

# ITEP-TWAC STATUS REPORT

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## Abstract

The ITEP-TWAC facility is in operation of 4000 hours per year with proton and heavy ion beams in several modes of acceleration and accumulation. The new configuration of laser ion source with 100J CO<sub>2</sub>-laser has been started to use for Fe-ion beam generation at the input of the pre-injector U-3 delivering separated species of Fe<sup>16+</sup> ions with energy of 1.1 MeV/u to booster synchrotron UK for acceleration up to the energy of 165 MeV/u and accumulation in the storage ring U-10 using multiple charge exchange injection technique. Some progress is achieved also in extension of experimental area and multi-purpose utilizing of machine to be used in a time sharing mode and running in parallel of several experiments and routine operation with various beams for a number of users. The machine status analysis and current results of activities aiming at both subsequent improvement of beam parameters and extending beam applications are presented\*.

## INTRODUCTION

The ITEP-TWAC Facility runs in three operation modes accelerating protons up to the energy of 9.3 GeV, accumulating nuclei at the energy of 200-300 MeV/u and accelerating ions and nuclei up to the energy of 4 GeV/u. The total operation time of machine in 2007 is 3936 hours (in 2006 – 3088 h), divided between operation modes as the following: 2268 h of protons acceleration, 828 h of carbon nuclei accumulation, 648 h of carbon nuclei acceleration up to relativistic energies. Distribution of ITEP-TWAC between different research fields and applications in 2007-2008 is given in Table 1.

Table 1. Operation of ITEP-TWAC for different subjects.

Research fields and applications	Beams	Operation time, hours		
		2007	2008	Req.
Relativistic nuclei physics	p,C, ...	1030	1200	1000
Methodical research	p,C, ...	1338	1500	2000
Physics of high density energy in matter	C,Al,Fe,Zn	344	350	500
Radiobiology	p,C	2520	2350	5000
Proton therapy	p			
Ion therapy	C	0	0	
Radiation treatment of materials	p,Fe,Sn,U	802	1200	6000
Total		6034	6600	14500

It can be seen in this table the trend of machine operation time increase for applications of proton and ion beams in biology, medicine and radiation treatment of materials. The required beam time for users exceeds the possible one by factor of two. This discrepancy has to be eliminated in a result of machine infrastructure development and extension of its experimental area.

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The ITEP-TWAC development for a progress in extreme beam parameters proceeds to increase of accelerated and stacked beam intensity as well as to raising of compressed beam power and to ion species extension on the base of laser ion source technology advancement.

The 100J CO<sub>2</sub>-laser system, based on a Master Oscillator – Power Amplifier (MO-PA) configuration has been designed, constructed and tested for the first time at CERN in 2003 [1,2]. Afterwards this laser has been moved to ITEP to be re-assembled for using in the TWAC Facility. For the first step of this work, the PA configuration of laser operated in free-running regime has been assembled to start testing the TWAC facility with heavy ions of up to A ~ 50.

## DEVELOPMENT OF ITEP-TWAC INFRASTRUCTURE

Experimental area of ITEP-TWAC facility (Fig.1) includes now five zones of beam utilizing. Two of them are secondary beams of internal targets installed in second and third periods of U10 lattice. Two another's are fast extracted beams from U10 ring to the target hall and to the building for medical applications. The 25 MeV beam of linac I2 is used in parallel for both injection to synchrotron U10 and different applications.

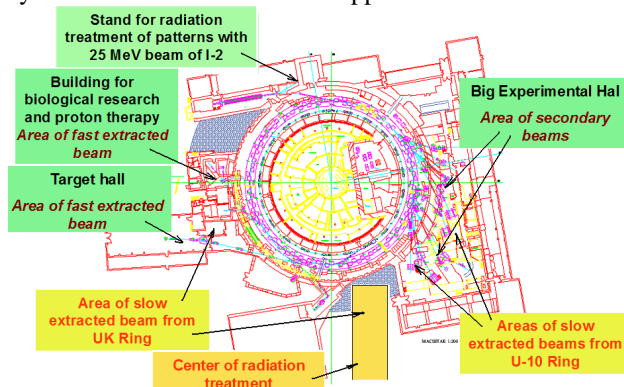


Figure 1: Experimental area of ITEP-TWAC facility, green - in operation, yellow – in projecting.

Extension of experimental area is planned on construction in two slow extracted (SE) beams from U10 and UK rings as shown in Fig.1. First SE system for beam extraction from 203-blok of U10 ring (Fig.2) has been constructed and its testing is now going on. Second order resonance in vertical plane is excited by single sextupole for beam extraction to existing beam transfer lines which are used also for transfer of secondary beams generated in the 203 internal target.

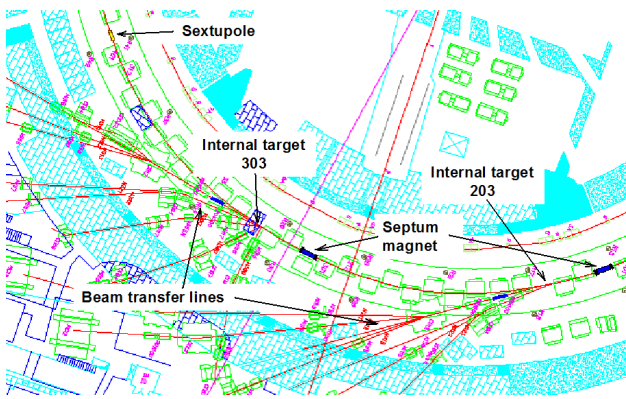


Figure 2: Slow extraction system of U-10 ring.

Continuous extraction of carbon nuclei beam stacked in the U10 ring is shown in Fig.3. The working point of storage ring in this mode of beam extraction has been set near sextupole resonance so circulating particles scattered on molecules of residual gas and in stripping foil putting on unstable trajectories to be extracted.

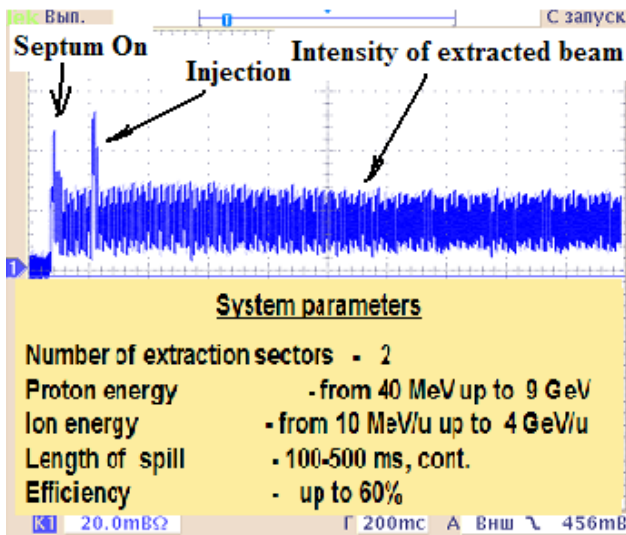


Figure 3: Extraction carbon beam accelerated in the UK ring up to the energy of 200 MeV/u at repetition rate of 0.25 Hz using U10 ring as stretcher.

### THE 100J CO<sub>2</sub>-LASER RUNNING FOR Fe-ION BEAM PRODUCTION

The new LIS optical scheme described in [4,5]. The typical laser radiation pulse at the free-running regime of laser operation is characterized by the sharp spike of 150 ns at the pulse front and a long low intensity radiation tail of 1-2 μs duration that contains up to 60% of the total laser pulse energy. Stretching in time the radiation energy investment to the target results in low-charge state ions domination in a generated ion beam and intensive evaporation of a target material.

Typical signal of ion beam extracted from laser plasma in Fe-target and measured at the extraction gap outlet shows (Fig.4) the presence in the beam the high current pulse of charge particles passing through the extraction gap before Fe-ions. This forward pulse of ions is created

in vacuum chamber by X-rays emitted from plasma spot on the target and ionizing residual gas.

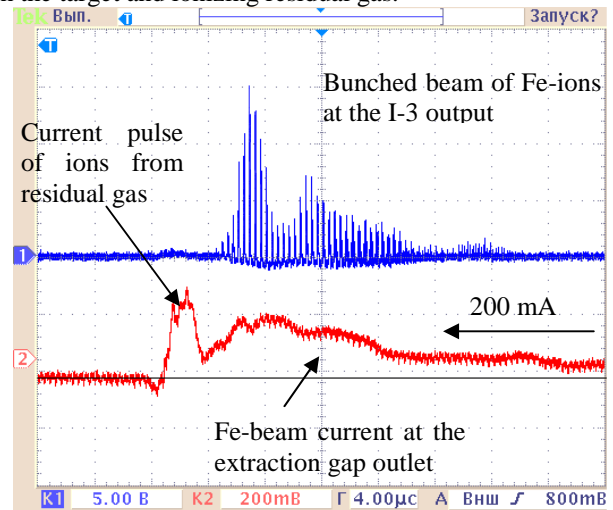


Figure 4: Signals of Fe-ion beam generated in LIS.

It can be seen in Fig.5 that Fe-ions of only few charge states of 14-16 are there at the head of beam pulse generated in LIS. Charge states of Fe-ions at the second vertex of the total beam current pulse are found in the expanded range of values from 12 to 16.

The total number of Fe-ions of charge states from 12 to 16 is estimated by the value of  $\sim 10^{12}$ , the number of Fe<sup>16+</sup> ions at the head of the beam pulse is order of  $5 \times 10^{10}$ .

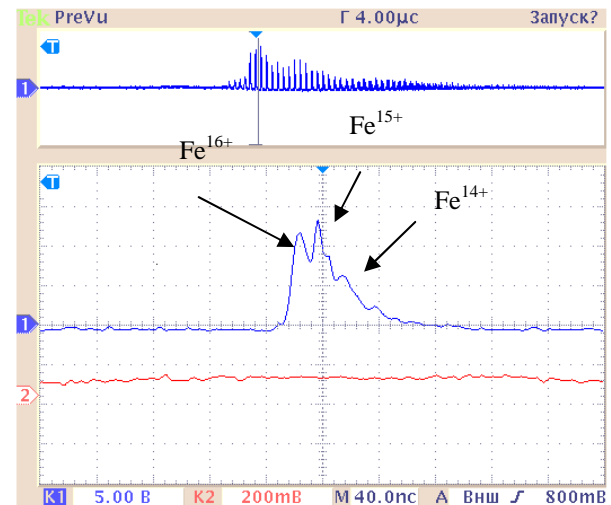


Figure 5: The Fe-ion species at the head of LIS beam.

The first run of the 100J laser for heavy ions generation has been continued three week scheduled by 12 hours per day at repetition rate of 0.25 Hz. Most part of run time has been spent for with the Fe-beam and two last days - with Al-beam. The laser has turned out more than  $10^5$  shots with high enough stability of pulse amplitude and energy distribution. Parameters of ion beam haven't been so stable in time because of dynamic processes in the target caused by intensive evaporation of target material, and in the vacuum volume of plasma drift tube due to intensive adsorption of residual gas from surfaces bombarded by high current beam.

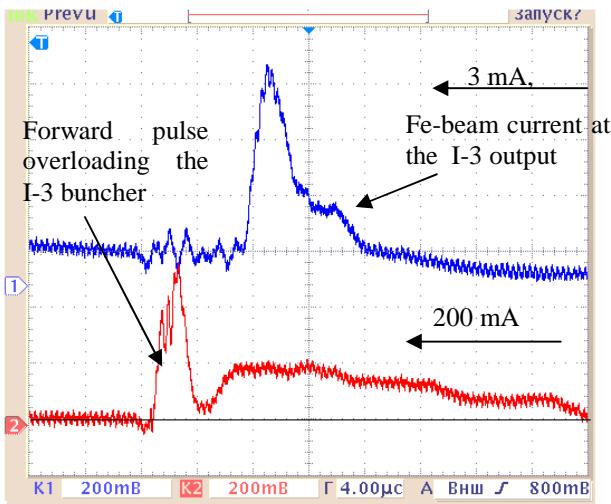


Figure 6: Current signals of total Fe-beam at the LIS extraction gap outlet and Fe<sup>16+</sup>-beam of 64 MeV at the I-3 linac output.

### FIRST RESULTS OF Al AND Fe NUCLEI STACKING IN THE STORAGE RING U-10

The charge-exchange injection technique is used in the TWAC facility from 2002 for carbon nuclei stacking at particles energy of 200-300 MeV/u. Optimised staking process by scheme of C<sup>4+</sup>=>C<sup>6+</sup> is characterised by stacking factor of  $k_{\infty} \sim 70$  and by maximum number of  $4 \times 10^{10}$  stacked carbon nuclei [4].

Parameters of stacking beams and injection system are listed in Tab.2. Energy of ions is high enough for its stripping to bare nuclei but the foil thickness provides 99% bare ion yield for C and Al and only 65-70% for Fe. Reduced yield of Fe-nuclei in stripping foil has to be compensated by decreasing of multiple Coulomb scattering and electron pickups increasing beam stacking efficiency. It was expected to get at experiments a little less efficiency of stacking for Fe-beam but a little more for Al-beam than it was obtained for C-beam.

Table 2. Parameters for nuclei stacking

Stacking ions	<sup>12</sup> C <sup>4→6</sup>	<sup>27</sup> Al <sup>10→13</sup>	<sup>56</sup> Fe <sup>16→26</sup>
Energy, MeV/amu	213	265	165
Charge changing factor	0.67	0.77	0.615
Injection rep. rate, Hz	0.3	0.25	
Stripping foil thickness, mg/cm <sup>2</sup>	1.5 (of mylar)		
Vacuum, Torr	$2 \times 10^{-9}$		
Acceptance filling	central		peripheral
Booster UK intensity, ppp	$\sim 2 \times 10^9$	$\sim 5 \times 10^7$	$\sim 1 \times 10^8$
Momentum spread, %	$\pm 0.04$		
Emittance, $\pi$ mm-mrad	$\sim 5$		
Stacked beam intensity	$> 4 \times 10^{10}$	$> 5 \times 10^8$	$> 2 \times 10^9$

Main experimental results shown in Fig.7 are the following: Fe<sup>16+</sup>-ions are stripping in the foil with predicted probability, but Fe-nuclei loss rate in the target (Fig.7) and in vacuum of  $10^{-8}$  Torr is order of magnitude higher than it was predicted by the theory [6-8].

The resulting process of Al-nuclei stacking have been as expected little differing from the C-nuclei stacking. The factor of Al-nuclei stacking was limited by the lack of optimization time and by injected beam instability

depending on imperfection of the LIS target station which has to be improved.

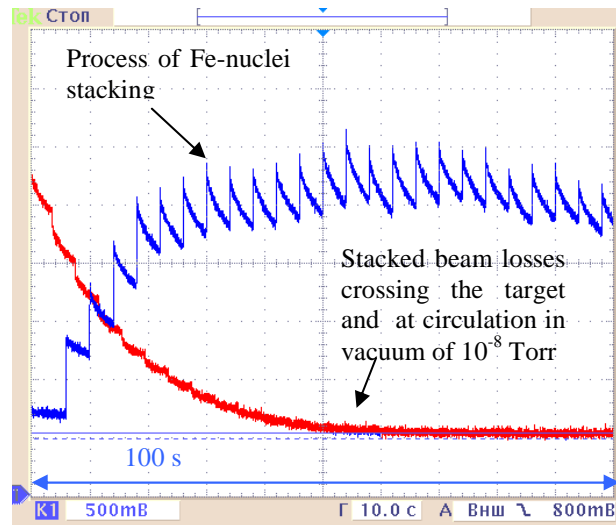


Figure 7: Stacking of Fe<sup>26+</sup>-nuclei in the U-10 ring..

### CONCLUSION

The ITEP Accelerator Facility is now successfully in operation by more than 3000 hours yearly accelerating proton and ion beams and stacking carbon nuclei for physics experiments and radiation technologies.

The nearest progress in the ITEP-TWAC project depends now on the Laser Ion Source commissioning with the master oscillator mode of the 100J CO<sub>2</sub> laser operation required for a heavier ion beam generation with ionization potential of more than 1 kV. Experiments with Fe-nuclei stacking at the energy of 165 MeV/u indicates the unexpectedly high cross section of particles losses by electron pickups at the beam crossing the stripping foil and traversing large distance in vacuum of  $10^{-8}$  Torr. The disagreement of experimental data with calculations has to be cleared in next experiments with stacking of Fe-beam at different conditions.

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