SIMULATION OF Au^{32+} BEAM LOSSES DUE TO CHARGE EXCHANGE AND DYNAMIC VACUUM IN NUCLOTRON BOOSTER

A.V. Philippov#, A.B. Kuznetsov , V.A. Mikhaylov , A.O. Sidorin , G.V. Trubnikov
JINR, Veksler and Baldin Laboratory of High Energy Physics Dubna, Russia
P. Puppel , P. Spiller
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Abstract

The StrahlSim code [1] was used to simulate the beam loss and the dynamic vacuum for the proposed Nuclotron booster [2]. The Nuclotron booster will accelerate Au32+ ions from 6.2 MeV/u to 600 MeV/u. The simulations have been carried out considering systematic injection (0% to 10%) and RF-capture losses (5% to 15%). Furthermore the influence of an ion catcher system on the beam loss has been investigated, in order to estimate, if such a system could stabilize the beam loss. Without an ion catcher system, zero systematic losses, and a static pressure of 10^{-11} mbar ($7.5\cdot10^{-12}$ Torr), the transmission was calculated to be 83%. The presence of an ion catcher system would stabilize the transmission at a considerably higher level than without such a system for all scenarios.

BOOSTER PARAMETERS LIST

The main functions of the Nuclotron booster are the following [2]:

- Accumulation of $4\cdot10^9$ Au^{32+} ions in the booster;
- Acceleration of the ions up to energy of 600 MeV/u that is sufficient for stripping the gold ions up to the charge state of 79+;
- Simplification of the requirements to the vacuum conditions in the Nuclotron owing to higher energy and charge state of the ions injected into the Nuclotron;
- Decrease of the ion beam longitudinal emittance at the energy of approximately 100 MeV/u by application of electron cooling.

The FODO lattice was considered for further investigation as the more preferable lattice design. The parameters for the booster are listed in tables 1, 2, and 3. A diagram of the booster cycle and a scheme of the booster vacuum system are shown in Fig. 1, 2.

SIMULATION SETUP

The acceleration ramp had to be divided into two parts, because StrahlSim is not capable of simulating a waiting time in the middle of the ramp, as it is foreseen in the Nuclotron booster cycle. The division of the simulation is shown in Fig. 1 (left and middle) and was used for all calculations. First part (red line): injection at 6.2 MeV/u, acceleration with 1 T/s to 100 MeV/u and 1 s waiting time (electron cooling) at this energy. Second part (green line): acceleration with 1 T/s to a beam energy of 600 MeV/u, followed by a fast extraction at this energy, and ramping down. The beam losses due to electron cooling were not simulated, because StrahlSim is unfortunately not able to consider these losses. So the simulated beam losses during the cooling time are only due to charge exchange processes, and therefore less than the beam loss that can be expected.

Table 1: Parameter list for the Nuclotron booster lattice.

Fold symmetry	4
Number of the FODO lattice cells per arc	6
Length of lattice cell, m	9
Length of straight sections per cell, m	4
Betatron tunes	5.8/5.85
Phase advance per cell	1.51
Amplitude of β-functions, m	17
Maximum dispersion function, m	2.9
Dipole	
Beam horizontal/vertical emittance, π·mm·mrad	10/10
Effective field length, m	2.2
Curvature radius, m	14
Quadrupole	
Bending angle, degree	9
Effective field length, m	0.4
Average aperture	
Chamber shape	elliptical
Vacuum chamber, m^2	0.065×0.032

Unfortunately there are no charge exchange cross sections for Au^{32+}. Therefore the cross sections for Au^{31+} have been used for all simulations discussed in this work. The differences between these cross sections are considered to be negligible.

Table 2: Parameter list for the Nuclotron booster.

Ions	Au^{32+}
Circumference, m	211
Injection/extraction energy, MeV/u	6.2/600
Magnetic rigidity, T·m	2.4÷25

#philippov@jinr.ru

Table 2: Parameter list for the Nuclotron booster (continue).

Dipole field, T	0.17÷1.8
Quadrupole gradient, T/m	20
Pulse repetition rate, Hz	0.25
Magnetic field ramp, T/s	1
Harmonic number	4, after cooling 1
Number of bunches	4, after cooling 1
Beam injection/extraction type	one turn/one turn
Time for injection or number of turns, s	$7\cdot10^{-6}$
Injection store duration, s	0.02
Start-up time for the ramp, s	0.02
Vacuum, Torr	10^{-11}
Beam intensity, ions per pulse	$2\div4\cdot10^{9}$

Table 3: Vacuum system: gauge, pumps and gates.

Cold cathode gauge head, IKR 060, DN40 CF	36
Robust thermal conductivity gauge, Pirani gauge	6
Roughing-down pump Varian TriScroll 300	42
TM pump, Pfeiffer TMU 071 YP DN63 CF	28
TM pump, Pfeiffer TMU 521 YP DN160 CF	14
Adsorption pump, speed 80 l/s	22
Magnetic-discharge pump, speed 80 l/s	6
Titanium sublimation pump, speed 80 l/s	6
High vacuum gate, 10836-CE44 DN63	56
High vacuum gate, 10848-CE44 DN160	14

The types of pumps that were considered for beam loss simulations due to dynamic vacuum effects include the following: adsorption, magnetic-discharge and titanium sublimation pumps (see Fig. 2). For the simulation a total pumping speed of about 1.3 m^3/s was assumed.

RESULTS

The Au^{33+} ions appear in the booster as a result of charge exchange interaction of the circulating beam ions of Au^{32+} with residual gas (electron loss process). The other process, i.e. ionization of circulating beam ions of Au^{32+}, occurs due to interaction with residual gas as well. A collimation of Au^{31+} and Au^{33+} ions would stabilize the dynamic vacuum.

In order to investigate the influence of an ion catcher system on the stability of the vacuum system and the beam loss, ion catchers have been placed in the lattice.

The tracking simulations by StrahlSim give a total catching efficiency for each charge exchange channel. Here we give only the values for the collimation efficiency of the two considered charge exchange channels: about 86% for $Au^{32+}\rightarrow Au^{31+}$ and about 91% for $Au^{32+}\rightarrow Au^{33+}$. These values were obtained with a theoretical catcher system.

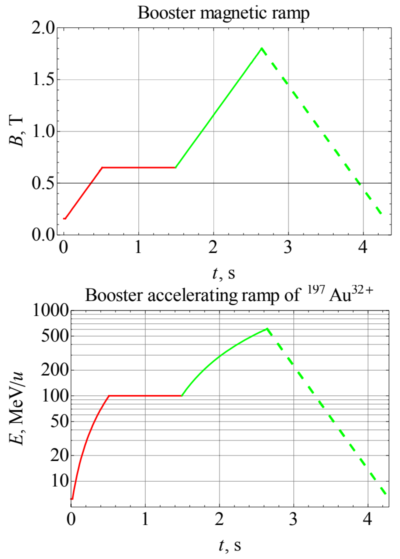

Figure 1: Nuclotron booster acceleration ramp for Au^{32+} magnetic ramp (top), accelerating ramp (bottom).

If such high collimation efficiencies can be reached in the real machine, has to be investigated separately. The collimation screenshots are shown in Fig. 3.

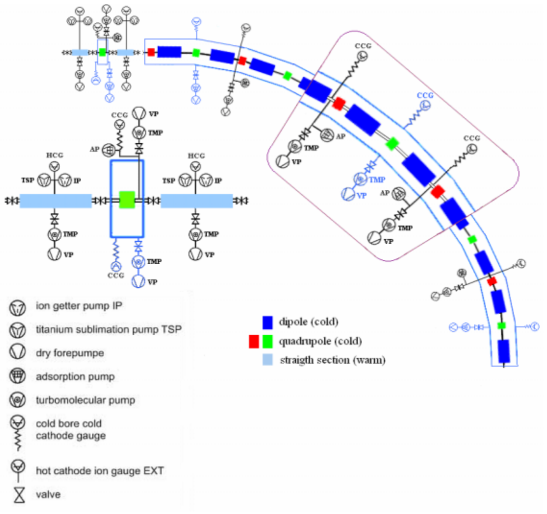

Figure 2: The Nuclotron booster vacuum system.

Tables 4 and 5 show the main simulation results. Simulations with extraction losses have been performed as well, but these results are not shown, because the pressure rise due to extraction losses would only have an influence on the simulation, if multiple cycles in a row would have been simulated. The transmission of simulations considering extraction losses only (5% to 15%), was stable at about 40% (with a static pressure of 10^{-10} mbar).

Table 4: Losses of Au^{32+} ion beams in the Nuclotron booster, with collimation.

Injection losses	Pressure, mbar		
	10^{-12}	10^{-11}	10^{-10}
0%	1%	6%	45%
5%		42%	64%
10%		61%	75%
RF capture losses	**Pressure, mbar**		
	10^{-12}	10^{-11}	10^{-10}
5%		41%	63%
10%		60%	75%
15%		72%	82%

Table 5: Losses of Au^{32+} ion beams in the Nuclotron booster, without collimation.

Injection losses	Pressure, mbar		
	10^{-12}	10^{-11}	10^{-10}
0%	2%	17%	73%
5%		77%	89%
10%		89%	94%
RF capture losses	**Pressure, mbar**		
	10^{-12}	10^{-11}	10^{-10}
5%		71%	87%
10%		85%	92%
15%		91%	95%

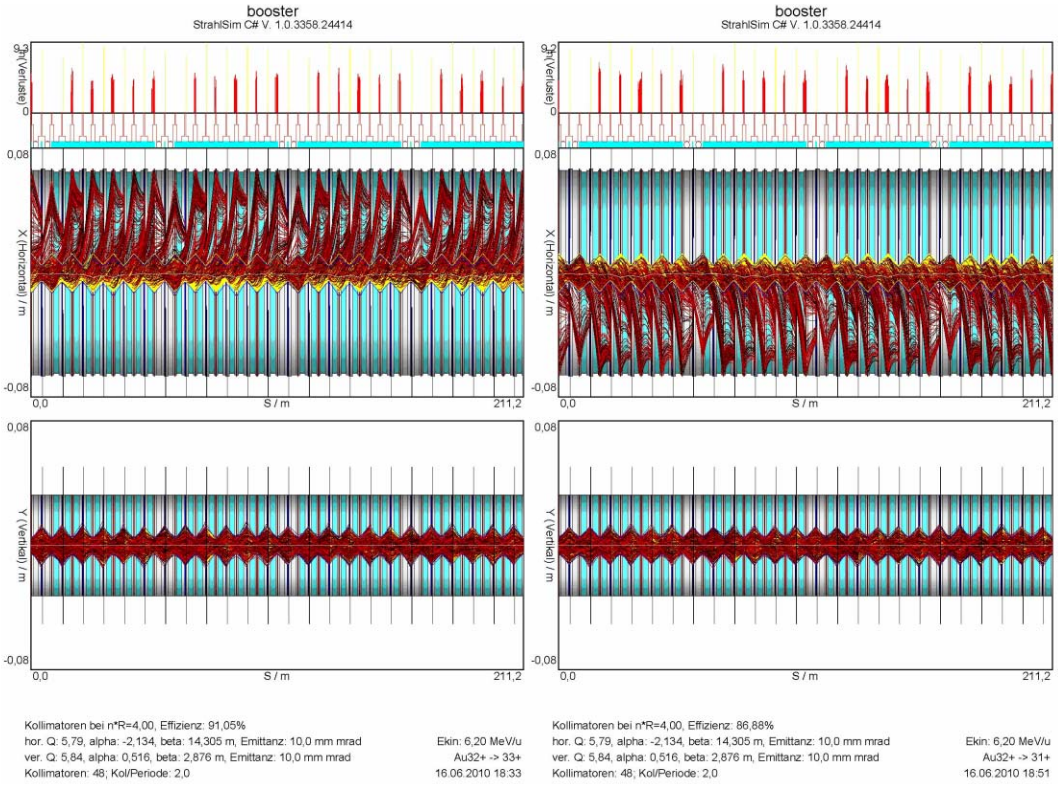

Figure 3: Collimation of Au^{32+} ions in the Nuclotron booster. Charge exchange channel: $Au^{32+} \rightarrow Au^{33+}$ (left) and $Au^{32+} \rightarrow Au^{31+}$ (right).

In total more that 100 simulations with different parameters have been taken out.

DISCUSSIONS

The simulation results show a strong dependence of the losses on the static pressure.

For a static pressure of 10^{-10} mbar the losses of all scenarios with (without ion catchers) is more than 40÷80% (70÷90%). As the Nuclotron booster is a cold machine, it is likely, that the static pressure is better than 10^{-10} mbar ($7.5 \cdot 10^{-11}$ Torr).

Furthermore the simulation results show, that the reduction of systematic losses to an absolute minimum is curtail for a stable operation of the Nuclotron booster with Au^{32+} ions.

REFERENCES

[1] C. Omet. Kollimatorsystem zur Stabilisierung des dynamischen Restgasdrucks im Schwerionensynchrotron SIS18: Ph. D. thesis. 2008.

[2] Conceptual Design Report of Nuclotron-based Ion Collider fAcility (NICA). JINR. 2008.