INJECTION SIMULATION STUDY AT ACCUMULATOR COOLER RING AT RI BEAM FACTORY

K. Ohtomo, RIKEN, Wako, Japan
T. Katayama, Center for Nuclear Study, Univ. of Tokyo, Tanashi, Japan

Abstract

In the proposed RI beam factory project[1] by RIKEN, Accumulator Cooler Ring (ACR)[2] will be used for the accumulation and cooling of the radioactive isotope (RI) beams which are produced by the beam from a Super-conducting Ring Cyclotron (SRC) and pass through a fragment separator. The momentum spreads of these RI beams will be significantly reduced in short time during injection by the electron cooling and stochastic cooling devices at the ACR. Numerical simulations for searching parameters of RF stacking and cooling force were performed. It was found that the required cooling time should be nearly or less than 0.1sec. Total number of injected particles is expected to be 10 times as much as that by not using RF stacking and cooling.

1 LATTICE DESIGN OF ACR

Lattice design study of ACR had been reported[3] and here parameters and layout are briefly summarised at Table 1 and Figure 1,2.

Table 1 Lattice Parameters of ACR

Circumference	C=168.4836 m
Max. Magnetic Rigidity	Bρ = 8.0 T.m
Max. Beam Energy	E = 400 MeV/u (A/Z=2.3)
Transition Gamma	γ = 4.987
Betatron Tune Values	Qx/Qy = 4.555/3.540
β-function at Injection point	βx/βy= 4.24m/8.75m
Dispersion at Injection point	Dx/Dy= 4.518m/0.0m

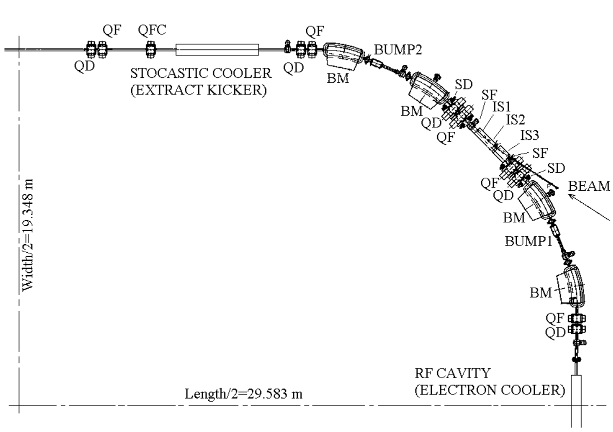

Figure 1: A quarter layout of ACR

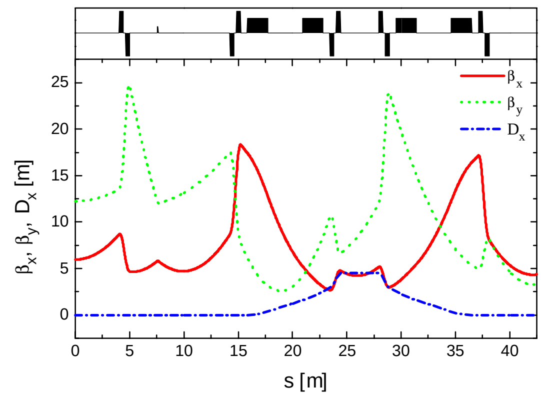

Figure 2: A quarter of lattice functions at ACR.

The ACR consists of 4 corner sections, 2 long straight sections and 2 short straight sections. An electron cooler and an RF cavity for RF stacking locate at short straight sections. Each longer straight section is divided into 3 parts by doublet quadruple magnets and occupied by a pair of stochastic cooling device, a fast extraction kicker and equipment for experiments. Each corner section consists of 4 bending magnets and 4 doublets which function as a dispersion suppresser. At center of corner, where a maximum value of dispersion exists, beams are injected into a bump orbit formed by 2 bump magnets.

2 DEBUNCHER SYSTEM

First estimations about injections into ACR had reported[4] and it was clear that a difficulty of injection directly from fragment separators because of large momentum spreads of RI beams.

In order to solve the problem, design of debuncher system to install on the beam transfer line prior to injection point at ACR and numerical simulations had been performed[5]. Beam parameters and required debuncher RF voltages in case of typical nuclei beams are listed in Table 2, here we assumed that initial phase and momentum spreads just after the fragment separator are ±5 degrees and ±0.5%, respectively. The distance between the fragment separator and the debuncher also affects debunching ratio. The distance turned to be 80m after optimisation in order that various beams having energy ranging from 60MeV/u to 400MeV/u with using a same tunable debuncher cavity. From view of importance compactness to design cavities, the harmonics of RF debucher with respect to RF of SRC was turned to be from 6 to 8.

Table 2 Beam Parameters and debuncher RF voltage

Nuclei	$^{12}C^{+6}$	$^{238}U^{+92}$
Kinetic energy [MeV/u]	400	100
Initial Δp/p [%]	±0.5	±0.5
Initial ΔE [MeV/u]	±3.4	±0.95
Initial Δϕ [degree]	±5	±5
Debuncher frequency [MHz]	229.02	160.59
Δp/p after debunching [%]	±0.20	±0.12
ΔE after debunching [MeV/u]	±1.35	±0.5
Δϕ after debunching [degree]	±12.6	±0.5
Required RF voltage	4.23	0.92

3 RF STACKING WITH COOLING

3.1 Model of RF Stacking Simulation with Cooling Effects

The model of the RF stacking process with cooling effects consists two stage.

In RF stacking stage, the motion of particles is under synchrotron oscillation equations given by below:

$$\frac{d\phi}{dt} = \frac{2\pi h \eta f_s}{\beta^2} \frac{E - E_s}{E_s},$$

$$\frac{dE}{dt} = \frac{Z}{A} eV(t) f_s \sin\phi.$$

Here h is a harmonics, η is a phase slip factor, f_s is a revolution frequency of synchronous particle, Z/A is a charge mass ratio and V is an RF voltage, respectively. In order to reduce the momentum spreads of particles after stacking, the RF voltage decreases as adiabatic decay curve which gives particle distributions the least blow-up on phase space:

$$V(t) = \frac{V_o}{(1 - 2\varepsilon\Omega_s t)^2}$$

Here V_o is a initial voltage, ε is an adiabatic factor and Ω_s is a synchrotron frequency, respectively[6].

In cooling stage, the RF is switched off and then cooling devices are switched on. We supposed that particles received cooling force given by below:

$$\frac{dE}{dt} = -\frac{E - E_{target}}{\tau_{cool}}$$

Here E_{target} is a target energy of cooling and τ_{cool} is a cooling time, respectively. τ_{cool} is treated as a parameter in this simulation. The examples of RF frequency and voltage pattern are shown in Fig. 3 for one cycle. Above process repeats till total time reaches 1 sec that equals a period of acceleration at Booster Synchrotron Ring.

Particle motion were simulated with Runge-Kutta method for carbon ions therefore the carbon has the largest energy and spreads among all ions come from SRC. The initial distribution of injected particles is the output data from debunching simulation result. Simulated particle number is 500 at every stacking cycle. The RF frequency starts from 38.166MHz corresponding to energy of 400MeV/u, decreases quadratically and reaches to 37.651MHz corresponding to 380.1MeV/u. The difference of energy corresponds to 3% in momentum. A threshold energy is set to 393MeV/u and all particle exceed this limit at every cycle end are regarded to be lost. The target energy of the cooling force is also set to the stacking bottom energy.

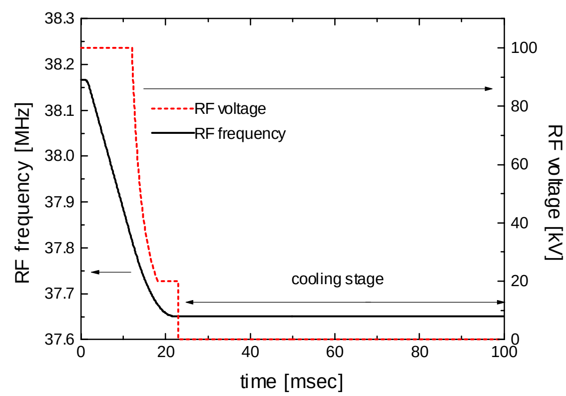

Figure 3 : An example of RF frequency and voltage pattern. Here initial RF voltage is set to be 100kV and reduced to 20kV with an adiabatic factor of –0.00016.

3.2 Capture Efficiency

Firstly a capturing efficiency were evaluated. One cycle stacking was simulated with keeping RF voltage constant. The results are shown in Fig. 4. This indicated that it is practically enough for use that the value of initial RF voltage is 50kV.

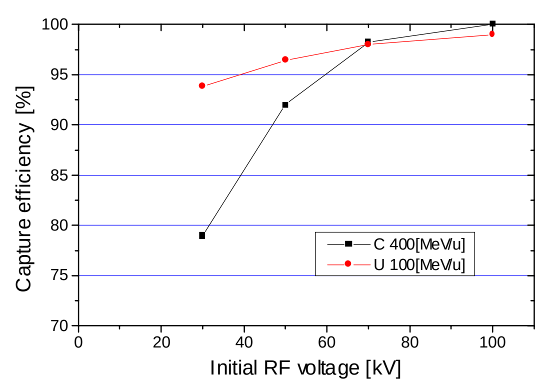

Figure 4 : Capture efficiency dependence on RF voltage.

Also one cycle stacking with voltage decay pattern were simulated. Capture efficiencies were calculated to be 95, 80, and 44% when the initial RF voltage of 100kV were reduced to 20, 5, and 1kV, respectively. In each case, energy spreads after one cycle were proved to be 1.0, 0.5, and 0.3MeV/u.

There was no remarkable difference in efficiencies and energy spreads with changing an adiabatic factor from –0.0016 to –0.00016.

3.3 Stacking Efficiency

A multi cycle simulation without cooling stage was tried to compare the cooling effect. A period time of one cycle and number of cycle were assumed to be 33msec and 30, respectively. Particles distribution on phase space and its histogram after RF stacking are shown in Fig. 5.

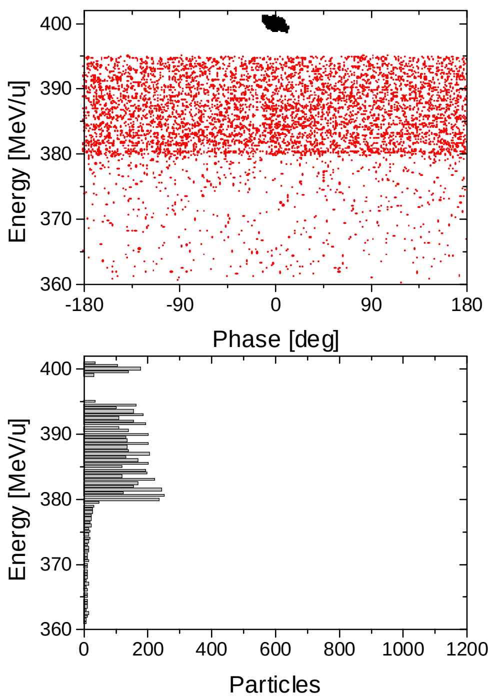

Figure 5: Particle distribution after 30 cycles of RF stacking without cooling. A bunch located at 400MeV/u is an injected beam bunch through debuncher.

The injection efficiency proved to be 34% and after the 11th cycle the number of stored particles was saturated. It suggests that we should reduce the number of cycles and take as long period for cooling stage as possible.

The period of one cycle was changed to 100msec and added the cooling stage in simulations(see Fig.3). The cooling times as parameters were set to 1, 0.5 and 0.1sec. The histograms of particle distributions are shown in Fig. 6.

The injection efficiencies in these case are almost 100%. As to the stored particles number in total time(1sec) both case are comparable to another. However the energy spreads of stacked particles are different from each other. The results show that the cooling time should be nearly or less than 0.1sec which is practical and realistic value in case that the total number of stored particles is supposed to be less than 10^7[7].

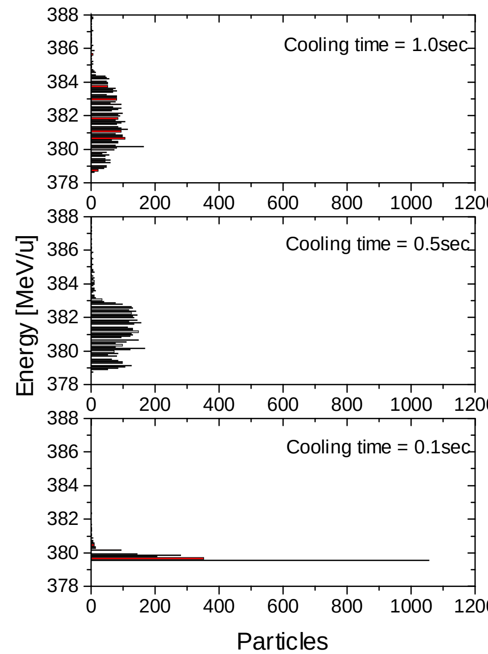

Figure 6 : Particle distribution after 10 cycles of RF stacking with cooling. The cooling times are 1.0, 0.5 and 0.1 sec from top to bottom, respectively.

4 CONCLUSION

The injection simulations with and without cooling effects were performed. It is enough for capturing particles in RF buckets that the maximum RF voltage is 100kV. The capture efficiency is not dependent to the voltage decay curve strongly. The total injection efficiency is dominated by cooling force and the cooling time must be nearly or less than 0.1sec in case of 10Hz cycle stacking.

REFERENCES

[1] Y. Yano et al., "Progress of RIKEN RI Beam Factory Project", EPAC'96, Sitges, June 1996, 536.
[2] T. Katayama et al., "MUSES Project at RI Beam Factory", ibid., 563
[3] J. W. Xia and T. Katayama, "Lattice for Accumulator Cooler Ring for MUSES", ibid., 932
[4] Y.J. Yuan et al., "Simulation of RF Stacking combined with Cooling Effects", ibid., 1338
[5] K. Ohtomo and T. Katayama, RIKEN Accel. Prog. Rep. **31** (1998) 225
[6] E. Ciapala, Proc. CERN Accelerator School 85-19 **1** (1985) 195-225
[7] N. Inabe et al., Proc. 11th Sympo. Accel. Sci. Tech., Harima (1997) 418