STORAGE, ACCELERATION AND SHORT BUNCHED BEAM FORMATION OF ^{197}AU^{+79} IONS IN THE NICA COLLIDER

A.V. Eliseev, O.S. Kozlov, I.N. Meshkov, A.V. Sidorin, A.V.Smirnov, G.V. Trubnikov,
JINR, Dubna, Moscow Region, Russia
T. Katayama, GSI, Darmstadt, Germany
V.N. Volkov, E.K.Kenzhebulatov, G.Y. Kurkin, V.M. Petrov, BINP SB RAS, Novosibirsk, Russia

Abstract

The regimes of high intensity beam of ^{197}Au^{+79} ions in NICA Collider are considered. The first stage – ion storage is proposed to be performed with Barrier Bucket technique at ion energy of 1 – 4.5 GeV/u. Ion accumulation at optimum for cooling energy level accompanied by slow acceleration with the same BB method to the energy of experiment also considered. Formation of bunched beam is fulfilled in two steps – first, at 24th harmonics and then, final formation, at 72th harmonics of the revolution frequency. The possibility of achievement of designed bunch parameters is shown.

INTRODUCTION

The goal of the NICA facility in the heavy ion collision mode is to reach the luminosity level of the order of 10^{27} cm^{-2}s^{-1} in the energy range from 1Gev/u to 4.5 Gev/u. Collider circumference is 503 m and beta-function in IP is supposed to be 0.35m. The beam parameters required to achieve the design luminosity are listed in the Table 1 [1]:

Table 1: ^{197}Au^{+79} beam parameters

Number of bunches	24		
Rms bunch length	0.6m		
Ion energy, GeV/u	1	3.0	4.5
Ion number per bunch	$2.75\cdot10^8$	$2.4\cdot10^9$	$2.2\cdot10^9$
Rms dp/p, 10^{-3}	0.62	1.25	1.65
Rms beam emittance, h/v, (unnormalized), π·mm·mrad	1.1/ 1.01	1.1/ 0.89	1.1/ 0.76

Collider RF systems have to provide:

- Accumulation of required numbers of Ions in the energy range 1÷4.5 Gev/u.
- Accumulation at some optimum energy and acceleration up to the energy of experiment
- Formation of necessary number of bunches (24)
- Achievement of designed bunch parameters

This can be done with the help of three RF systems: one broad band type and two narrow-bands. The first one accumulates particles in longitudinal phase space with application of RF barrier bucket (BB) technique. By applying additional voltage meander between barriers it can be used also for acceleration (inductive acceleration). Second RF system works on 24-th harmonics of revolution frequency and is used for formation of proper number of bunches. The third RF system is used for the final bunch formation and maintenance bunch parameters during collision mode.

All stages of bunch formation as well as collision mode are accompanied by cooling process either stochastic or electron. General scheme of beam preparation is represented in the Fig. 1.

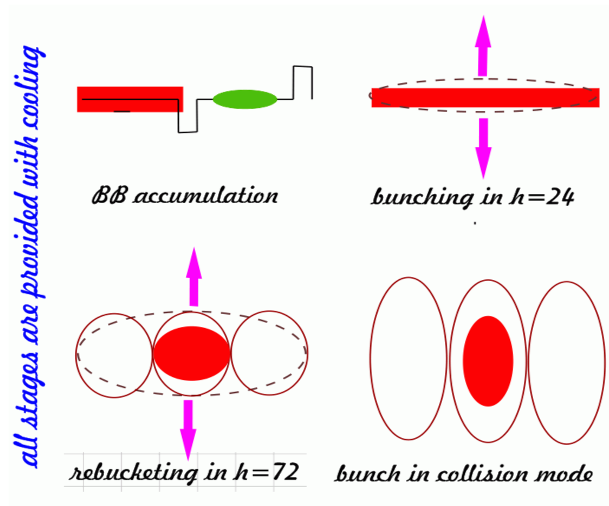

Figure 1: Scheme of RF cycle in Collider.

SHORT BUNCHED BEAM FORMATION

Accumulation of Ions ^{197}Au^{+79}

Application of RF barrier bucket (BB) technique provides independent optimization of the bunch intensity, bunch number as well as controlling of the beam emittance and momentum spread during the bunch formation. In presence of cooling the number of the injection pulses can be large enough with suitable stacking efficiency. Intensity of the injected portion influences on the stacking process duration only and can vary widely.

Collider rings receive bunch every 4-5 seconds from Nuclotron. Bunch contains $1\div2\cdot10^9$ particles. Its total length and momentum spread are about 10 m and 10^{-3} accordingly. The BB pulses divide the ring circumference by two zones of equal length: the injection zone (where the synchrotron motion is unstable) and that one for the stack (with stable synchrotron motion). Barrier pulse phase width – π/6 rad and voltage amplitude – 2kV.

Numerical simulations of ion stacking with barrier bucket method have been performed independently by T.

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Katayama [2] and A. Smirnov [3]. Both simulations have shown a sufficiently high efficiency of the stacking procedure (Fig. 2).

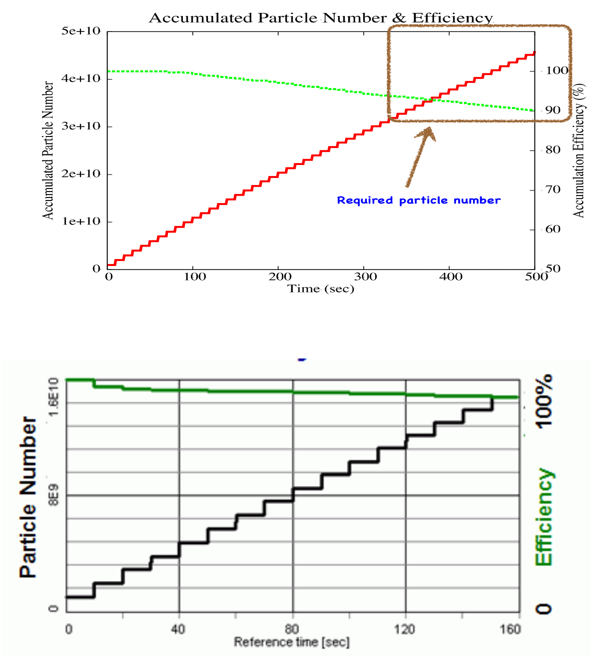

Figure 2: Increase of accumulated particle number as a function of time: up) - T. Katayama (3.5 GeV/u), down) - A. Smirnov (1.5 GeV/u); step curves: accumulated particle number vs. time, green lines: accumulation efficiency vs. time.

It was shown that time duration of approximately 200 seconds is enough for accumulation of required number of ions in energy range 1÷2.5 Gev/u notwithstanding the substantial dropping of its efficiency with the energy increase: At 1.5 GeV/u – 92% and at 2.5 GeV/u – 67%. The equilibrium between cooling and IBS processes corresponds to the momentum spread of ~$2\cdot10^{-4}$. This number is used for longitudinal emittance evaluation of coasting beam after barriers are off. Similar results were obtained for accumulation process accompanied by stochastic cooling for the energy 4.5 Gev/u [3].

Acceleration in Collider

There are two main reasons for acceleration in the Collider:

- Significant dependence of the accumulation efficiency on the ion energy
- Saturation flux density of Nuclotron's magnets is about 1.8T while 4.5 GeV/u corresponds to 2.2 T.

The possibility of ion accumulation at "optimal" energy level and further acceleration up to the energy of experiment with the help of BB RF system (induction acceleration) was considered. Design of BB resonator permits to create an accelerating "meander-type" voltage up to 300V amplitude. This implies acceleration rate at 0.024 T/s and acceleration time from 1 GeV/u to 4.5 GeV/u – 51 sec.

Beam Preparation for Collision Regime

At collisions the bunch has to have proper longitudinal emittance (see Table 1.). At 1 Gev/u rms emittance is equal to 1.25 eV·s while after accumulation its equivalent portion is about 5 eV·s. Final emittance is lesser then starting one over the whole energy range thus further beam manipulations have to be accompanied by cooling.

Preparation of beam for collision occurs in two stages. Firstly 24 bunches are produced using adiabatic capture technique: slow increase of RF voltage starting from "zero" level (ideally). Under cooling the bunch shrinks not only in its length but in emittance as well. Then the bunch length becomes short enough it is intercepted into third collider RF system working on 72th harmonics. Here it is possible to make a lower estimation of RF2 voltage needed in collider: emittance at interception must be equal to the final emittance and its length (±3σ) just fitted into bucket of RF3 (Fig. 3).

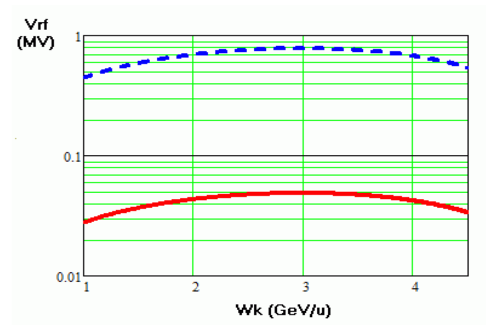

Figure 3: RF voltage amplitudes. RF2 – red. RF3 – blue vs. energy.

Although wide variety of scenarios is possible it is preferable to finish longitudinal emittance formation before RF3 starts working. In this case total voltage of RF2 can be limited by 50 kV. Bunch formation continues until its parameters meet conditions shown in Table 1. ESME code [4] was used for simulation of bunch transformation in longitudinal phase space after the rebucketing. Digest of simulation is represented on Fig. 4.

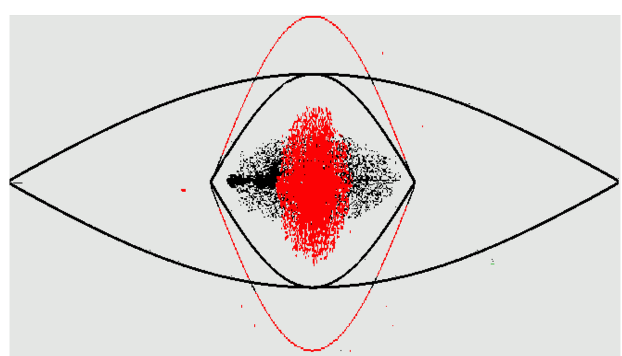

Figure 4: Bunch transformation after rebucketing

Total time of cooling needed for beam preparation after its accumulation in BB RF in both harmonic RF systems was estimated for the stochastic cooling with Palmer

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method at 4.5 GeV/u [3]. The result is about 250 c. Time needed for e-cooling is of the order of 10 seconds.

RF STATIONS

Preliminary design of all RF stations has been done in BINP Novosibirsk.

BB Station

Induction accelerator of BB station has 14 sections 12 of which are used for BB accumulation and 2 sections for acceleration. The total amplitude of pulses gathered on BB sections is equal to ± 5 V. Two acceleration sections create meander shaped pulse of amplitude ± 300 V. Other parameters are: magnetic permeability of amorphous iron - ~60000, saturation flux density – 1.3 T, maximum dissipated power of the station – 22 kW.

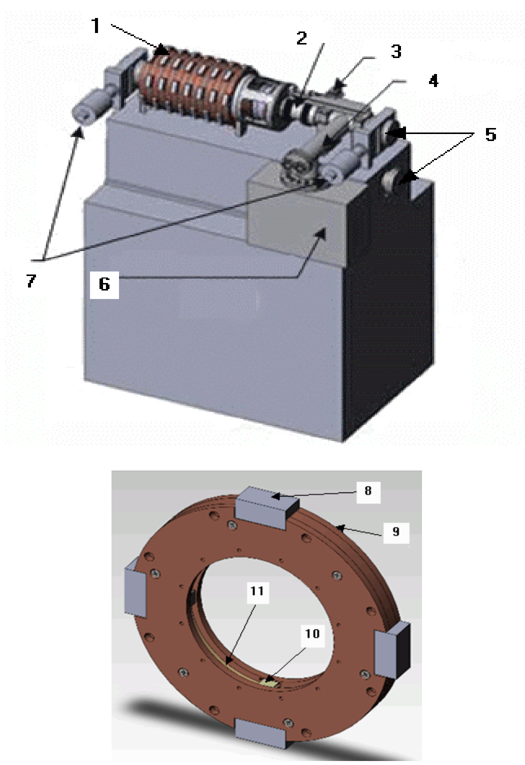

Figure 5: General view of BB station (up) and design of a section of the inductive accelerator (down). 1. Induction accelerator. 2. Contactor within vacuum chamber. 3. Drive for contactor. 4. Manometric tube. 5. Vacuum chambers. 6. Vacuum pump. 7. Gates. 8. Box of electronic keys. 9. Cover. 10. Excitation coil. 11. Amorphous iron coil

RF2 and RF3 Stations

Accelerating stations of 2^{-nd} and 3^{-d} RF systems (Table 2) have similar design and its general view is represented on the Fig. 6.

Table 2: Parameters of RF2 and RF3 resonators

parameter	RF2	RF3
Frequency range, MHz	12.528÷ 14.088	37.584÷ 42.264
Characteristic impedance, Ohm	15.4÷17.3	36.9÷42.5
Quality	3570÷3750	5490÷ 5820
Shunt impedance, kOhm	54.8÷60.0	252÷304
Accelerating voltage, kV	25	125
Dissipated power, kW	4.8÷5.7	32.1÷ 38.6
Number of resonators per ring	4	8

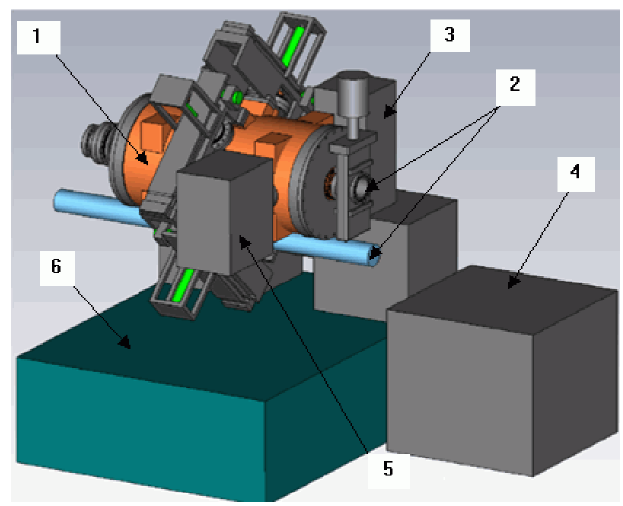

Figure 6: General view of the accelerating resonators of RF2 and RF3 for the upper collider ring. 1. Resonator. 2. Vacuum chambers. 3. Generator. 4. Air cooling for generator. 5. Vacuum pump. 6. Stand

CONCLUSIONS

1. The presented scheme of the bunch formation based on three RF systems seems to be optimal.
2. The parameters of all RF systems are achievable with present-day technologies.

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