reliability of high current low energy beam dynamics simulation in a "real" fields. The above objective is achieved by particle motion equations used in the most general type without any simplifications and with taking into account real interaction of moving particle with 3-dimensional electromagnetic fields. It is especially important for low energy beam when transversal velocity of particles is comparable with longitudinal one. In heavy ion linacs this ratio between them reach up to 10%. It is clear that it considerably influences on beam dynamics.

The another important feature of the code is the possibility to simulate the motion of the mixture of particles with different charge states.

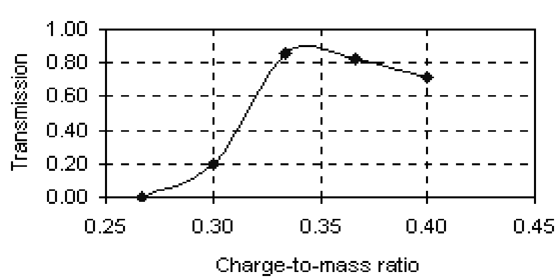

Figure 1: Transmission of ions with different charge states.

The simulations of particle motion in RFQ carried out for symmetric charge spectrum of Al ions with five charges (8+, 9+, 10+, 11+, 12+) and corresponding weights 0.4, 0.7, 1.0, 0.7, 0.4. Total current of the beam was 70 mA. The calculated transmission for different ions is shown on Figure 1. From this figure we notice that the losses of ions with design value of charge to mass ratio (Z/A=0.3) does not exceed 15%. The transmission of ions with lower charges rapidly decreases. It is because the ions with charges lower than basic value drop out of the resonant acceleration and do not form a stable bunches. Practically no ions with these charges have nominal output energy. The motion of the ions with higher charges is stable both in longitudinal and in transverse planes. The transmission of such ions is only few percents lower than for the basic ions. The difference appears because the ions with higher charges have different frequencies of

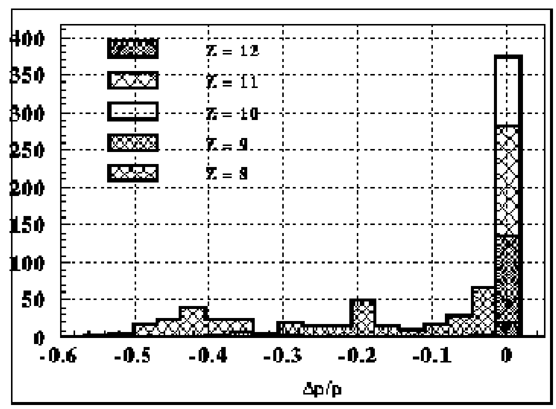

Figure 2: Pulse spreads of the beams with all charge states.

transverse oscillations in comparison with basic one. It means that its motion is slightly mismatched.

Pulse spreads of the ion beam with all charge states are shown on Figure 2. It can be seen, that particle energies and pulse spreads for the different beam species

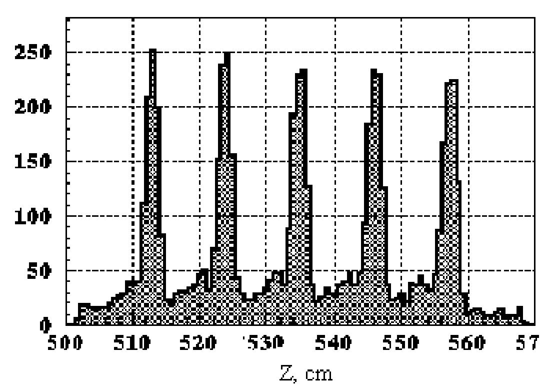

Figure 3: Particles density distribution in RFQ.

coincide thus these ions can be efficiently transported to accelerating ring.

The simulations shown that availability of the unaccelerated particles result in the reduction of peak to average currents ratio, that reduces Coulomb effect. The particle density distribution for the five last RFQ cells is shown on Figure 3.

It can be seen from this figure, that the effective peak current for mixture of ions is approximately 30% lower than for beam with single charge state.

In Table 2 the calculated parameters of RFQ are presented.

Table 2: The injector design parameters

Radio frequency, MHz	81.4
Voltage, kV	180
Peak E-field on the electrode surface, Kilpatric units	2.0
Average aperture R_0, cm	1
Beam energy, MeV/u	0.02÷1.6
Relative velocity	0.00653÷0.05827
Number of cells	159
Full length, cm	593
Modulation factor m	1.0÷2.5
Synchronous Phase φ_s	$-90^0 \div -25^0$
Aperture a, cm	1.0÷0.5714
Transit-time factor	0.00÷0.549
Acceptance, mmmrad	27.79÷5.11÷5.20
Phase advance, rad	1.13÷1.00÷1.28
Tune depression at 70 mA	10%

3. RESONANT STRUCTURE

Well-known 4-vane structure is often used for high current RFQ. In general, it has good mechanical rigidity, it is simple in manufacture and has relatively high shunt-impedance. Nevertheless 4-vane RFQ has one principal lack - weak magnetic coupling between neighboring quadrants. As a result the unwanted dipole modes usually located near operating quadruple mode, which causes the tuning problems.

The resonant structure recently developed in ITEP allows to avoid above mentioned problem. This structure is the version of the so-called "4-ladder RFQ", based on a 90^0-apart-stem geometry. The main advantage of the structure is that it provides better frequency separation between operating quadruple mode and dipole modes. The stabilization of field distribution is achieved by gaining of the magnetic coupling between neighboring quadrants. The numerical simulations and measurements on cold model showed that the nonuniformity of the fields both along axis and in azimutal direction does not exceed 1% with very moderate requirements to accuracy of manufacture and assembling.

Very important feature of the structure is that there is some freedom in choice of its outer diameter. It allowed us to use existing vacuum tanks.

The mechanical design of the structure is quite simple: rings with two stems jointed with the longitudinal bars present spatial balk construction. Copper electrodes are placed on rigid basements, connected with stems (vertical or horizontal) in series. Each spatial period of the structure is formed by stems of the two rings with same

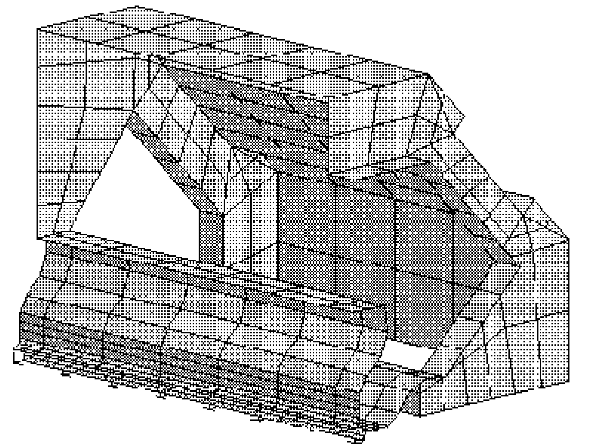

Figure 4: Finite elements model of 1/2 period of the structure in "OPERA-3D" code.

orientation. All parts of the structure are manufactured from copperplate aluminum alloy. Only exceptions are electrodes and shell that were made from oxygen free copper.

The resonant structure for TWAC injector has been designed using "OPERA-3D" code. A part of the structure used for simulation is shown on Figure 4. The main design parameters are presented in Table 3.

Table 3: RFQ structure parameters

Resonant frequency, MHz	81.4
Outer diameter of the structure, m	0.49
Length of the structure, m	6
Window size (width x height), m	0.645x0.151
Dipole modes, MHz	98
Q-value	13920
RF losses (at 180 kV voltage between electrodes), kW	387

Given in the Table 3 outer diameter and length of the RFQ are determined by existing vacuum tank. The nearest mode is very far from operation frequency.

REFERENCES

1. VA Andreev, G. Parisi, "90^0-apart-stem RFQ Structure for Wide Range of Frequencies". PAC'93, Washington, D.C., May 1993, p. 3124.

2. B.Yu. Sharkov, "TeraWatt Heavy Ion Beams", CERN Courier, Vol. 38, may 1998, p.16.