ITEP-TWAC PROGRESS REPORT

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Abstract

The program of the ITEP-TWAC Facility upgrade for next three years has been approved last year in the frame of National Research Center Kurchatov Institute taking up ITEP in accordance with government decision. It includes expanding of multimode using proton and heavy ion beams in different applications on a base of new accelerator technologies development. The laser ion source advantage of high temperature plasma generation has to be transformed to high current and high charge state ion beam of Z/A up to 0.4 for elements with A ~ 60 to be effectively stacked in the accumulator ring by multiple charge exchange injection technique at the beam energy up to 700 MeV/u. The new high current heavy ion RFQ section is in progress for the beam test. Design of proton injection and beam slow extraction for booster synchrotron ring UK is performed for its utilizing as self-depending synchrotron in medical application and for imitation of cosmic radiation. The machine status analysis and current results of activities aiming at both subsequent improvement of beam parameters and expanding beam applications are presented.

INTRODUCTION

This year is 50-th Anniversary of ITEP Ring Accelerator starting for operation undivided with machine modernization and new accelerator technologies development that continues up today. Main millstones of ITEP accelerators history are the following:

1958-1961 – construction of 7 GeV proton synchrotron U-7 with 5 MeV Van de Graaf Injector;

1967 – construction of 25 MeV proton linear injector for U-7 Ring;

1973 – reconstruction of the U-7 lattice for the machine energy increase up to 10 GeV, accelerator gets new name U-10;

1985 – new project of U-10 reconstruction was started for heavy ion acceleration, but it was not finished and terminated in 1989;

1997-2003 – proton synchrotron U-10 was reconstructed to proton-ion accelerator-accumulator facility named ITEP-TWAC;

2004-2011 – ITEP-TWAC operation for fundamental research and applications, machine parameters optimization and new accelerator technologies development.

Many people take a part in ITEP Accelerator Facility construction, maintenance and development throughout the long time of its existence. Great creators of this machine were V.V.Vladimirsky, L.L.Goldin, L.M.Kapchinsky, D.G.Koshkarev, E.K.Tarasov, K.K.Onosovsky, … and a lot of scientists, engineers, technicians and workers participated in constructive labour under accelerator technique development [1].

Contemporary state of ITEP-TWAC Facility is in keeping with its age requiring some additional efforts for rejuvenation of obsolete equipment, communications and structural components proceeding with machine operation. Modernization of high power electro-technical equipment is the most labour-consuming task acquiring now the urgent actuality.

Amalgamation of ITEP with three another Institutes in the frame of National Research Center under the patronage of Kurchatov Institute appears as occasion to sum up results of foregoing scientific activity and to renew the program of ITEP-TWAC subsequent development in the forthcoming decade.

Proton synchrotron U-10 transformed to heavy ion accelerator-accumulator facility as a result of 2003-reconstruction acquired new quality of claimed for many applications machine but assumed as a basis for the TWAC project concept to reach terawatt level of heavy ion beam power using charge exchange injection technique at the energy level of <1 GeV/u has not yet been realized and got tied up in the mire of unconceptual but traditional managerial problems.

Two main scenarios for ITEP-TWAC existence for the next decade are now considered. First of them supposes systematic extension of machine operation for a lot of current experiments and applications in parallel with equipment upgrade and implementation step by step of new structural components and new operation modes bringing required beam instruments to conformity with time and modern science. The second one limits ITEP-TWAC operation by 2017th minimizing as a corollary of that decision any activity for equipment upgrade and machine development.

The program of the ITEP-TWAC Facility upgrade for the next three years has been presented to the new administration and preliminarily approved last year but not yet really supported by required resources.

ITEP-TWAC OPERATION

The ITEP-TWAC Facility consisting of main synchrotron-accumulator U-10 with 25 MeV proton injector I-2 and booster synchrotron UK with 4 MV ion injector I-3 runs now in several operation modes accelerating protons in the energy range of 0.1-9.3 GeV, accelerating ions in the energy range of 0.1-4 GeV/u and accumulating nuclei up to Cu at the energy of 200-400 MeV/u. Accelerated beams are utilized in several modes: secondary beams generated in internal targets of U-10 Ring are transferred for experiments to Big Experimental Hall (BEH); beams extracted from U-10 Ring in one turn are transferred to Target Hall (TH); and proton beam bunch extracted from U-10 Ring on ramp of magnetic cycle is transferred to Biological Research Hall (BRH). Some of secondary beam lines are used now for transferring of slow extracted beams from U-10 Ring.

The total beam time of near 4000 hours per year is divided between three operation modes: acceleration of protons (~50%), acceleration of ions to intermediate and relativistic energy (~30%) and nuclei stacking (~20%). Statistic of machine using for different research fields (Fig.1) shows the tendency of beam time increase for applications such as biology, medicine, protonography and testing of heavy ion radiation steadiness of electronics destined for cosmic apparatus. The demand for beam time exceeds now the offering one by factor of two. This discrepancy is supposed to be cardinally reduced in a result of machine infrastructure improvement and extension of its experimental area.

Research fields with proton and ion beams	Beams	Accelerator operation time, (hours)		
		2009	2010	Require-ments
Adron physics and relativistic nuclear physics	p (2-9 ГэВ, 10^{11}с$^{-1}$) C,Al …(4 ГэВ/н, 10^{8}с$^{-1}$)	1100	850	1000
Methodical research	p (1-9 ГэВ, 10^{11}с$^{-1}$) C(0,2-4 ГэВ/н, 10^{8}с$^{-1}$)	2100	2045	2500
Physics of high density energy in matter	C, Al,Fe,Cu (300-700 МэВ/н, 4x10^{10}с$^{-1}$)	350	330	500
Radiobiology and medical physics	p (250 МэВ, 10^{11}с$^{-1}$) C (200-700 МэВ/н, 10^{9} с$^{-1}$)	2150	2040	4000
Proton therapy	p (250 МэВ, 10^{11}с$^{-1}$)			
Ion therapy	C (100-700 МэВ/н, 10^{9} с$^{-1}$)	0	0	
Radiation treatment of materials	p (20-800 МэВ, 10^{11}с$^{-1}$) Fe,Ag,Bi,U (40-200 МэВ/н, 10^{9} с$^{-1}$)	1100	550	>2000
TOTAL		6800	5815	>10000

Figure 1: ITEP-TWAC using for different research fields.

LASER ION SOURCE DEVELOPMENT

First compact configuration of LIS with 5J CO_2 laser L5 [2] has been in operation at ion injector I-3 until 2006 when it was reconstructed into the new universal optical scheme with the 100J CO_2 laser L100 [3]. Laser L5 is used now for generation of C-ions only, the LIS with laser L100 is in operation from 2008 and it's used now with target materials of C, Al, Si, Fe, Cu and Ag operating ~1000 hours per year.

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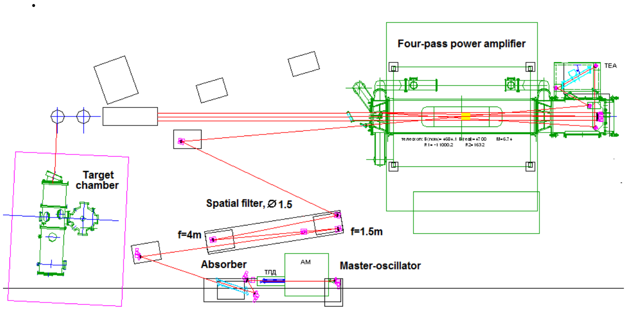

Figure 2: Optical scheme of LIS in amplifier mode.

The first configuration of laser L100 was assembled as auto-generator [4], then it was modified for operation as amplifier by optical scheme shown in Fig.2. Modification of laser L100 to amplifier mode of operation brings to increasing three times the pulse amplitude of radiation power at the total radiation energy decreasing by factor of two as can be seen on Fig.3.

Out-of-axis scheme of laser ray focusing on the target by spherical mirror which is used now in LIS don't allow to get the size of radiation spot on the target less then 0.5 mm, so the maximum power density on the target surface is estimated now by the value of 1.5x10^{12} W/sm^2.

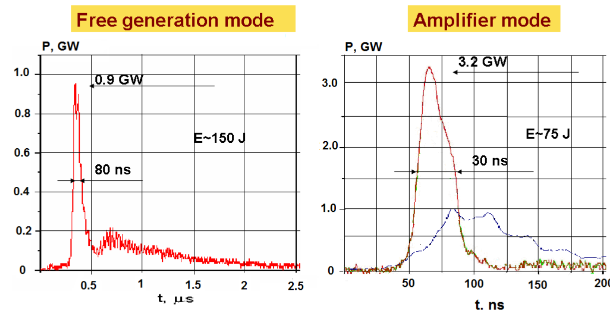

Figure 3: Pulses of L100 laser radiation for auto-generator and amplifier modes of operation.

Charge states of ions generated in the LIS are shown in Fig.4. It's seen that to reach the contemplate charge state of ions corresponding to Z/A up to 0.4 for elements with A~60, we need to increase the laser radiation power density on the target surface by order of magnitude.

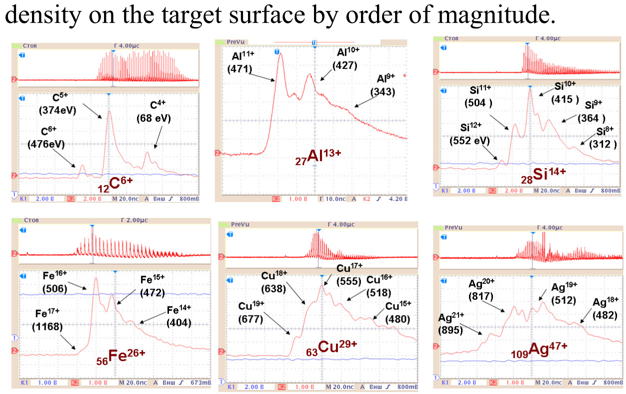

Figure 4: Ions generation in LIS with laser L100.

Experiments on the ion beam generation in LIS give evidence of some optic imperfections reducing the laser radiation power density on the target surface considerably. New focusing scheme for target station is elaborated on a base of new target station construction for axis-symmetrical scheme of laser ray focusing which is free of visible imperfections. Substantial factor of power density increase will be achieved also replacing KCl-windows by patterns of better quality.

HEAVY NUCLEI STACKING

The charge exchange injection technique is used now for accumulation of C-, Al-, Si- nuclei at the beam energy of ~300 MeV/u with stacking factor of several tens. The efficiency of Fe- and Cu- nuclei stacking at the energy of ~200 MeV/u is limited on the level of stacking factor ten due to disturbing effects of beam interaction with stripping foil [4]. Efficiency of beam stacking for nuclei of mass number A~60 will be increased essentially with progress in LIS technology and increasing the energy of injected beam up to 600-700 MeV/u. For nuclei with A<30, disturbing effects of beam interaction with stripping foil are small enough and efficiency of beam stacking is a function of injection scheme parameters and of storage ring dynamic aperture. One of the ways to improve the multiple injection scheme is to raise the charge change factor at injection Z_i/Z_n from 0.7 to 0.85.

BEAM TEST OF RFQ SECTION

The 4 vane RFQ resonator with magnetic coupling windows as initial part of the new high-current Heavy Ion Linac for ITEP-TWAC is presently under construction [5]. The RFQ section was assigned for acceleration of ions with Z/A=1/3 to the energy of 1.57 MeV/u with beam current up to 100 mA.. First beam test of RFQ has been carried out with proton beam for experimental studying of beam dynamics in the wide range of rf power in resonator. The best beam transmission has been obtained in order of 30% at the rf power level near to 1/3 from the nominal value for heavy ions corresponding to rf amplitude of 182 kV. Detailed information concerning beam test of RFQ section is given in [6].

PROJECT OF NEW INJECTION COMPLEX FOR UK RING

Elaborated strategy of ITEP-TWAC infrastructure development is aimed to redouble beam time for physics experiments and applications extending of functionality of booster synchrotron UK for acceleration of not only ions but protons too and for beam slow extraction to the area of beam using for applications. Layout of expanded Injection Complex with additional beam lines from injectors both I-2 and I-4 to UK Ring is shown on Fig.5.

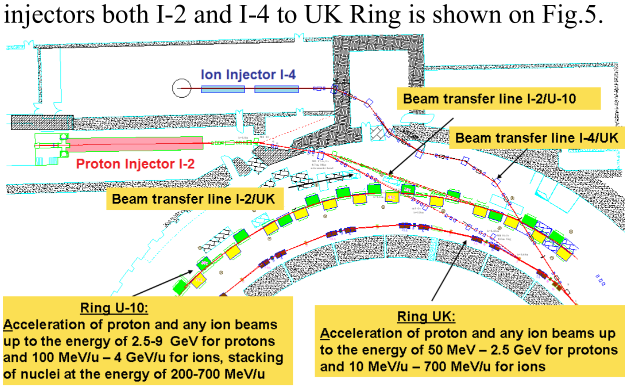

Figure 5: Project of ITEP-TWAC Injection Complex.

EXPANDING OF EXPERIMENTAL AREA

Project of experimental area expanding for applications with proton and ion beam at energies of <1 GeV/u is shown on Fig.6. New beam line for slow extracted beam from UK Ring has to be directed to free space of TH (where stands will be installed for biological research and radiation treatment of materials) and linked with beam line from U10 Ring used now for proton therapy. We consider also possibility of construction the second slow extraction system for U-10 Ring with beam transfer line to the shielded corner of BEH [4] at the beam maximal momentum up to 10Z GeV/c for experiments in relativistic physics and protonography of fast processes.

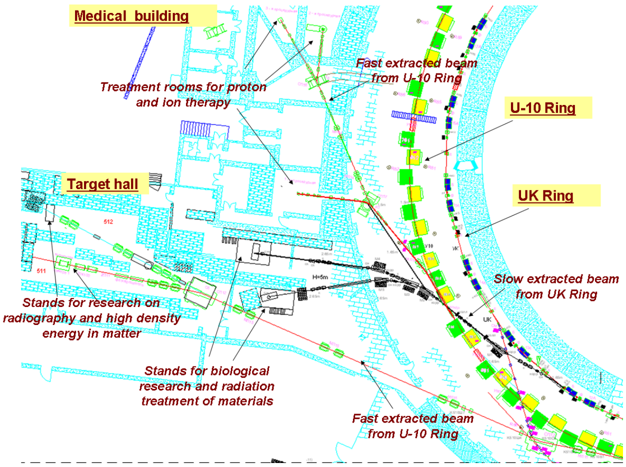

Figure 6: Layout of experimental area for applications.

CONCLUSION

The ITEP Accelerator Facility is in operation on the 50^{th} Anniversary of its life with beam time of ~4000 hours yearly accelerating proton and ion beams and stacking nuclei for physics experiments, methodical research and radiation technologies.

The achieved state of LIS technology provides now reliable operation of machine for acceleration of different ions up to Ag making up to 10^6 shots per year. Detailed studying of optimal conditions for high charge state ions generation reveals some imperfections of working optical scheme restricting the grade of heavy atoms ionization.

The charge exchange injection technique is experienced and implemented in operation for stacking of heavy nuclei up to Cu at the energy of 200-300 MeV/u.

Construction of the new heavy ion injector I-4 for booster synchrotron UK is in progress: first beam test of RFQ section has been successfully carried out with acceleration of proton beam.

The elaborated projects of ITEP-TWAC Facility Infrastructure development is aiming to redouble beam time for physics experiments and applications making operation of both U-10 and UK synchrotrons in parallels.

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