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ITEP COMPLEX FOR PROTON AND HEAVY ION ACCELERATION

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A complex for proton heavy ion acceleration is being constructed on the base of the existing ITEP synchrotrone. The synchrotrone magnet system is not to be changed. During the years of operation several new buildings have been built around the ITEP accelerator. Their presence makes it difficult to find place for a new linac - an injector of heavy ions (fig. 1). The existing linac is used now for proton acceleration only. After certain changes it would be possible to use it for acceleration of helium.

The developed project provides for acceleration of ions (from hydrogen to uranium) with different initial states of charge. The project is to be accomplished in three stages. First of them is based on the existing magnet ring only. In this case, the ions of the first half of the Mendeleev's table can be accelerated up to about 3,5 GeV/a.m.u., and the heaviest ions up to 0,7-1,0 GeV/a.m.u.

At the second stage of reconstruction an additional magnet ring is to be installed in the existing tunnel, and the third stage includes a superconducting accelerator. In the process of transition from the first ring to the folowing ones the ions would be entirely stripped. When the second stage of reconstruction is accomplished the energy of heavy ions would reach about 5 GeV/a.m.u.; the realization of the third stage would raise it to 20-25 GeV/a.m.u.

Ion sourse. As it was mentioned above we have no room for a long injector system. By means of a short system it is impossible to perform a big number of rechargings, and the initial state of charge must be high enough. It seems inexpediant to begin the acceleration of medium ions from $i/A < 0{,}1$, and that of heaviest ions from $i/A < 0{,}05$. It means that the medium and heavy ions states of charge must be not less than 12-14, and preferably $\geqslant 20$. A sufficient amount of such ions can be generated by CO_2, laser source [1] if its pulse energy is greater then several tens of joules. Laser sets generating such energies have been manufactured in several places.

Ion sources based on electron cyclotron resonance [2], as well as cryogenic sources with electron beams [3] can be considered as reserve sources. A laser source with accumulated energy about 200 J is now under development. We hope that it would provide ions with charge values of about 20.

Injector. A two-gap resonance accelerator with single or twofold beam passage (fig.2) will be used as an injector. Experiance of INP (Novosibirsk) shows [4] that 3 MV at 3 MHz can be obtained on the drift tube. Energy increase in a single passage would be not less than 5 MeV/charge, i.e. about 70 MeV per nucleus if i=14. The second passage would increase this energy to 140-190 MeV. The first of the figures is valid for acceleration repeated without recharging, and the second one if the ions are stripped between the first and the second acceleration. If the source emits ions with charges $\geqslant 20$, the second passage through the accelerator can be avoided.

The system of twofold acceleration with external particle return channel makes it easy to change the channel length and thus to ajust the high voltage phase of the second acceleration. Such a possibility is of great importance for an universal injector which is to be used for acceleration of ions with different i/A values.

An important feature of the two-gap accelerator is its stability against i/A changes. The calculated values of the mean ion energy and the useful phase range at different values of i/A are presented in the following table. In the calculations it was supposed that buncher is installed in front of accelerator.

Input and output beam parameters of two-gap injector accelerator

Beam parameters	Relative ion charge i/A		
	0,1	0,2	0,3
Injection energy, KeV/i	50	50	50
Ion energy at injector output, MeV/i	5,7	5,4	5,0
Beam momentum variation at injector input, $\Delta p/p$, %	± 1	± 1	± 1
Beam momentum variation at injector output, $\Delta p/p$, %	$\pm 0{,}6$	$\pm 0{,}5$	$\pm 0{,}3$
Phase range captured into acceleration	200°	160°	145°
Bunch phase range of the beam leaving injector	30°	20°	30°

Vacuum problems. A cardinal improvement of vacuum in the synchrotrone vacuum chamber is required when changing from proton to ion acceleration due to the fact that recharge cross-sections have very great (atomic) values. The experimental data analysis indicates the possibility to estimate total recharge cross-sections in the most important range from 0,5 to 100 MeV per nucleon by a simple empiric formula

$$\sigma \approx k \cdot 10^{-17}/\beta \quad cm^2.$$

The K-values depend on ion types and their charge. For U^{20+} its value is 7, for U^{20+} - 2,4 [5], for U^{30+} - 0,6, for Ti^{6+} -1, for Cr^{5+} - 2,0 [6] and so on, Simple calculations show that for t=0,5 s acceleration time the necessary vacuum is about 10^{-10} tor to accelerate U^{20+}, $5 \cdot 10^{-10}$ tor for U^{30+}, and $3 \cdot 10^{-11}$ for U^{10+} (what seems impossible in our conditions). It was considered that not more than three to fivefold vacuum losses can be adopted in the project. Greater loss values are dangerous, because two or three times vacuum deteriorations which are always possible disturb in this cases the acceleration totally.

At present the vacuum in the accelerator chamber is 1-2 x 10^{-6} tor. Thus it is necessary to undertake a radical reconstruction of the vacuum chamber as well as that of the whole evacuation system. We are planning to

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use distributed evacuation with notsprayed getter. First experiments have been successfilly fulfilled at ITEP.

R.F. system. The acceleration frequency range raises from 4 to 25-30 with transition from protons to ions. To make an acceleration system with so big frequency range is not a trivial task. Two possibilities are under consideration. The first one is a relay acceleration scheme with two acceleration systems working one after another. In this case it would be necessary to install new acceleration stations instead of those we have now. The second possibility consists in transition from higher to lower r.f. harmonics in the process of acceleration. Such a transition was used JINR [7] and IHEP [8]. The main difficulty here is the necessity to accomplish it in very beginning of the acceleration cycle, when the magnet field pulsations are particularly pronounced. The efficiency of this process is experimentally investigated at present.

Particle extraction. The existing ITEP synchrotrone has no slow exstraction system, and with the existing magnetic block arrangement its creation is impossible.

Particle extraction can be accomplished by means of their scattering, degrading or recharging on internal targets. The calculations show that lightest ions only can be extracted by scattering. The most simple method of ion extraction is their recharging, i.e. beam stripping in the target material. If the beam approaches the target slow enough, the extraction process can be well stretched. The ions stripped in the target are swept by the synchrotrone magnetic field and brought out of the accelerator vacuum chamber. The extracted beam can be directed to the existing ionguides if i/Z is smaller than 0,7.

Some considerations about intensity. Let us evaluate intensity losses at injection, acceleration and extraction. Losses depend on the acceleration scheme. Each ion recharge deminishes their number by a factor of 7 . Loss factor evaluations for single recharge are given below.

	Loss factor
Acceleration in injector	4,0
Recharge before the injection into the main accelerator	7,0
Beam transportation and input losses	1,5
Capture into acceleration process	2,5
Harmonic number change	2,0
Output losses	1,5
Total losses	300

To get 10^8 accelerated particles we need 10^{11} particles at the injector input. We consider this number as realistic. (With electron beam sources, particle number may be an order of magnitude lower because such sources strip ions much deeper, what makes unnecessary their recharging before injection into the main accelerator).

As it is clear already the scheme with single transition of ions through injector is most attractive from the point of view of its simplicity. This scheme either needs or does not need ion recharge before their injection into the synchrotron depending on the charge of ions emerging from the source. The scheme with double transition through injector permits two recharges. Number of ions from the source increases faster than recharge losses, which becomes necessary if the charge is reduced. Therefore it is too early now to choose the final injection version.

Conclusion. As it follows from above, the realization of the first stage of reconstruction is not connected with any serious civil engineering work or special equipment construction. The need of very high vacuum (10^{-10} tor) and therefore the total reconstruction of the vacuum system is the most difficult feature of the project. As it was mentioned above development works in this field are successfully advancing. The two-gap accelerator-injector is in the process of installation. High-frequency system is intensively worked at. Development of heavy ion sources is started. The first part of the project can be accomplished within next few years. The works on the second and the third project parts are yet in an initial stage.

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