SIMULATION STUDY OF BARRIER BUCKET ACCUMULATION WITH STOCHASTIC COOLING AT GSI ESR

T. Katayama, C. Dimopoulou, F. Nolden, G. Schreiber, M. Steck, GSI, Darmstadt, H. Stockhorst, FZJ, Jülich, T. Kikuchi, Nagaoka University of Technology, Nagaoka, Niigata

Abstract

The beam accumulation experiments with use of barrier bucket cavity and stochastic cooling system was performed at the ESR, GSI. Two methods of barrier voltage operation, moving barrier and fixed barrier cases were tried, and for the moving barrier case the electron cooling was additionally employed as well as the stochastic cooling. In the present paper, the beam accumulation processes are simulated with particle tracking code where the cooling force (stochastic and electron cooling), the diffusion force and the barrier voltage force are included as well as the IBS diffusion effects. The simulation results are well in agreement with the experimental results.

INTRODUCTION

In the original concept of the FAIR project, the function of 3 GeV antiproton accumulation is planned in the RESR ring where the stochastic stacking method is planned. However, the RESR was postponed due to the budgetary limitation as the 2nd phase project. Then, a strong demand of the beam accumulation directly from the Collector Ring to the High Energy Storage Ring (HESR) urgently occurred. The barrier bucket accumulation method using the barrier voltage system assisted by the stochastic cooling was proposed as a most promising way. [1, 2]

The concept of beam accumulation with barrier bucket system with beam cooling was already tried in 2007 at the GSI, ESR where the heavy ion beam 40Ar18+, 60 MeV/u was injected into ESR from SIS 18. The experiment was successfully achieved to demonstrate the possibility of beam stacking with BB system assisted by electron cooling. The electron cooling is effective for the low energy and high charge state ions while in the HESR 3 GeV antiproton beam has to be accumulated. In this case the stochastic cooling is exclusively a main cooling means.

To verify the principle of BB accumulation with stochastic cooling, the Proof Of Principle (POP) experiment was performed at ESR, GSI where both the stochastic cooling and electron cooling are available. The experimental results are presented in the accompanied paper in this conference [3]. In the present report the simulation results of BB accumulation are presented and compared to the experimental results to bench-mark the simulation code.

STOCHASTIC COOLING AT THE ESR

In Table 1 the main parameters for experiment and simulation are tabulated.

Table 1: Parameters of Stochastic Cooling at ESR

Ion species	40Ar18+	Energy	0.4 GeV/u
Ring Circumference	108.36 m	Revolution Period	500 nsec
Number of ions/shot	5e6/shot	Dp/p (rms) of Injected beam	5.0e-4
Bunch length of injected beam	150 nsec (simulation) 60 nsec (exp., cut by kicker)	Ring slipping factor	0.309
TOF from PU to Kicker	0.253e-6 sec	Dispersion at PU & Kicker	4.0 m
Band width	0.9-1.7 GHz	Number of PU &Kicker	8
PU Impedance	50 Ohm	System gain	90-130 dB
Atmospheric temperature	300 K	Noise temperature	40 K

The typical momentum cooling process with this stochastic cooling system is analyzed with the Fokker-Planck code as given in Fig. 1 with 1e6 particles.

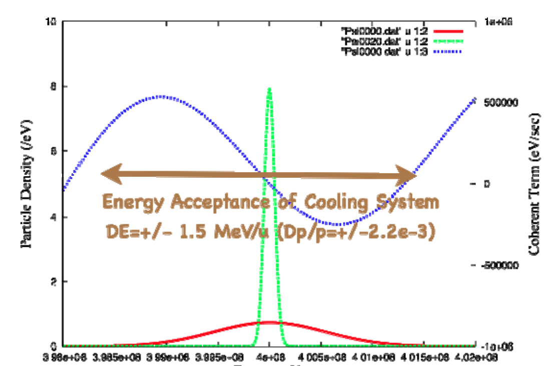


Fig. 1 The evolution of momentum cooling process analyzed with Fokker-Planck code. Red: Initial particle distribution, Green: Particle distribution after 20 sec. Blue: The coherent term of the cooling system. Gold line with arrow: Energy acceptance of the cooling system. Particle number is 5e6 and the cooling system gain is 120 dB.

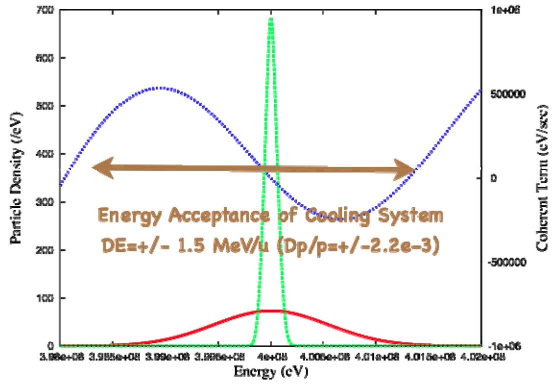


Fig. 2 The same parameters as in Fig. 1 but the particle number is 1e8.

From these results it is confirmed that the present stochastic cooling system could cool the momentum spread well below 1e-4 (rms) within 20 sec even when the particle number is as large as 1e8.

BARRIER BUCKET ACCUMULATION

There are two schemes of barrier bucket accumulation, fixed barrier and moving barrier schems. In the former one, 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 and amplitude of barrier voltage are controlled in proper way. The fixed barrier scheme is apparently simpler way but concerning the accumulation efficiency we have to carefully compare numerically calculated results for two methods.

The particle tracking code for the BB accumulation has been developed which includes the effects of RF field by barrier voltages, stochastic and electron cooling forces, 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 details of algorithm are given in [1].

For the barrier voltage accumulation, one of the serious parameters is the separatrix height and the synchrotron tune. It should be noted that at the ESR POP experiment the available voltage was as small as 120 Volt, and then the separatrix momentum height is 2.6e-4. This small separatrix height is the main limitation of the stacked particle number.

COMPARISON OF SIMULATION & EXPERIMENTAL RESULTS

Fixed barrier method

The fixed barrier experiments was performed with following conditions: the barrier voltage is 120 Volt, the frequency of 5 MHz (one wave length is 200 nsec).

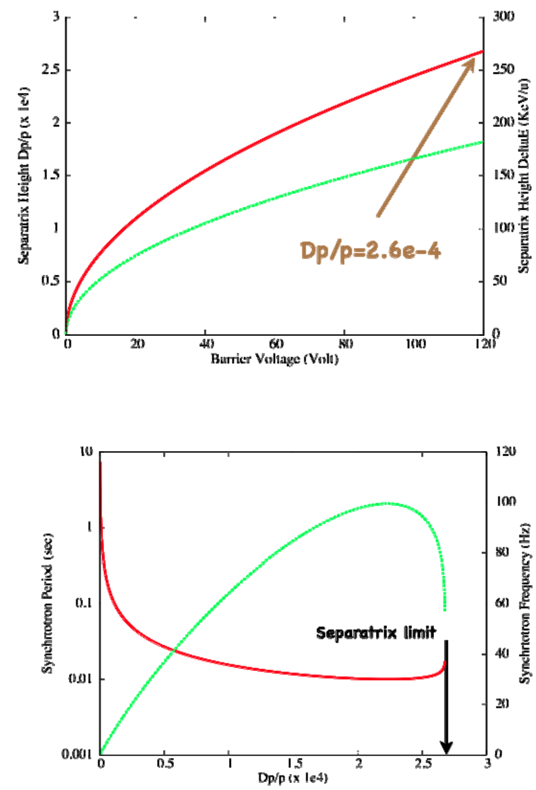


Fig. 3 The separatrix height (top) and the synchroton tune (bottom) at the ESR POP experiment. The barrier voltage is 120 Volt.

The simulation results is given in Fig. 4, where the cycle time is 13 sec, and the stacking was continued up to 400 sec, 300 times injection. The injected particle number/shot was estimated around 2e6. As the intensity is not so high then the IBS effects did not play important role in the experiments. The un-stacking process means that the beam was not injected but the injection fast kicker magnet was fired. The reduction of the accumulated intensity is due to the fact that the part of accumulated beam is continuously kicked out by the kicker fringing field.

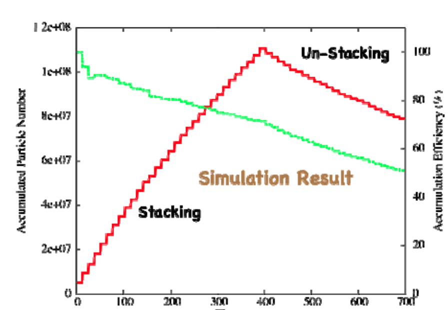


Figure 4 Simulation results of beam accumulation (stacking) and un-stacking at the fixed barrier bucket system.

The experimental results are given in Fig. 5 which is quite well agreement with the simulation results in Fig. 4.

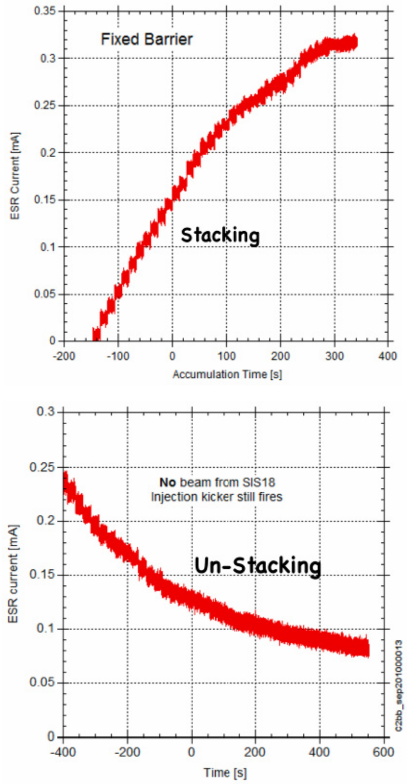


Figure 5 The experimental results of beam accumulation (top) during the periood 500 sec with cycle time 13 sec and the un-stacking (bottom). Fixed barrier case.

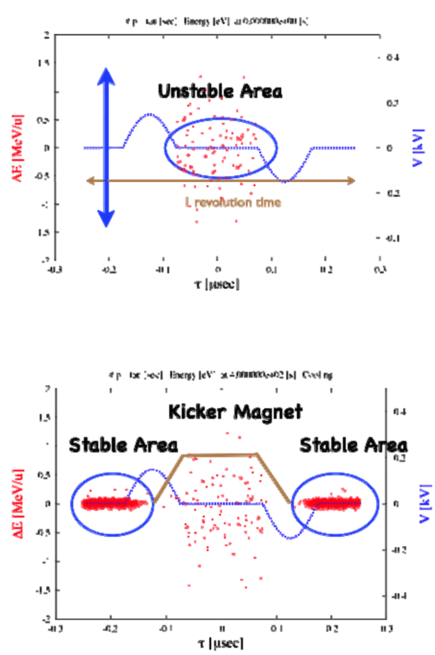


Figure 6 Phase space mapping at the 1st injection and 20th injection. The fast kicker magnet, of which the magnetic field is illustrated schematically with the pulse length 300 nsec. Particles populated in the kicker magnetic field are labelled as "lost" particles.

Moving barrier method

First the moving barrier accumulation experiment was tried with the barrier voltage of 120 Volt and the cooling gain was 120 dB. However we could not observe the any increase of beam current though the accumulation process. From the simulation it is clearly shown that the stochastically cooled momentum spread of the coasting beam is too large and then the beam can not be compressed to prepare the empty gap for the next beam injection. That is a reason for no beam accumulation.

The ESR is equipped with the electron cooler which is able to cool down further the beam momentum spread. The parameters of electron cooler are as follows. length of cooler=2.5 m, electron diameter =5cm, electron current=0.2~0.5 A, effective electron temperature=1e-3 eV, beta function at cooler=15 m. The simulated cooling process is given in Figure 7 where the evolution of *Dp/p* (rms) is given as a function of time during two cycles. (Now the cycle time is 20 sec.) The blue line shows the case of only electron cooling, the green line the case of only stochastic cooling and the red line shows the case of simultaneous use of stochastic cooling and electron cooling. It is clearly shown that the electron cooler alone could not give the effective cooling during the cycle time 20 sec as the initial *Dp/p* (rms) is as large as 8e-4 while with simultaneous use of stochastic and electron cooler, the *Dp/p* is reached to around 2e-5.

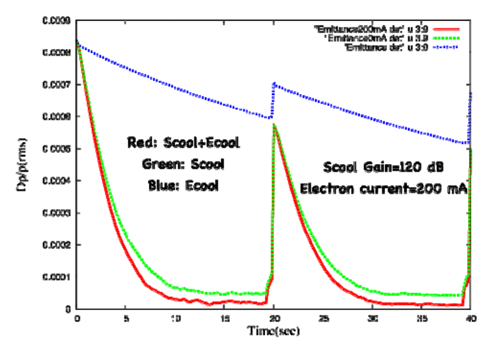


Figure 7 The evolution of *Dp/p* (rms) value during two cycles operation of moving barrier. The blue line shows the case of electron cooler alone, the green line the case of stochastic cooling alone and the red line the case of simultaneous use of electron cooler and the stochastic cooler.

The simulation and experimental results of increase of the stacked particle number are given in Fig. 8 where the accumulation efficiency is defined as the accumulated particle number/total injected particle number. The agreement of results are remarkable. At the time 800 sec, after 400 injections, we find the dip in the accumulated particle number in both results. Presently, the reason why both results have such a dip is not clear.

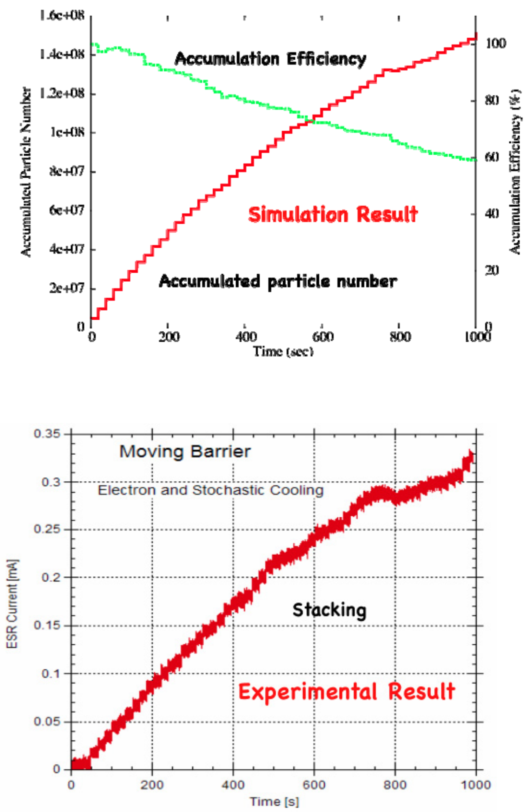
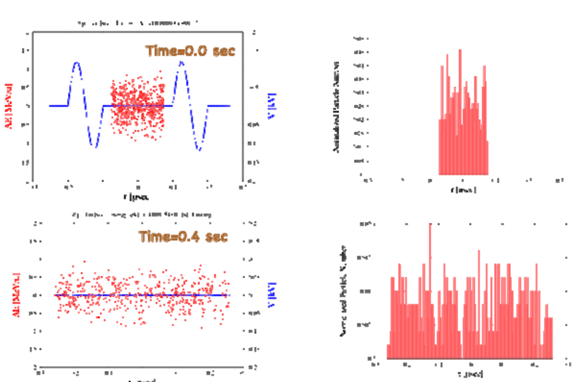


Figure 8 The simulation (top) and the experimental (bottom) results of the moving barrier operation. The red line in the top figure shows the accumulated particle number and the green line the accumulation efficiency.

The timing and amplitude of barrier volatge in the 1st cycle are illustrated in Fig. 9 as well as the particle distribution in the phase space for the moving barrier method with stochastic and electron cooling. At t=0 sec, the batch is injected in the gap between two barrier voltages, and shortly after the voltage is swiched off and the beam becomes coasting one. After cooling well the coasting beam, two barrier voltages are excited and moved to the original position when the cooled beam is compressed into the acculation area and the central part is empty for the next beam injection.



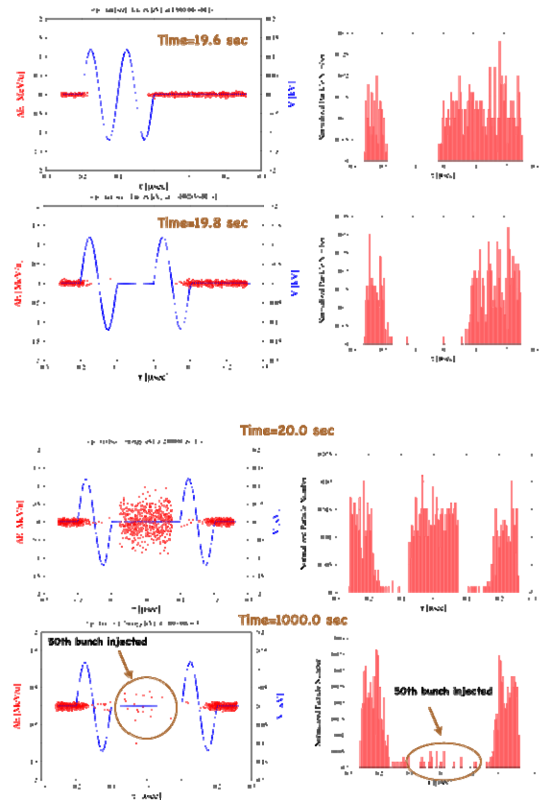


Figure 9 Particle distribution in the longitudinal phase space (left) at t=0, 0.4, 19.6, 19.8 and 20 sec for the moving barrier case. The right figures show the particle distribution along the ring. The bottom figure corresponds to t= 1000 sec (after 50th injection).

CONCLUSION

We have investigated the barrier bucket accumulation process with stochastic and electron cooling for the POP experiment at the ESR with simulation method. Both for the fixed and moving barrier accumulation process the experimental and simulation results are close in agreement. The particle tracking code developed for the simulation is bench-marked to be reliable. The application of BB accumulation with stochastic cooling to the HESR in FAIR project, and the Collider in NICA project with stochastic and electron cooling are proposed after the analysis with this code.

REFERENCES

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