BEAM ACCUMULATION WITH BARRIER VOLTAGE AND STOCHASTIC COOLING

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Abstract

The accumulation scheme of anti-proton beam with the barrier bucket and stochastic cooling is numerically investigated for the HESR storage ring of FAIR project. The particle tracking code is developed to investigate the particle dynamics under the effects of RF field, stochastic cooling and diffusion factors. The application of the concept to the heavy ion accumulation in a collider is proposed.

INTRODUCTION

The accumulation of anti-protons was performed with use of the stochastic stacking system at CERN and FNAL where the pre-cooled beam was injected into the straight section of an accumulator with large dispersion. It was radially stacked with the stochastic cooling force which was shaped as decaying radially with exponential form from the injection position to the stack top. The accumulation has been successfully achieved up to around 1000 stacking times without any significant beam loss. This concept is planned for the anti-proton accumulation ring RESR of FAIR project [1, 2]. The other idea of beam accumulation is to use the barrier voltage as well as the stochastic cooling. The circumference of the accumulator ring is separated into the injection and accumulation areas. With the assist of beam cooling, the injected beam is moved into the accumulation area, lower potential area, until the next injection cycle. [3] This concept is planned for the accumulation of the radio-isotope beam in the NESR Storage Ring of the FAIR project with use of electron cooling and was experimentally demonstrated at the ESR of GSI. [4, 5]

In view of the budget limitation, the starting plan of FAIR has postponed the construction of RESR and instead proposed the installation of anti-proton accumulation function in the HESR (High Energy Experimental Storage Ring) downstream of the Collector Ring, the pre-cooling ring of anti-proton beam.

In the present paper, results of numerical study of the barrier bucket accumulation scheme in the HESR is reported as well as the application to the heavy ion collider.

BARRIER BUCKET ACCUMULATION IN HESR

The stochastic cooling system of the HESR is mainly designed to attain the smallest momentum spread with internal target. [6] The main specifications of stochastic cooling with a notch filter system are as follows: beam energy= 3 GeV, ring slipping factor=0.03, TOF from pickup to kicker=700 nsec, number of loop couplers of the pickup and kicker=64, band width=2-4 GHz, coupling impedance=50 Ohm, electronic gain=110-130dB. The injected particle number/shot is 1e8 and the *Dp/p* (rms)=5e-4.

Coasting beam approximation

Firstly the cooling process of particle number *N*=1e8 and 1e10 are studied with the Fokker-Planck solver under the assumption that the beam is coasting. The evolution of momentum stochastic cooling is given in Fig. 1.

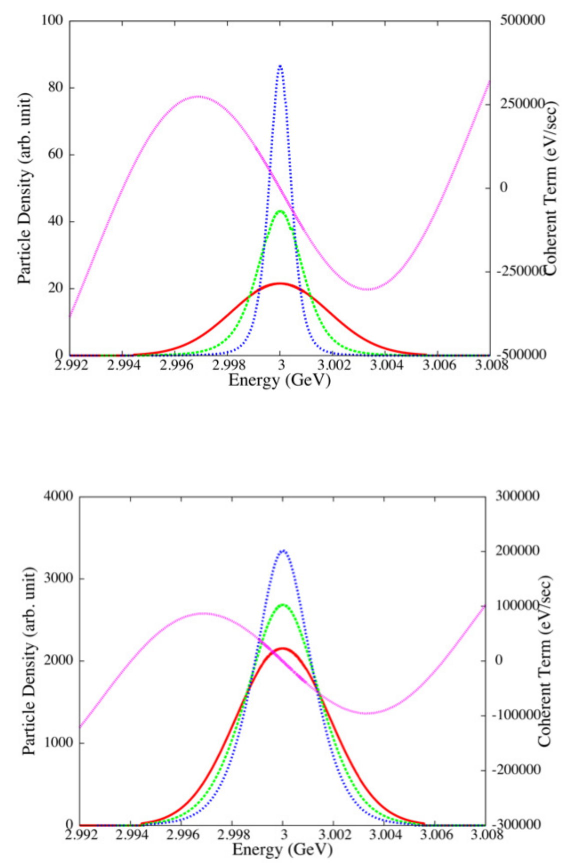

Figure 1: Evolution of momentum beam cooling. Particle number=1e8 (top) and 1e10 (bottom). Initial distribution (red), 5sec cooling (green) and 10 sec cooling (blue). System gain=120dB (top) and 110 dB (bottom). Coherent term (pink) is given with right scale.

It is found that the system gain could be as high as 120 dB to cool down 1e8 particles within the cycle time 10 sec while the gain has to be reduced to 110 dB for the particle number 1e10.

Simulation code of stochastic cooling with RF field

The particle tracking code is developed by the present authors (TKs) which includes the effects of RF field by barrier voltages, stochastic cooling force, diffusion forces such as Schottky diffusion, thermal diffusion and Intra-Beam-Scattering effects. If necessary other effects associated with internal target, mean energy loss and multiple scattering, could be included. The essential points of the code are as follows.

The stochastic cooling force is calculated with the cooling formulae developed by the present authors (TK & HS) as a function of energy. If the gain of the cooling system is varied with time, it is reflected at each computing cycle.

The thermal diffusion force is simply calculated with given cooling parameters. On the other hand the Schottky diffusion term requires the energy spectrum of the particles, and then at each computing cycle the energy spectrum is calculated and the Schottky diffusion term is obtained.

The IBS heating term is calculated with use of Martini formula [7] with use of lattice Twiss functions of the ring. The transverse emittance is assumed to be constant during the whole stacking cycle.

Once the cooling force and diffusion force are obtained it is straightforward to calculate the energy decrease by the cooling force and the increase by the diffusion force as a random kick to each particle. The longitudinal equations of motion to be solved are as follows.

$$d(\Delta E)/dt = q\omega_0/2\pi\, V(\tau) + F(\Delta E) + \xi_s(\Delta E, t) + \xi_t(\Delta E) + \xi_{IBS}(t) \quad (1)$$

$$d(\tau)/dt = -\,\eta/(\beta^2\gamma E_0)\Delta E \quad (2)$$

where V is the barrier voltage, F the cooling force, ξ_s, ξ_t, ξ_{IBS} the diffusion terms associated with Schottky, thermal and IBS diffusion. q is a charge state of ion and η the ring slipping factor.

It is proved that the code well reproduces the experimental results of the bunching process with RF field (barrier voltage or RF field of harmonic number=1) and stochastic cooling at the COSY proton beam [8, 9].

Barrier Bucket Accumulation Scheme

There could be two schemes of barrier bucket accumulation, fixed barrier scheme and the moving barrier scheme. In the former scheme, two half-wave barrier voltages are produced in the one revolution period while in the latter case two full-wave barrier voltages are excited and the timing position and voltages are controlled in proper way. The fixed barrier scheme is simpler but the accumulation efficiency becomes worse when we try to accumulate the many stacking. In the following, results of moving barrier case are illustrated. In Fig. 2 the barrier voltages and particle distribution at 50th injection, 500 sec after the start of accumulation, are given where in the central part is a newly injected beam and in the left and right areas the stacked particles are populated.

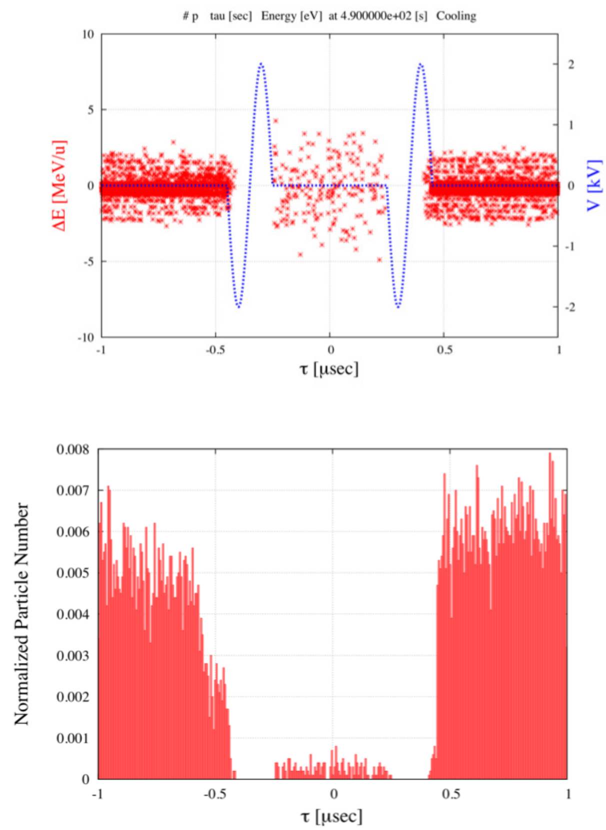

Figure 2: Phase space mapping (top) and the particle density along the ring orbit (bottom). Two full wave barrier voltages, V=2kV, T=200 nsec, are excited. In the central area the newly injected beam and in the left and right areas the stacked particles are populated.

Just after the beam injection the barrier voltages are switched off and the beam becomes coasting. The stochastic cooling is applied to this coasting beam until the next beam injection timing. In the well cooled coasting beam two full-wave barrier voltages are excited adiabatically and the right hand voltage moves to the original position within the period of 0.5 sec.

This process is repeated up to 100 times to obtain the required intensity 1e10. In Fig. 3 the accumulated intensity and the electronic gain of the cooling system are given as a function of time. As a typical value the electronic gain is varied from 130 dB to 115 dB during the whole stacking cycle of 1000 sec.

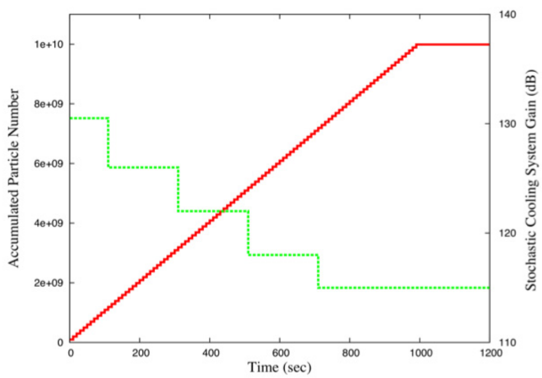

Figure. 3 The accumulated particle number (red, left scale) and the electronic gain of the cooling system (green, right scale). Horizontal scale is time (sec).

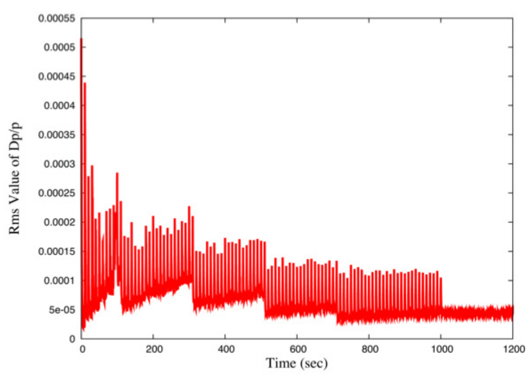

Figure 4: The variation of *Dp/p* (rms) value during the stacking period. Horizontal scale is time (sec).

After stopping the beam injection the cooling is continuously applied and the equilibrium value of *Dp/p* (rms) is 5e-5. The microwave power is calculated as 70 W at the initial high gain (130 dB) while the real engineering power will be a factor of 3-5 larger than this value.

APPLICATION TO HEAVY ION COLLIDER

The heavy ion collider of a 1 - 4.5 GeV/u Au beam is planned at JINR, Dubna [10]. The barrier bucket accumulation method will be a useful to accumulate the heavy ion beam from the injector synchrotron Nuclotron. The bunch length of the injected beam is 200 nsec, and no need of special bunch compression device in the Nuclotron. In addition the special cooling is not necessary in the injector chain as the beam cooling is performed in the accumulation process in the collider.

The injection cycle time is 10 sec and the intensity is 1e8/shot. Note that the injection intensity of 1e9/shot is the goal of the project but the proposed scheme allows to work at lower number of injected ions. Therefore here the accumulation scheme is studied at the lower injected intensity case. The stochastic cooling system of the NICA collider is designed to make the short bunch from the coasting beam [8] as well as to suppress the beam diffusion due to IBS effects. The same cooling system can be used for the beam accumulation.

The main specifications of the stochastic cooling with the Palmer cooling method are as follows: beam energy= 3.5 GeV/u, ring slipping factor=0.0232, TOF from pickup to kicker=400 nsec, number of pickup and kicker loop couplers=128, band width=2-4 GHz, coupling impedance=50 Ohm, atmospheric temperature=300 K. barrier voltage=5 kV and frequency=5 MHz. The electronic gain of the cooling system is 90 dB and the required maximal microwave power is 50 W.

In Fig. 5 the calculated accumulated particle number and the accumulation efficiency, (defined as the ratio of accumulated particle number to the total injected particle number), are illustrated..

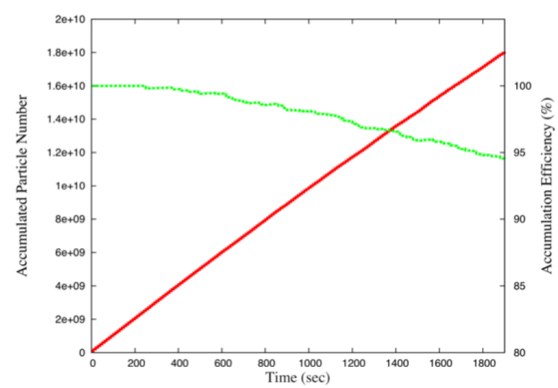

Figure 5: Accumulated particle number (red, left scale) and accumulation efficiency (green, right scale) for the NICA collider.

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