Simulation study to compensate for growth in energy spread and emittance in RUNBA

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A small heavy-ion storage ring called RUNBA,[1)] equipped with an internal target, is under construction at the E21 room. This project aims at the development of a beam recycling technique, which will be a novel tool for nuclear reaction studies involving rare RI's. A few RIs, less than 10 in number, are accumulated in RUNBA, which is equipped with an internal target, and they hit the target many times until a nuclear reaction occurs. For establishing this technique, we will install an energy dispersion corrector (EDC) and angular diffusion correctors (ADCh and ADCv) to compensate for an energy-spread growth and an emittance growth, respectively (see Fig. 1). Their required characteristics, which were obtained analytically, are described in Refs. 2) and 3). In this report, we show the results of a particle simulation in RUNBA for supporting the analytical solutions.

When an ion passes through the target, its energy is modulated by an energy straggling, $\Delta\epsilon_t$ $(= \Delta E_t/E)$, in addition to an energy loss, U, and the angle (traveling direction) is modulated by an angular straggling, $\Delta x'_t$. The energy loss is recovered in a radio frequency (RF) cavity. The energy difference is correctly modulated by $\Delta\epsilon_e$ at EDC, which is proportional to the difference in flight time from the design particle from the target and EDC. It is expressed as

$$\Delta\epsilon_e = \lambda_e \Big\{ \frac{q\eta_{te}T_{te}}{A\beta^2}\Big(1+\frac{\gamma^2+1}{\gamma^2-1}\frac{U}{E}\Big)(\delta\epsilon+\Delta\epsilon_t) + \frac{q\delta_t}{AE}\Big\}, \quad (1)$$

where λ_e is a proportional coefficient; A is the mass number; q is the charge numbers, E, γ, and β are the total energy (sum of mass and kinetic energy), Lorenz factor, and velocity of the design particle, respectively; η_{te} is the partial slipping factor between the target and EDC defined by the ring design; T_{te} is the flight time of the design particle from the target to EDC; $\delta\epsilon$ $(= \delta E/E)$ is the energy difference from the design particle; and δ_t is the expected uncertainty in the timing acquired at the target. Due to $\Delta\epsilon_t$ and $\Delta\epsilon_e$, the RF phase is unusually shifted in one turn by $\Delta\phi_t$ and $\Delta\phi_e$, respectively. On the other hand, the angle of ion incidence is modulated in one turn by an angular straggling, $\Delta x'_t$, at the target; an angular correction, $\Delta x'_h$, at ADC; and an adiabatic damping effect, $\Delta x'_c$, at the RF cavity. $\Delta x'_h$ is proportional to the position, x, measured at the target and expressed as

$$\Delta x'_h = \kappa_h(x+\delta_x), \quad (2)$$

where δ_x is the uncertainty in the position measurement. In this simulation, $\Delta\epsilon_t$, δ_t, $\Delta x'_t$, and δ_x are given as random numbers with Gaussian statistical distributions.

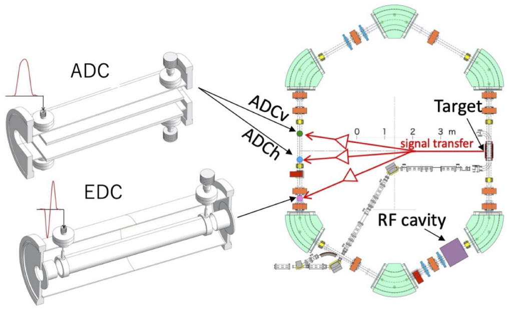

Fig. 1. RUNBA structure (right) and the designed ADC and EDC devices.

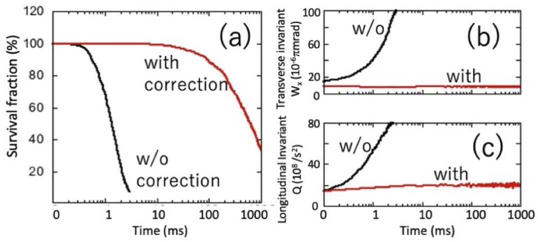

Fig. 2. Results of the present simulation. (a) Trends of the survival fraction and (b), (c) time evolution of the transverse invariant W and longitudinal invariant Q, respectively. The black and red curves show the simulation results without and with appropriate correction at the ADCs and EDC, respectively.

Using the RUNBA lattice structure designed in Ref. 1) and assuming that the beam is a 10 MeV/nucleon $^{12}C^{6+}$ beam and the target is ^{12}C with a thickness of $10^{18}/cm^2$, we performed a particle tracking simulation taking all the effects described above into account. As shown in Fig. 2(a), although the lifetime of the beam accumulation is less than 1 ms without corrections by the EDC and ADCs, it can be extended to ∼1 s with the corrections. Appropriate corrections keep the invariants of transverse motion, W,[3)] and longitudinal motion, Q,[2)] almost constant, as shown in Figs. 2(b) and 2(c). The coefficients λ_e and κ_h in this case are 240 V/ns and 2.5 μrad/mm, respectively. They are consistent with the solutions obtained analytically in Refs. 2) and 3). On repeating this 1-s accumulation process for isotopes with a production rate of 1 Hz, the collisional luminosity reaches $10^{24}/(cm^2 s)$.

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References
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