SIMULATION OF THE ACCUMULATION PROCESS IN THE ITEP TWAC STORAGE RING

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Abstract

Fully stripped heavy ion beam of a nearly relativistic energy and a super high intensity is supposed to be accumulated in the storage ring of ITEP-TWAC Facility that is under construction at ITEP on the base of existing accelerators. Nonliouvillean multiturn injection technique is elaborated to store in the accumulator ring as much as one thousand batches, which are accelerated in the booster synchrotron with acceleration cycle frequency of 1 Hz. Computer simulation of the beam accumulation process is done with taking into account effects of intrabeam scattering and interaction with stripping foil: ionization energy loss, multiple Coulomb scattering and electron capture. Evolution of the 5-D phase space volume of the accumulating beam is calculated as a function of injection batch number, accumulation time, stripping foil thickness, foil matter and other multiturn injection system parameters. Results of simulation are presented and discussed.

INTRODUCTION

ITEP accelerator facility includes now four accelerators: the U-10 proton synchrotron (9,3 GeV), the I-2 proton injector (25 MeV), the I-3 ion injector (1-2 MeV/amu), and the UK accelerating ring (3 GeV for protons). The last one was constructed for ion acceleration, but doesn't used for a lack of physical program with financial support. The idea of a new reconstruction for ITEP accelerator facility has been proposed by the researches of a high energy density in matter produced by heavy ion beams and a heavy ion fusion technology [1]. It was found that not very much efforts have to be applied to existing ITEP accelerators to obtain some new configuration in the best way adapted for high intensity and high power heavy ion beam technology promotion. New project was named ITEP-TWAC [2] and guided by two main objects of activity. First goal is the reaching of the terawatt range power in the heavy ion beam accumulated in the ring, compressed, extracted and focused on the small size target for experiments with production of high density heavy ion plasma. The second one is a creation of some accelerator assembly suitable for studies and tests in heavy ion and high intensity beam technology. Main features of the project are considered in [2]. This report is devoted to the multiturn injection scheme to be used for accumulation of heavy ion beam with utmost intensity.

1 MULTITURN INJECTION SET-UP

Charge exchange injection scheme was selected for filling the accumulating ring with a heavy ion beam to get over Liouville theorem. One of the main obstacle for this type of injection is the disturbing influence of the stripping foil upon the coasting beam. Disturbing effect of foil on the beam is supposed to be radically reduced by minimising a total foil thickness penetrating by any particle at accumulation process. The technique to be used is the following: stripping target is placed outside of the coasting beam which is moved in it only at injection for a time of one revolution to absorb the injecting batch of beam. The kicker magnet bump will be installed in the accumulator ring for this purpose.

Additional minimisation of a number of particle passing through the target is supposed to be reached by taking into account the fact that phase volume of coasting beam is two orders more than injecting beam emittance, so only small part of coasting beam may penetrate through the target at batch injection The scheme of transverse phase space filling at injection is shown on fig.1.

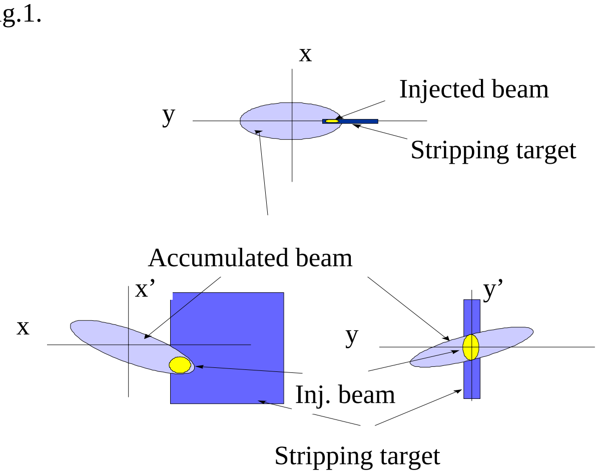

Fig.1. Transverse phase space filling at the beam multiturn injection into U-10 ring.

1.1 *Injected beam parameters*

Looking through the Mendeleev Table we've taken the $_{59}Co^{27+}$ fully striped ions as a specimen for beam dynamics calculations and accumulator parameters definition. Ions of Cobalt type are heavy enough for effective using in high density plasma production and are not hopeless for striping to nearly bared (in 24 or 25 charge states) in laser source[3].

Main parameters of the Cobalt beam expected at the output of booster synchrotron are listed in Table 1.

Table 1: Booster beam parameters

Ion type	$_{59}Co^{25+} \Rightarrow {}_{59}Co^{27+}$
Kinetic energy	40 GeV
Intensity	10^{10} ppc
β / γ	0.816 / 1.729
Momentum spread	±0.05%
Horizontal emittance	5 π mm mrad
Vertical emittance	3 π mm mrad
U-10 hor. acceptance	110 π mm mrad
U-10 vert. acceptance	60 π mm mrad

1.2 Ion beam interaction with foil matter

The yield of charge fractions of relativistic ions penetrating through the foil is determined by a competition between electron stripping and pickup, and depends on projectile energy, foil matter and thickness. The yield of bare ions is increased with projectile energy and becomes independent of foil thickness after a sufficient (equilibrium) thickness is traversed. In order to minimise multiple Coulomb scattering the equilibrium thickness has to be used for stripping. The electron stripping cross section is nearly proportional to the second power of charge state of target nucleus (Z^2), and the specific weight of material is proportional to Z, so equilibrium thickness is near inversely proportional to Z.

There are three basic relevant effects of ion projectile interaction with target: energy loss for ionisation, transverse emittance growth and particle loss due to multiple Coulomb scattering, and ion loss due to electron pickup. Characteristics of beam disturbance occurred from ion single penetrating through the target were estimated previously in [4] using analytical approach.. Results given in Table 2 for three target matters have shown that disturbance is not extraordinary and doesn't present a serious obstacle for accumulation of thousand and more beam batches. The best material for recharge target has to be found in light elements like Aluminium or near to it.

Table 2. Foil influence on the penetrating beam

Target material	Mylar	Al	Cu
Equilibrium thickness for 80% bare ion yield, mg/cm^2	5	3	1.5
Ionisation loss, MeV	8	3,9	1,8
Momentum loss, x10^{-2}%	1.2	0.6	0.2
Rms angle of multiple scattering, mrad 10^{-2}	7	7	7
Electron pickup cross section (non-radiative), barns	0.2	3.5	135
Electron pickup cross section (radiative), barns	1.0	1.8	4.1
Loss probability due to electron capture x10^{-4}	2.5	3.5	20

Additional and more clear information concerning dynamic properties of accumulating beam has been obtained by computer simulation.

2 SIMULATION CODE

The computer simulation was aimed to consider evolution of particle distribution function in 5D phase space (transverse degrees of freedom and momentum deviation) during accumulation process with account of initial distribution function of the injected beam, scheme of phase space filling at injection, beam interaction with stripping target and intrabeam scattering (IBS).

2.1 Accumulating beam model

Simulation algorithm is based on the method of macro-particles. Truncated Gaussian distribution was used for definition of betatron amplitudes and momentum deviations in the injecting beam, the azimuthal variable being distributed uniformly. The process of accumulation is treated as the sequence of following steps: 1) coasting beam ensemble is supplemented by particles of injected beam with corresponding co-ordinate transformation according to accepted injection scheme (Fig.1); 2) the betatron phases of the coasting beam ensemble are distributed uniformly, then the target penetrating particles are identified and their new co-ordinates being found with account of Coulomb scattering and energy loss formalism; 3) procedure of the IBS (see bellow) is applied to the coasting beam for the time interval of the booster synchrotron repetition rate; 4) particles with betatron amplitudes or momentum deviation exceeding permissible values are excluded from ensemble, then cycle of simulation is repeated.

2.2 IBS simulation

We have developed a new method of Monte-Carlo kind for numerical simulation of IBS effect on the beam distribution function. This method is based on a conception of «equivalent event» introduced for the particle with a fixed co-ordinates as a result of its multiple IBS during subsequent time interval, which is considered relatively short for appreciable change of beam parameters. Effect of the «equivalent event» on the particle is defined as randomised time derivatives for squared betatron amplitudes and momentum deviation ($\delta\varepsilon_x/\delta t$, $\delta\varepsilon_y/\delta t$, $\delta(\Delta p/p)/\delta t$) similar to that introduced in the Piwinski's model [5] for the whole beam in stationary state. It may be shown that coincidence with Piwinski's model is provided by introducing rms angle of multiple scattering of macro-particle calculated as

$$\chi_{eff} = \frac{2\sqrt{\pi} r_i}{\left(\bar{\beta}\right)^{3/2}\gamma}\sqrt{c \cdot \bar{n} \cdot \delta t \cdot \ln\frac{2d\left(\bar{\beta}\right)^2}{r_i}}$$

where $\bar{n}(\varepsilon_x, \varepsilon_y, D, \theta)$ is averaged density of ions in the neighbourhood of particle trajectory for the considered interval of time (δt). Other designations are similar to [5]. Using the χ_{eff} value as an effective angle of scattering for considered macro-particle and taking random values for scattering direction and lattice point, the values of $\delta\varepsilon_x$, $\delta\varepsilon_z$, $\delta(\Delta p/p)$ are calculated.

3 RESULTS

Firstly, processes of coasting beam interaction with stripping foil and IBS effect have been simulated separately to evaluate their comparative contribution into the beam dynamics. Main results are presented in Fig.2-4 where it's seen evolution of the transverse emittance and beam momentum in the accumulating ring. Calculations were done for the aluminium foil of 3 mg/cm^2 thickness and one second injection period. The influence of the foil penetration is shown for the one thousand injection cycles, the IBS considered for the 300 s. The particle loss registered at acceptance exceeding (A_x, A_y, or A_s values). The loss factor at the end of simulation is 8% for the foil interaction at 1000 injections and near to 10% for the IBS at 300 injections. It's seen very clear in Fig.4 sufficiently strong effect of momentum dispersion growth for the IBS.

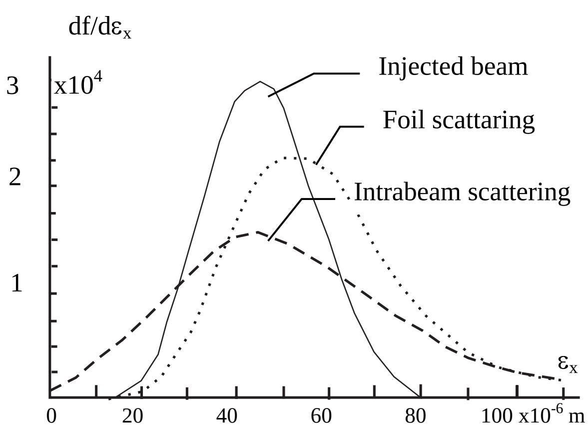

Fig.2. Horizontal emittance growth under beam scattering in foil and IBS (A_x=1.1 10^{-4} m rad).

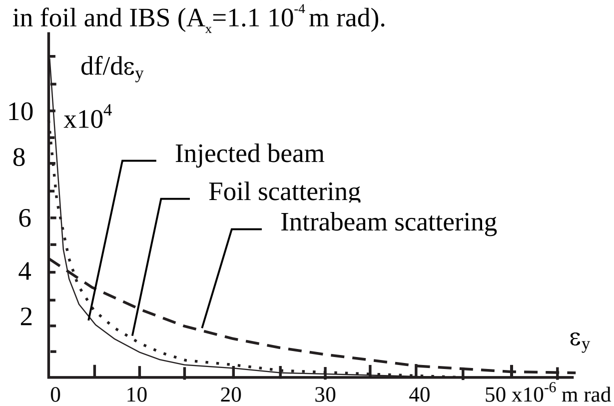

Fig.3. Vertical emittance growth under beam scattering in foil and IBS (A_y=60 10^{-4} m rad).

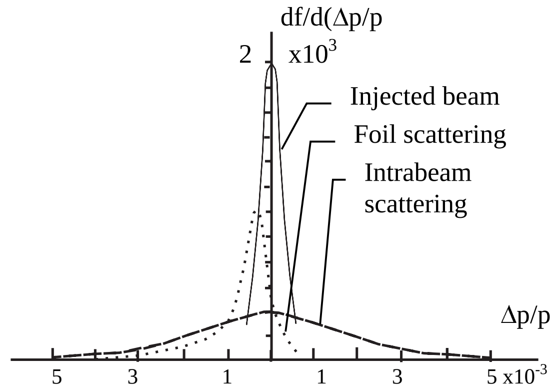

Fig.4. Distribution of momentum deviation (A_s=±0.8%)

The accumulated beam parameters arising from the IBS effect for time interval equaled to 300 s are the following: accumulated intensity is near to $3{\cdot}10^{12}$, horizontal emittance for the 90% beam is less than 80 π mm mrad, vertical emittance is less than 30 π mm mrad, momentum spread for the 90% beam is ±0.25%. Last value is the most crucial for accumulator because it limits final beam compression.

CONCLUSION

Computer code based on macro-particle method has been elaborated for simulation of the ion beam accumulation with account of interaction with foil and IBS processes.. First results of simulation received for preliminary scheme of accumulation process in the ITEP-TWAC ring at high intensity Co-ion beam give estimation of utmost value for the beam intensity in the ring, beam emittances and momentum spread. Excessive growth of the beam momentum spread for IBS makes difficult high compression of the beam in time domain. Forthcoming work is to consider possibilities to improve the results by optimising the injection process, increasing of the accumulation rate, implementing of electron cooling and other ways.

REFERENCES

[1] D.G. Koshkarev et all., "ITEP Accelerator Facility Upgrade", XV Workshop on Charged Accelerator, Protvino, October 1996, v.2, p.319.

[2] B.J. Sharkov et all, "Heavy Ion Facility ITEP-TWAC: Status of Upgrading Project", EPAC'98.

[3] V.Yu.Baranov et all. Laser and Particle Beams, 1996, v.14, N3, p.347.

[4] N.N.Alexeev et all., "Investigation of Multiturn Injection Scheme for ITEP-TWAC", ITEP, Int. report, 1997, N969.

[5] A.Pivinsky, Proc. 9th Int. Conf. on High Energy Accelerators, p.105, 1974.