ITEP TWAC STATUS REPORT

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Abstract

Three years of successful operation the ITEP-TWAC facility delivers proton and ion beams in several modes of acceleration and accumulation of by using the multiple charge exchange injection technique [1]. Substantial progress is achieved in output ion beam current intensity of the linear injector I3, in intensity of the buster synchrotron UK, in efficiency increasing of ion beam stacking and longitudinal compression in the storage ring U10. The machine status analysis and current results of activities aiming at subsequent improvement of beam parameters are presented.

INTRODUCTION

The upgrading of the ITEP's 10 GeV Proton Synchrotron U-10 for the heavy-ion Accelerator-Accumulator ITEP-TWAC Facility was started in 1997 [2]. The basic project parameters of the complex are given in Table 1.

Table 1: Project parameters of the ITEP-TWAC Facility

Operation mode	Beam parameters	
Proton Accelerator	Energy, GeV	10
	Intensity, c^{-1}	10^{11}
Ion Accelerator	Accelerated ions	to U
	Energy, GeV/amu	2-4
	Intensity, n/c	10^{11}
Ion Accumulator	Accumuletad ions	to Zn
	Particle energy, MeV/amu	to 700
	Beam energy/power, kJ/TW	100/1

Technological scheme of the heavy ion facility was commissioning and experiments started with carbon beam acceleration and accumulation in 2003. The 4 MV ion linear injector I-3 was built [3], a booster synchrotron UK was put into operation [4] and a multiple injection of ions from the UK into the U10 ring using charge exchange injection technique was realized [5]. Several modes of machine operation are now in using for experiments and applications: secondary beams generation in internal targets by proton and relativistic carbon beams, fast extraction of proton and carbon beams with momentum of up to 3Z GeV/c, fast extraction of stacked and compressed carbon beam with energy of up to 400 MeV/amu. Slow extraction system is now under construction to be started for operation at the beginning of next year.

Main milestones of the TWAC project first stage were gone past in general successfully outlining shortcomings and limitations in the used schemes and equipment components [5-6].

LASER ION SOURCE DEVELOPMENT

Our experience with laser ion source in application to the linear accelerator I3 is restricted now in generating of only one type of ions (C^{4+}) using the 5J CO_2 laser. More powerful laser ion source is now under construction on the base of 100J CO_2 laser to be used in operation at the end of this year. Main features of laser ion source construction are given in [8]. Different extraction system geometries have been tested to obtain as high as possible yield of C^{4+} ions at the input of the I3 injector. The highest yield of ions was found for the largest extraction aperture, 80 mm, and removing the beam focusing between two grids installed in the first and the second electrodes. The beam total current measured at the extraction system outlet reaches now >250 mA at current density of >20 mA cm^2 as can be seen at the top of Fig.1. The charge state distribution changed along the beam pulse are shown lower for the first, second, and third peaks of beam current. It's seen that the 2/3 of beam width (~10 μs) contains the C^{4+} ion component as dominated.

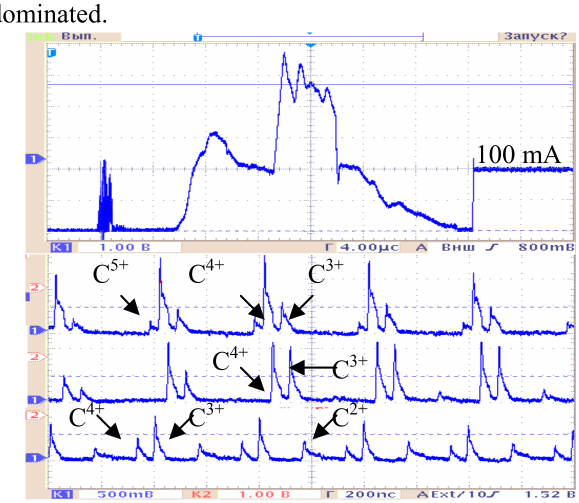

Figure 1: Carbon ions beam at the outlet of the 5J-CO_2 laser ion source.

INJECTOR I-3 MODIFICATION

The linac I-3 with two accelerating gaps is not ideal injector for the high intensity synchrotron because of the low accelerating frequency (2.5 MHz) and the high on-off time ratio for beam bunches [2]. But it has advantages over conventional ion injectors. They are both, high rate of acceleration in the first gap (2 MV per 0.2 m) and non-resonance acceleration of practically any type of ions.

The last modification concerns the bunching system for matching dynamics of the charge density increase with focusing properties of the first accelerating gap in resonator. As a result of this work, the accelerated C^{4+} beam current observed after analyzing magnet has been increased by factor of 3-4 up to the value of 6-7 mA. The structure of this beam is formed of very short (~5 ns) bunches with the very high (~400 mA) amplitude. This beam can't be transported to the booster synchrotron without particles loss through the existing 40 m ion-guide which has to be reconstructed.

BEAM ADIABATIC TRAPPING IN BOOSTER SYNCHROTRON UK

Speciality of longitudinal beam dynamics in the UK ring arises from the super high local charge density at low bunching factor of the linac I-3 beam at injection to the synchrotron ring, requiring debunching in the coasting beam, following the RF ramping for the ideal adiabatic trapping and acceleration of the captured beam up to the maximum energy [9]. This process is illustrated by oscillograms on Fig.2. The bem loss of ~20% at the RF amplitude ramp arises from some exceeding of longitudinal acceptance by injected beam phase volume and transition dropping of RF amplitude.

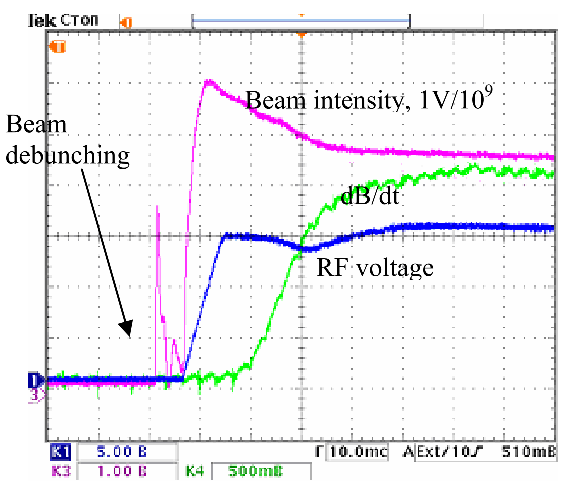

Figure 2: Adiabatic trapping of the beam in booster synchrotron UK.

STORAGE RING DYNAMIC APERTURE STUDIES

The lattice and the magnetic field quality of the U10 ring were constructed for the beam acceleration but not for the beam accumulation requiring the essentially different life time for the beam. But, the ring dynamic aperture studying by simulation [10] shows that decrease of the ring acceptance from the known magnetic ring perturbations is not so large and the value of 100 π mm mrad for the stacked beam emittance in both planes seems to be achievable. But experiments with the beam stacking shows that the real ring acceptance is the order of less. To estimate the resonance's width, we have measured the function of the stacked beam intensity on the tune shift for the beam injected into the small size sepratrix outlining the beam spot of $(2x8)10^{-3}$ size on the $(Q_x x Q_z)$ plane . The optimized working point was localized in the vicinity of the sextupole resonance $3Q_z=28$ and it has been changed using the tune shift correction system of the U-10 ring. As can be seen on the Fig.4, the top of intensity localized in the middle of resonance's four-angular is sharp enough and the sum resonance's of up to five order of magnitude are critical for the stacking beam.

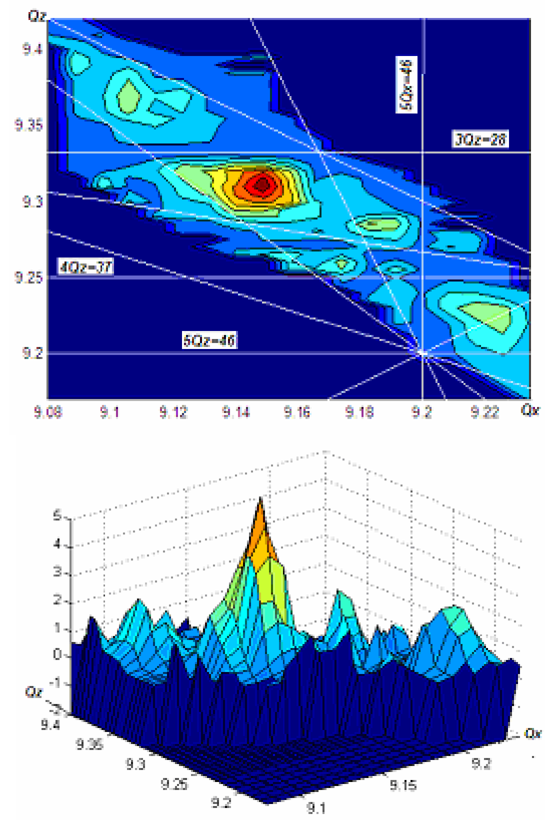

Figure 3: The function of stacked beam intensity on the working point.

ACCUMULATION PROCESS OPTIMIZATION

The ion accumulation procedure is based on the charge-exchange injection with using a fast bump system for minimising the stacked beam perturbation over penetrating through the stripping foil material [5]. Parameters of the stacked beam achieved in accumulator ring U10 are listed in Table 3. The injection efficiency is now limited by the rise time of the pulse in the UK ejection kicker magnet and some particle losses (~10%) in beam transfer line between booster and accumulator rings. The efficiency of beam stacking is near to absolute for particles crossing stripping foil. The maximum intensity achieved last time in the booster synchrotron has not yet been used in the mode of beam accumulation so we have possibility to increase the stacked beam intensity in the next accumulator run by factor of two. The process of the beam accumulation is shown on Fig.4.

Table 3: Parameters of the C^{6+} beam stacking

	Realized	Expected	Plans
Energy, MeV/amu	200	400	700
Injection rep. rate, Hz	0.3	0.5	1
Booster UK intensity, ppp	$\sim 10^9$	$\sim 3\ 10^9$	$\sim 10^{10}$
Momentum spread, %	±0.04	±0.03	±0.02
Emittance, π mm·mrad	~5	~3	~3
Injection efficiency, %	~50	~80	~80
Beam stacking efficiency,%	>90	>95	>95
Stacked beam intensity	$>3\cdot 10^{10}$	$>2\ 10^{11}$	$>10^{12}$

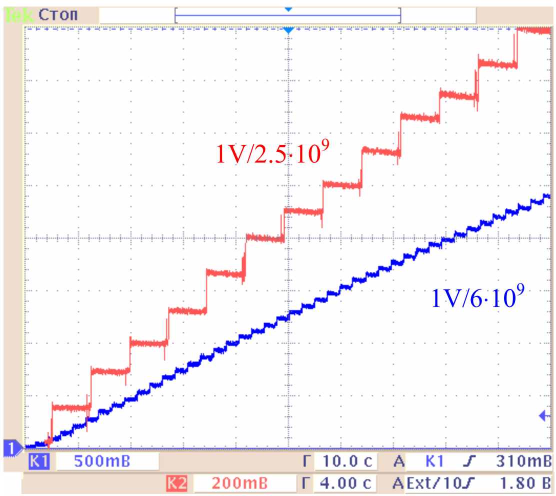

Figure 4: Steps of beam stacking in the U-10 Ring.

The efficiency of accumulation process is characterized by lifetime of the stacked beam with fast bump system on (τ_Σ) and off (τ_o) [6]. Using equality τ_o=25·$A_{x,z}$, we get estimation of the accumulator ring dynamic acceptance as $A_{x,z}$ ~ 12 π mm·mrad. Designating δA as acceptance reduction from the orbit displacement by the fast bump at injection, and considering equality $(\tau_o\tau_\Sigma)/(\tau_o-\tau_\Sigma)$= 20($A_{x,z}$-δA), it gets estimation of δA ~ 2 π mm·mrad. The factor of stacked beam losses at injection of a new portion of particles is calculated as $\delta=(\tau_o-\tau_\Sigma)/(f_{inj}\tau_o\tau_\Sigma)$=0.005, and the factor of stacking intensity increase is equal to $k_\infty=(f_{inj}\tau_\Sigma)$ ~70.

LONGITUDINAL COMPRESSION OF STACKED BEAM AT EJECTION

The stacked beam longitudinal compression is fulfilled with the 10 kV accelerating resonator which is used also with low voltage (~1 kV) for the beam keeping at the process of its accumulation. Due to the Non-Liouvillian saving of the longitudinal phase space for the stacking beam at multiple charge exchange injection, the particle density seems to be maximal after compression and the grade of compression depends on a beam forming in the booster synchrotron at its acceleration and ejection. Result of beam compression up to the pulse width of 150 ns is illustrated on Fig. 5.

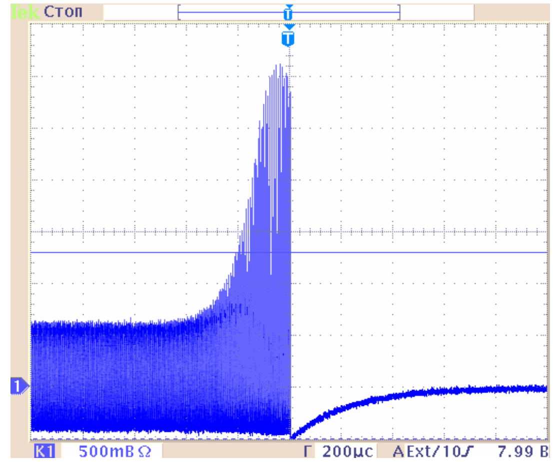

Figure 5: The bunch density increase at compression.

IONS ACCELERATION UP TO RELATIVISTIC ENERGY

The mode of Relativistic Ion Facility was realized using synchrotron U-10 as the Main Ring with Booster synchrotron UK as its Injector and modifying of charge exchange injection scheme for the ramping magnetic field in the U-10. The maximum energy 4 GeV/amu has been achieved for the carbon nucleus with intensity of $3\cdot 10^8$ ppp [11].

CONCLUSION

Summarizing the current status of the ITEP-TWAC project, it should be noted that essential progress has been achieved for the machine parameters in three years after it's commissioning. The problem of the booster synchrotron intensity increase is now the main one and it will be partly overcame by means of beam treatment components improvement from the ion source to the booster synchrotron ejection system, but it'll be cardinally solved with the new injector I-4 installation.

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