STACKING MODES WITH BARRIER BUCKETS METHOD IN NICA COLLIDER

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Abstract

A new accelerator complex NICA is under construction at JINR. The main goal of this project is to reach a luminosity of 10^{27} [cm^{-2} s^{-1}] in the colliding experiments with gold ions in the energy range of 1 ÷ 4.5 GeV/u. Both electron and stochastic cooling methods are planned to be used to provide the required beam parameters. The comparison of the beam stacking in the longitudinal phase space with stationary and moving barrier buckets under action of electron cooling or without cooling are presented in this report.

BEAM STACKING IN LONGITUDINAL PHASE SPACE

The beam accumulation in the collider was proposed to be realized in longitudinal phase space with application of RF barrier bucket (BB) technique. If no cooling applied, the minimum longitudinal emittance of the beam after accumulation cannot be less than the sum of the injected bunch emittances:

$$\left(\frac{\Delta p}{p}\right)_{stack} L_{stack} \geq \left(\frac{\Delta p}{p}\right)_{inj} L_{inj} N_{cycles}\,, \qquad (1)$$

where $(\Delta p/p)_{stack}$ and $(\Delta p/p)_{inj}$ – momentum spreads, L_{stack} and L_{inj} – lengths of the stacked and injected regions correspondingly, N_{cycles} – number of injected cycles.

The maximum rms momentum spread of the stack cannot exceed the longitudinal acceptance which can be estimated as the barrier height in units of dp/p divided by 3 (±3σ include 95% particles). Thus the rms momentum spread of the injected bunch has to be less then:

$$\left(\frac{\Delta P}{P}\right)_{inj} \leq \frac{1}{3}\times\left(\frac{\Delta P}{P}\right)_{barrier}\times\frac{L_{stack}}{L_{inj} N_{cycles}}\,. \qquad (2)$$

This condition (2) shows the limit where accumulation without cooling is possible in principle. Otherwise the implementation of cooling is necessary.

Simulations of the particle accumulation for NICA collider with the stationary barrier buckets and the electron cooling system [1, 2] show that the efficiency of accumulation is good at low ion energies and is not sufficient at higher energies (Table 1). These simulations were made for the following parameters: the rms momentum spread of the injected beam - 5×10^{-4}, injection and stacking regions - 2π/3, interval between injections - 10 s, barrier voltage - 2 kV and length – π/3.

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Table 1: Stacking Efficiency with Stationary Barriers

Ion energy, GeV/u	1.5	2.5	4.5
Electron cooling rates, s^{-1}	0.32	0.08	0.013
Stacking efficiency, %	92	65	20

There is serious disadvantage of using stationary barriers. Particles are injected into unstable region (potential "top"). Their phase motion is slow in comparison to that of in stack. The time then particles are in injected region is lost for cooling. In addition while travelling through barriers from injection zone into stack, particles experience positive energy kick if their energy is above synchronous one and negative - if below. That means that momentum spread in stack is more than in injection region, as a result the time of cooling increases.

STACKING WITH MOVING BARRIERS

The simple scheme of stacking [3] with moving barriers can be proposed if the parameters of the injected beam satisfy to the condition (2). The pulse of the injection kicker is designed to be no less than 800 ns i.e. it occupies 1/2 of the Collider's perimeter in phase space. So the injection zone cannot exceed 1/2 of the circumference. But this difficulty can be circumvented because phase space occupied by barrier pulses can be used for the leading and trailing edges of the kicker pulse. That means that injection zone can be diminished up to π/5.

For simulations (Fig. 1) the following parameters were taken: ion energy - 4.5 GeV/u, the barrier rf amplitude - 5 kV, barrier phase width - π/10. In addition, the initial momentum spread of injected beam was chosen to be 1×10^{-4} that meets well the expected parameters of the NICA collider (Table 2). The barrier height of 5 kV corresponds to $(\Delta p/p)_{barrier} = 2\times10^{-3}$, so the injected beam is well satisfied to the condition (2).

Table 2: Parameters of the Injected Bunch [4]

Ion Energy, GeV/u	1.0	4.5
RMS bunch length, m	5.9÷17.5	2.5÷6.2
Momentum spread, 10^{-4}	2.8÷0.95	2.1÷0.85

Particles are injected into the stable region (Fig. 1a). 1st and 4th barriers are moving during 3 sec more close to the injection region (Fig. 1b). Amplitudes of 3rd and 4th barriers are decreasing during 4 sec to zero value (Fig. 1c). 1st barrier is moving during 3 sec to the own initial position and 2nd barrier is moving to the initial position of the 4th barrier (Fig. 1d). Just before the next injection cycle all barriers jump back to their initial positions (Fig. 1a) and procedure repeats.

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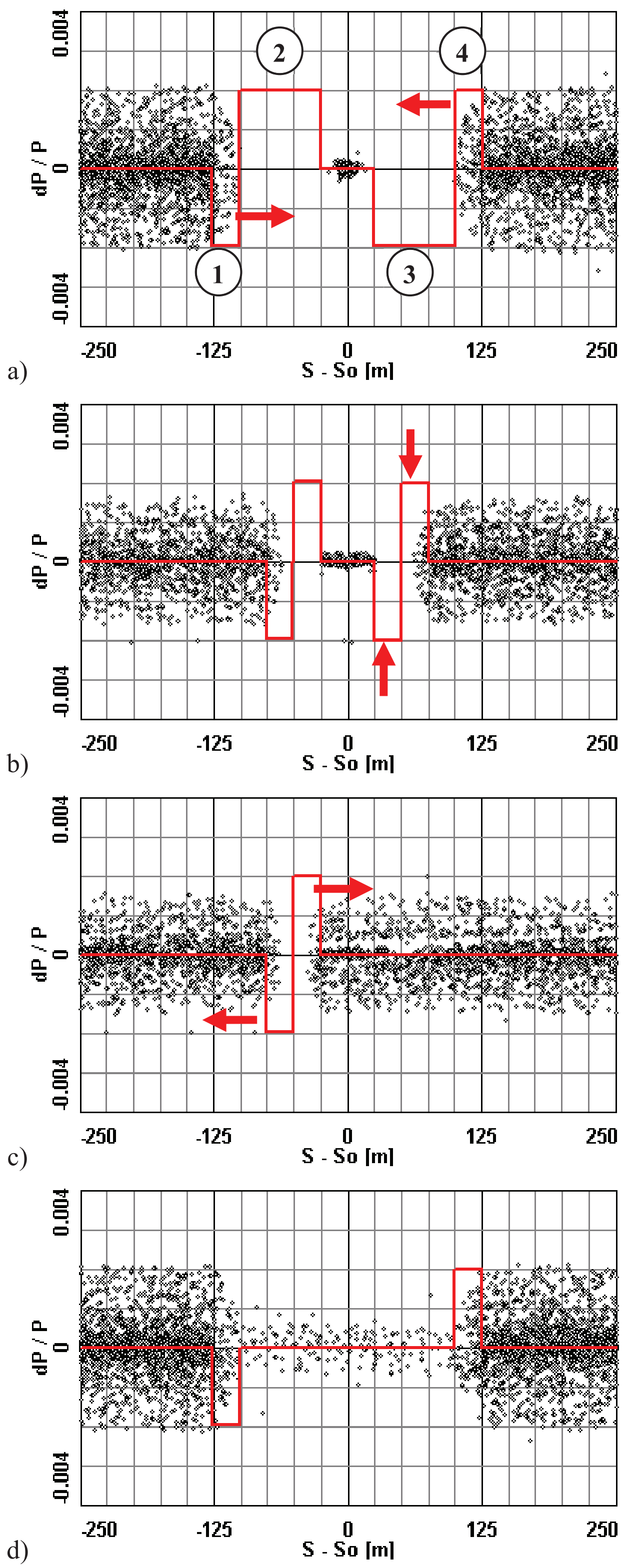

Figure 1: Particle distributions and positions of barriers during the stacking process with moving barriers (barrier height is shown in units of momentum spread): a) t=230 sec (24th injection), b) t=233 sec, c) t=.236 sec, d) t=239,9 sec (before 25th injection). Ion energy 4.5 GeV/u.

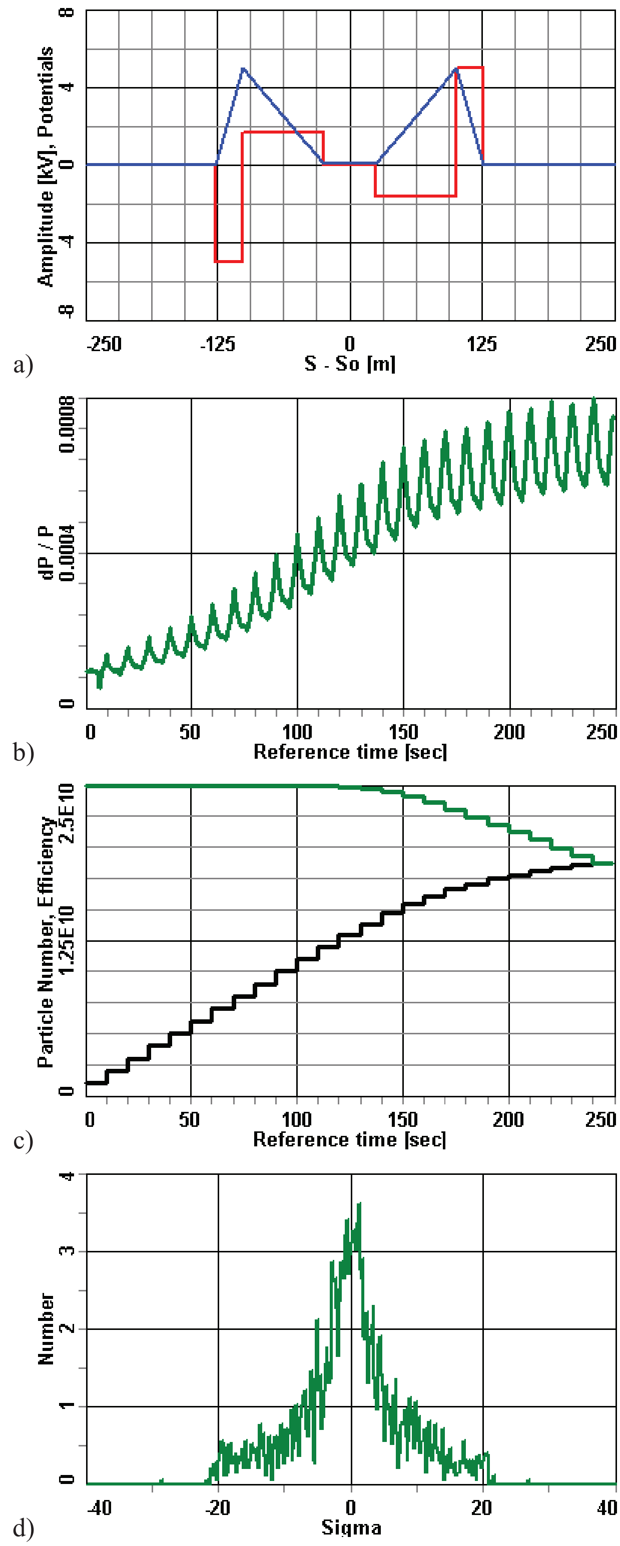

Figure 2: Accumulation of particles in Collider: a) initial barrier amplitudes and potential distribution, b) momentum spread evolution, c) evolution of particle number (black) and accumulation efficiency (green, full scale - 100%) d) final momentum spread distribution (one Sigma corresponds to the initial momentum spread 10^{-4}).

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Before the injection 2nd and 3rd barriers have amplitude 1.66 kV and width 3π/10 (Fig. 1a and Fig. 2a). Then all barriers have amplitude 5 kV and width π/10 (Fig. 1b) what is defined by technical reasons of the RF system.

The presented stacking scheme (Fig. 1) is not 100% adiabatic that leads to the additional emittance growth in comparison to the ideal stacking process (1). Under assumption that the barrier widths are small in comparison to the widths of injected and stacked zones one can write a simple expression for stack's momentum spread increase during accumulation:

$$\left(\frac{\Delta p}{p}\right)_{stack} = \left(\frac{\Delta p}{p}\right)_{inj} \times \left(\frac{L_{stack} + L_{inj}}{L_{stack}}\right)^{N_{cycles}} . \quad (3)$$

Simulations show that growth of stack's momentum spread satisfies well to this simple expression up to the 11th injection (Fig. 2b). Further the character of dependence change when losses begin (Fig. 2c) and at last reaches saturation. This saturation is defined by the particle losses of tails of the distribution (Fig. 2d) that exceed the barrier height.

The key element for the adiabaticity of the accumulation process is the "correct merging technique" of newly injected and stacked beam (steps represented on Fig. 1b-c). One can formulate these conditions as follows:

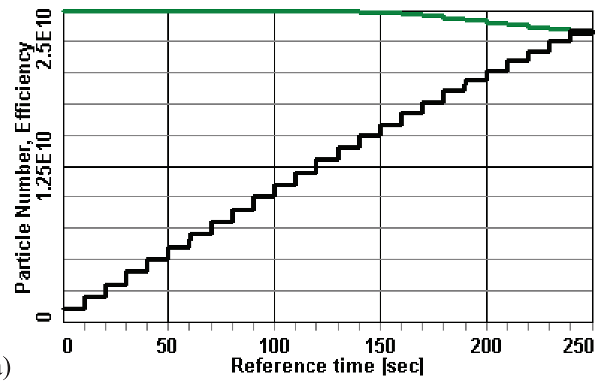
- Momentum spreads of the injected and stacking beam should be equal before the merging.
- The barrier width and height between the injected and stacking beam should be adiabatically decreasing in precise and proper way.

These conditions show that more elaborated scheme of the particle accumulation with moving buckets is needed. Authors plan to perform further simulations**.**

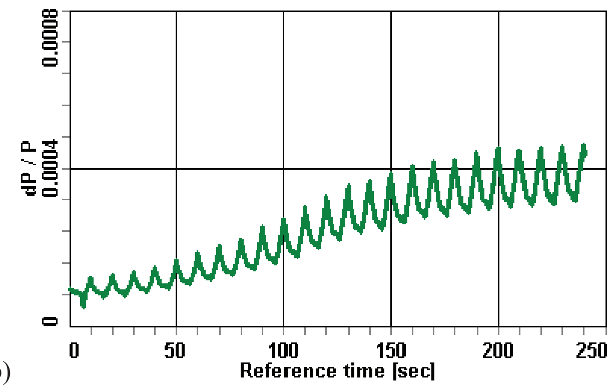
STACKING WITH MOVING BARRIERS AND E-COOLING

The using of the electron cooling with moving barriers can significantly decrease the particle losses as well as final momentum spread (Fig. 3). As it was mentioned above the electron cooling time exceeds the time interval between injections for the energy of ions above 2.5 GeV/u if the scheme with 2 stationary barriers is implemented. The presented stacking scheme with 4 moving barriers permits to apply the cooling method to all particles during whole accumulation procedure without particle losses in the injection region.

The ring optics of the NICA collider was optimized for the stochastic cooling at the maximum energy 4.5 GeV/u. The relativistic gamma of the transition was chosen 7.1. The barrier height (in units of momentum spread) has the maximum value for the maximum ion energy 4.5 GeV/u and smaller values for low energies. On other hand the electron cooling is faster for lower energies. Simulations of the stacking efficiency for the different energies for the same parameters of barrier bucket system without and with electron cooling are presented in Table 3.



a)



b)

Figure 3: Accumulation with electron cooling and IBS: a) particle number (black) and accumulation efficiency (green), b) momentum spread. Ion energy 4.5 GeV/u.

Table 3: Stacking Efficiency (%) with Moving Barriers

Ion energy, GeV/u	1.5	2.5	4.5
Barrier height,(Δp/p)×10^{-3}	0.87	1.08	2
Electron cooling rates, s^{-1}	1.0	0.25	0.03
Without cooling, %	68	70	74
With electron cooling, %	93	91	93

CONCLUSION

The presented simulation with moving barrier buckets shows that the beam stacking in the longitudinal phase space can reach a good efficiency for the expected parameters of injected beam even without cooling. However implementation of cooling methods is mandatory for the colliding mode when the maximum luminosity is to be reached.

REFERENCES

[1] A. Smirnov, A. Sidorin. Long Term Beam Dynamics Simulation with the BETACOOL Code. Proc. of RuPAC'2012.
[2] T. Katayama, I. Meshkov, A. Sidorin, G. Trubnikov. Beam Cooling at NICA Collider. Proc. of RuPAC'2012.
[3] C.M. Bhat. Applications of Barrier Bucket RF Systems at Fermilab. Proc. of RPIA2006, March 7-10, 2006, KEK, Japan, FERMILAB-CONF-06-102-AD.
[4] N. Agapov, A. Butenko, A. Eliseev, et.al. Present Status of NICA Project. Proc. of COOL'13, Murren, Switzerland.

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