EXPERIMENTS WITH CARBON IONS ACCUMULATION IN THE ITEP-TWAC STORAGE RING

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Abstract

The ITEP-TWAC Facility is in two years of experiments with accumulation of fully stripped carbon ions of near relativistic energy (200-400 MeV/amu) by using the charge exchange injection technique. First stacking of the beam has been obtained in the storage ring U-10 in 2002. Adjustment of the multiple injection conditions, the magnetic field correction, and diminishing of disturbing influence of the relevant equipment components to the coasting beam let to gain an injected beam intensity by factor of fifty to reach the level of $2 \cdot 10^{10}$ stacked particles. Current results of activities for the accumulation process optimisation are presented.

INTRODUCTION

The upgrading of ITEP's accelerator complex with the aim of creating a heavy-ion accelerator-accumulator ITEP-TWAC on the base of U-10 proton synchrotron was started in 1997 [1]. In modifying the proton synchrotron into a heavy-ion accumulator, the existing proton-beam acceleration technology was retained, and an opportunity to accelerate ions in the U-10 up to relativistic energies was also provided. The basic project parameters of the complex are presented 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, kJ	100
	Beam power, TW	1

The first stage of the reconstruction is completed with the result that the technological scheme of the new facility is fully created to do experiments with carbon beam accumulation using charge exchange injection technique. During the reconstruction, a 4 MeV/amu ion linear injector I-3 was built [2], an ion booster synchrotron UK was started up [3] and a multiple injection of ions from the UK into the accumulator ring, converted from the U-10 proton synchrotron, was realized [4-8]. The adjustment work had resulted in stacking of the carbon nuclei in the U-10 ring at an energy of 200 MeV/amu, as well as their acceleration in the U-10 up to an energy of 4 GeV/amu [8]. The intensity of the stacked carbon nuclei beam reaches presently $2x10^{10}$ particles, with the factor of 50 for the injected beam intensity increase. The stacked beam is compressed in the longitudinal direction and extracted into a transport channel to be used in experiments.

MULTIPLE INJECTION LAYOUT

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. Schematic layout of the beam trajectory at injection and the injection elements are shown in Fig.1.

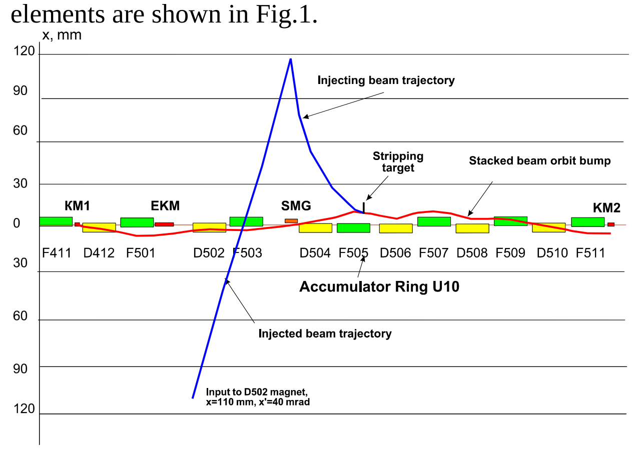

Fig.1: The ion beam trajectory at injection from booster synchrotron UK to accumulator ring U-10.

The septum magnet SMG with magnetic length of 0.8 m is placed outside of the U10 ring between magnets F503 and D504. This magnet is used not only for the beam injection but for extraction too. The SMG steers the injected beam to the centre of the stripping foil of the 10x20 mm size, which is placed in the vacuum chamber of the F505 with displacement of 20 mm from the ring equilibrium orbit. The fast bump system matching of both injected and circulating beams includes three kicker magnets installed in the short straight sections after of the magnets F411, F511 and F711. The first kicker magnet gives the kick of ~3 mrad deflecting the stacked beam to the stripping foil at a moment of the injected beam passing through the transfer line. The two beams becoming one after passing through the stripping foil are set to the ring orbit downwards by the kicker magnets in straight sections of F511 and F711. The foil material is mylar with the thickness of 1.5 mg/cm^2.

There are many factors to be responsible for the charge exchange injection effectiveness. Some of them are raised from the beam interaction with the stripping foil material; others are depended on vacuum and beam stability conditions in accumulator ring. Parameters of the stacking beam are listed in Table 2. The calculated values of the beam interaction with the stripping target parameters are presented in Table 3. As can be seen from this table, the

Table 2: Parameters of the stacking beam

Type of ions	C^{4+}=>C^{6+}
Energy, MeV/amu	200
Momentum spread, %	±0.04
Emittance, π mm·mrad	~5
Beam intensity, ppc	~$5\cdot10^{8}$

beam loss factor is less than 10^{-4}, so it can be neglected. The momentum spread increase may be essential, but in our case it can be not taken into account because of the beam stacking with accelerating voltage of ~1 kV that matched with momentum spread of the injected beam.

Table 3: Parameters of beam interaction with the target

x_t, mg/cm^2	1.5
σ_l, barn	2
$\overline{\delta x'^2}$, (rad)^2	10^{-8}
$\overline{\delta p/p}$	$5\cdot10^{-5}$
$\overline{\delta\varepsilon}$, π mm·mrad	0.15
$\overline{\delta Q_x}$	$4\cdot10^{-4}$
$\overline{\delta Q_z}$	$1\cdot10^{-3}$

Emittance increase by the multiple coulomb scattering is the main factor of beam loss at interaction with the stripping foil. The beam lifetime for parameters from table 3 is estimated by the value of ~$20\cdot A_{x,z}$ [s].

The beam lifetime in the real machine depends not only on the particles interaction with the target but on the vacuum and beam stability conditions in accumulator ring too. Summarizing the beam disturbing factors listed in Tables 4-5 we got the estimated beam lifetime as ~$25\cdot A_{x,z}$.

Table 4: Beam interaction with residual gas parameters

P, Torr	10^{-8}
x_v, mg/cm^{2}s	0.2
$\overline{\delta x'^2}$, (rad)^2/s	$1.5\cdot10^{-9}$
$\overline{\delta p/p}$, s^{-1}	$7\cdot10^{-6}$
$\overline{\delta\varepsilon}$, π mm·mrad/s	0.02
$\overline{\delta Q_x}$	$4\cdot10^{-5}$
$\overline{\delta Q_z}$	$1.5\cdot10^{-4}$

As can be seen from the working diagram of the U-10 ring shown on Fig.2, there is two accessible regions of beam stability between betatron stopbands of third, forth and fifth orders. The stable spot of the beam tune shift

Table 5: Parameters of U-10 magnet imperfections

Pulsed magnetic fields of beam transfer line UK/U-10	$\delta r<10^{-3}$, $\delta Q<10^{-3}$
p kicker magnets	$\overline{\delta\varepsilon}$ ~10^{-2} π mm·mrad
Imperfection from UK magnetic cycle	$\delta B/B<10^{-4}$, $\delta Q<10^{-3}$
The orbit distortion from the fast bump	δA_x~10-20 π mm·mrad
Ripples of power supplies of main magnet and correction circuits	$\delta B/B$~$1.5\cdot10^{-5}$, δQ~$3\cdot10^{-4}$

$\Delta Q_x x \Delta Q_z=(2x8)\cdot10^{-3}$ occupied by the injected beam is small enough and should be changed by moving the working point to the free space of top-right square.

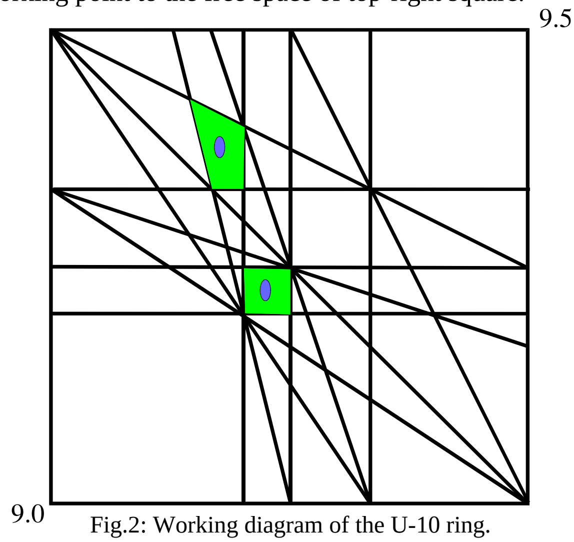

Fig.2: Working diagram of the U-10 ring.

EXPRIMENTAL RESULTS

First beam accumulation was obtained in March 2002. Subsequent improvement of the charge exchange injection technique and the quality of accumulator ring let us to rise beam stacking stability. The beam transfer from booster synchrotron UK to the accumulator ring U-10 is shown on Fig. 3. It's seen that only six bunches from tens in the UK ring are transfered to accumulator ring due to the small

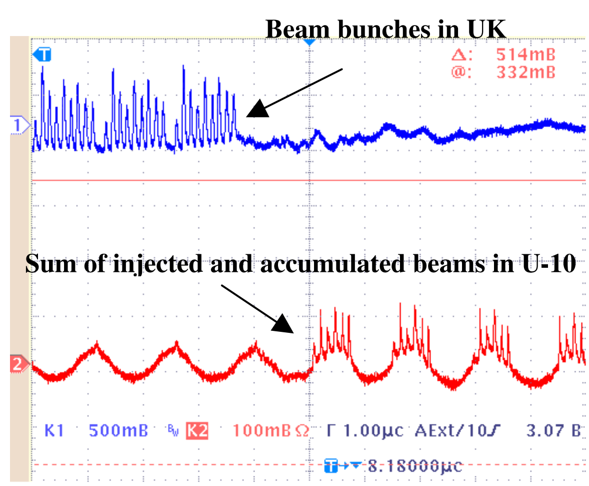

Fig.3: Beam transfer from UK to U-10.

width of fast bump pulse that is shorter than revolution time of the beam. This discrepancy should be eliminated by longitudinal compression of the beam before ejection. We had successfully tested methodic of beam compression on the raising magnetic field in the UK ring ency increase because of the momentum spread and tune shift extension. We hope to get positive result after im correction system and changing the working point.

The stabilized process of the beam accumulation is shown on oscillograms of Fig.4-6. It' seen linear increase of the stacked beam intensity during more that thirty injection cycles. This is result of successive stabilization a

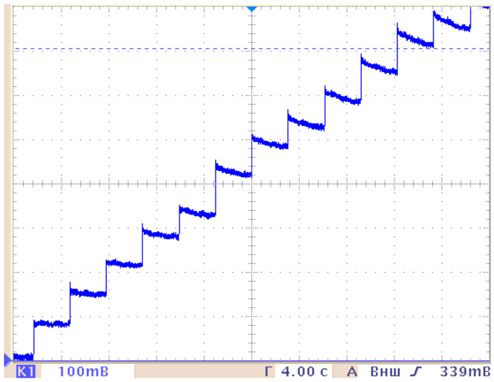

Fig.4: The start of beam stacking in U-10.

whole lot of elements on the way from laser ion source to stripping foil. Reduction of the intensity growth rate coursed by growing loss of stacked particles leads to the saturation of the stacked beam intensity. As can be seen from Fig. 6, the level of saturated intensity is more than 50 times of injected one.

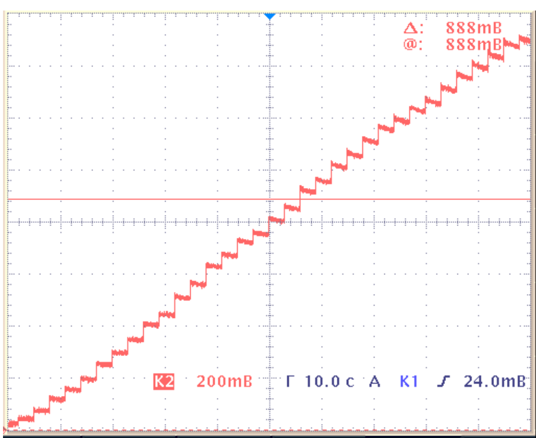

Fig.5: The linear increase of stacked beam intensity during more than 30 injection cycles($1V/10^{10}$).

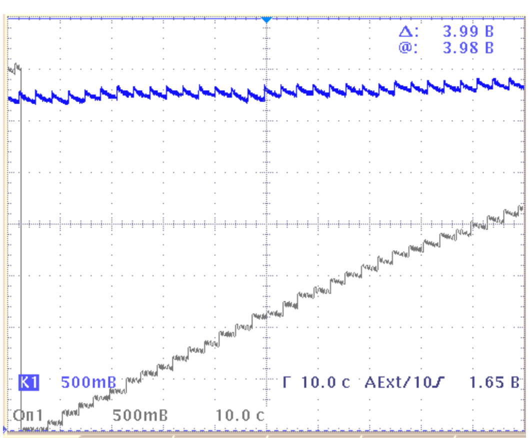

Fig.6: Saturation of the stacked beam intensity on the level of $2 \cdot 10^{10}$ particles.

factors contribution to the beam loss rate can be done measuring the beam lifetime at the fast bump to be on and off. Results of these measurements at some preliminary state of machine and vacuum in the accumulator ring of $\sim 10^{-8}$ Torr are shown on Fig. 7. Using equality $\tau_o = 25 \cdot A_{x,z}$, we get estimation of the accumulator ring dynamic acceptance as $A_{x,z} \sim 10\ \pi$ mm·mrad. Designating δA as acceptance reduction from the orbit

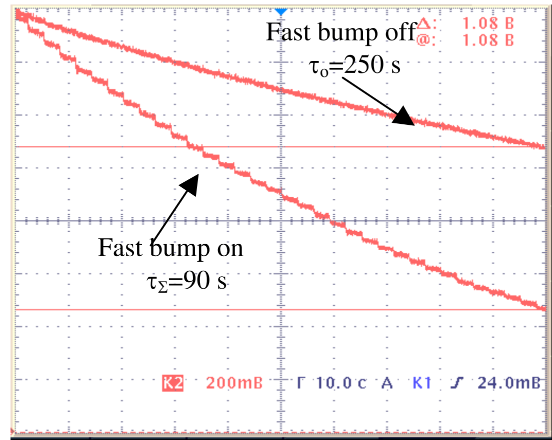

Fig.7: The stacked beam loss time.

displacement by the fast bump at injection, and considering equality $(\tau_o \tau_\Sigma)/(\tau_o - \tau_\Sigma) = 20\ (A_{x,z} - \delta A)$, it estimates $\delta A \sim 3\ \pi$ mm·mrad. For the intensity growth shown on Fig.5-6, the beam lifetime is $\tau_\Sigma = 150$ s that was reached by reducing the value of δA.

CONCLUSION

1. Experiments with carbon ions accumulation in the U-10 ring demonstrated the progress in the accumulated beam intensity that is fifty times the intensity of injected beam.
2. Further advance in intensity is expected from improvement of vacuum in the ring, decrease the stripping foil thickness and elimination of difference in the waveforms of the fast bump kickers.
3. The accumulator acceptance and momentum spread of accumulated beam are limited now through irregular setting of working point because of the settling problem of the tune shift correction limit.

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