THE CONCEPTUAL DESIGN OF COLLIMATION SYSTEM FOR CSR *

LI Peng[1, #] YUAN You-Jin[1] YANG Jian-Cheng[1] JIANG Pei-Yong[1, 2] ZHENG Wen-Heng[1, 2]
MENG Jun[1] CHAI Zhen[1]
1 Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
2 University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

The heavy ion beams would be easily lost at the vacuum chamber along the CSRm when it is used to accumulate the intermediate charge state particles. The vacuum pressure bump due to the ion-induced desorption in turn leads to an increase in beam loss rate. In order to avoid the complete beam loss, the collimation system is investigated in the CSRm. The beam loss distribution is simulated considering the particle charge exchanged process. Then the collimation efficiency of the lost particle is calculated and optimized under different collimator's position, geometry, and beam emittance and so on. Estimation of beam loss positions and optimization of collimation system is completed by a newly developed simulation program. Two prototype collimators are under designing and will be tested in the CSRm.

INTRODUCTION

The heavy ion beams from HIRFL are injected into the CSRm, then accumulated, electron cooled and accelerated, before being extracted to the CSRe for internal target experiments and other physics experiments [1, 2].

Ions in an accelerator can interact with residual gas molecules and, in particular, change charge state by electron capture or, for partially stripped ions, by electron loss. Lost ions release gas molecules from the vacuum chamber walls. Molecules released from the vacuum chamber increase the pressure and the beam loss rate [3].

In order to accumulate the beams to higher intensity to fulfil the requirements of physics experiments [4] and better understanding of the dynamic vacuum pressure caused by the beam loss, accelerator machine protection method such as collimation system is considered to be installed in the CSRm. Furthermore, an international accelerator facility-High Intensity heavy ion Accelerator Facility (HIAF) project has been proposed by the IMP [5]. This complex can accumulate the reference particle 238U34+ to energy 1.2 GeV/u with intensity 5×10^{11} ppp. Therefore, a collimation system will be tested in the current CSRm to establish the technical storage for the new accelerator complex HIAF.

SIMULATION CODE

In order to simulate the charge exchange driven beam loss and dynamic vacuum effects in heavy ion synchrotrons, GSI firstly developed a program package named StrahlSim during the past ten years [6, 7]. With the scientific collaboration between GSI and IMP, a new program package (ColBeam) designed for optimizing the collimation efficiency is developed by taking different types of errors into account in the accelerator. In order to obtain more accurate beam loss positions, this program package divides each lattice element into small pieces with a certain length. For example, in this simulation, the CSRm is discretized into elements with a length of about 10 cm. Then the program package will draw the geometry of the ring or beamline according to the parameters loaded before. The lattice file with extension "LAT" for the simulation software Winagile [8] is used as the default input file.

For the charge exchanged particle, the deviation of the m/q ratio of a particle with a different charge state q compared to the reference ion with the charge state q0 is equivalent to a momentum deviation of [6]

$$\frac{\Delta p}{p} = \frac{q_0}{q} - 1 \quad (1)$$

All the charge exchanged particles are generated in the first turn. Multiple turn tracking for the charge exchanged particles will be implemented when these generated particles aren't lost in one turn. During the simulation, the twiss parameters of particles that are not lost in one turn will be recorded and are viewed as the initial transfer parameters to be calculated during the next turns. The simulation won't terminate until all the generated particles are lost.

BEAM LOSS DISTRIBUTION

In this paper, only the electron loss processes are simulated for the CSRm. Uranium beam $^{238}U^{32+}$ which was accumulated in the CSRm in 2011 is chosen as the reference ion to simulate the beam loss distribution with the machine operation parameters. The simulation beam parameters are listed in table 1.

Table 1: Simulation Beam Parameters

Reference ion	$^{238}U^{32+}$
Energy (MeV)	1.273
Transverse Tune (Qx/Qy)	3.605/2.61
Horizontal emittance (pi mm.mrad) 5-sigma	150

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#lipeng@impcas.ac.cn

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Vertical emittance (pi mm.mrad) 5-sigma	25
Momentum deviation	~10^{-4}
Charge exchanged ion (Coasting beam)	$^{238}U^{33+}$

With a constant vacuum pressure around the ring, the beam trajectory for one electron-loss $^{238}U^{33+}$ is illustrated in Figure 1(a). In this figure, the red rectangle is the focusing quadrupole in horizontal and the blue rectangle is the defocusing quadrupole. The light blue rectangle is the dipole and the red line in the element is the charge exchanged particles' trajectory. It should be noted that some other element such as sextupole, kicker, and corrector and so on are replaced by simple drift space.

The loss position and intensity of the charge exchanged particle at each point is counted and shown in the Figure 1(b). Semi logarithmic coordinate system is employed to illustrate the beam loss intensity at each position along the CSRm.

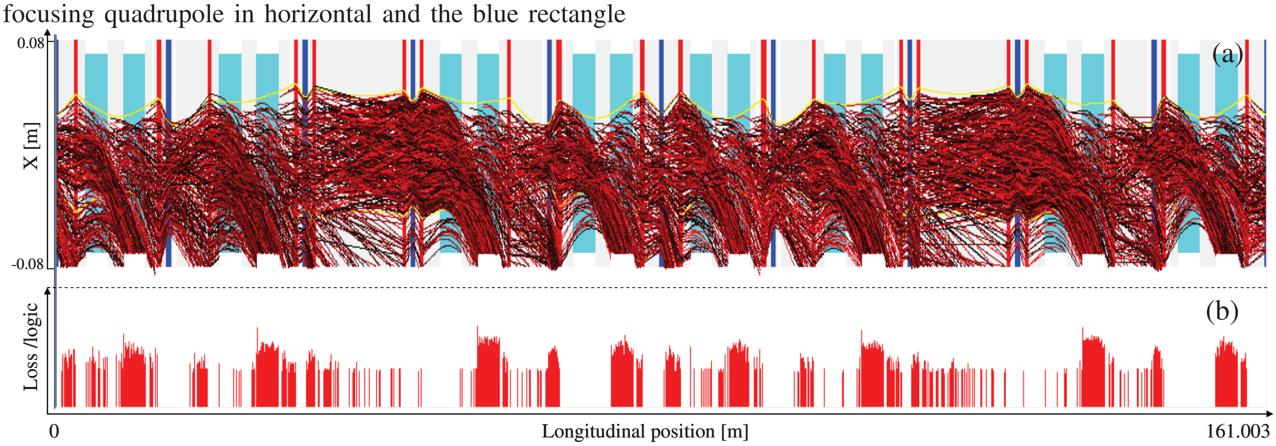

Figure 1: Simulation results for one electron-loss $^{238}U^{33+}$: (a) Beam loss trajectory. (b) Beam loss distribution. Loss/logic means: the logarithmic value of the lost beam intensity at each position.

COLLIMATION EFFICIENCY

In order to avoid vacuum chamber desorption caused by the particle loss, several specially designed catchers (collimators) should be mounted 'upstream' of the positions with high impact probabilities [6]. Most of collimators are rectangle copper block with coated low-desorption material such as gold and nickel [7, 9]. However, the length and positions of collimators are limited by the actual mechanical structure in the compact CSRm. Some beam position monitors (BPMs) will be moved out to install the collimators [10].

For a detailed analysis of the performance for the collimation system, the intensity factor of particles hitting the collimators N_c and the wall N_w defines the collimation efficiency θ with [6]

$$\theta = \frac{N_c}{N_w + N_c} \quad (2)$$

With higher collimation efficiency, most of the charge exchanged particles are lost on the collimators but not the vacuum chamber to avoid the gas desorption. Generally, the collimation efficiency is the function of the beam emittance as well as the machine's acceptance, the beam energy, the distance to the vacuum center and so on.

Collimator Length in the Horizontal Direction

According to the beam trajectory at the collimator positions, the lengths of collimators are optimized. The calculation of collimation efficiency is carried out twenty times with Gaussian distribution for charge exchanged particles in the phase space. Average value is obtained from twenty samples. Maximum and minimum deviations of the collimation efficiency are viewed as the error bars. The caching efficiency evolution with collimator variable length for one electron loss process is shown in Figure 2.

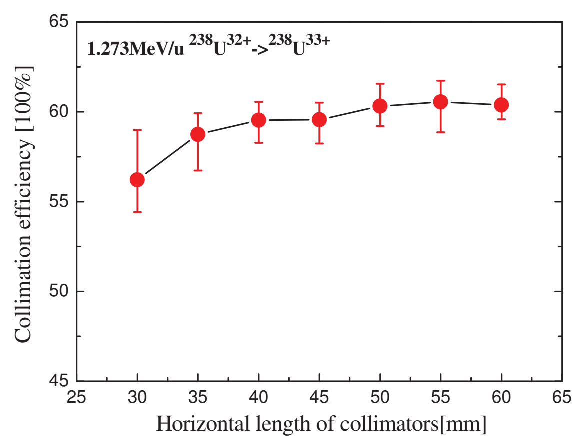

Figure 2: Collimation efficiency with variable horizontal length of the collimators.

Collimator Distance to the Beam Edge

The collimation efficiency will be affected by the beam orbit distortion due to the alignment and field errors of the magnets. If the collimator locates at the beam envelope edge refers to the ideal central orbit, and then the circulating normal beam will hit the collimators. Based on

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the fixed locations and length of the collimators, the collimation efficiency is simulated by adjusting the distance from the collimator to beam edge. The calculation result is illustrated in Figure 3 where collimation the efficiency decreases quickly when the collimators are pulled out from the beam edge.

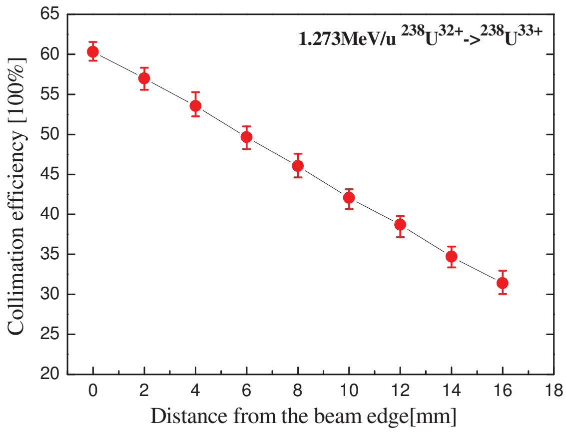

Figure 3: Collimation efficiency with variable collimators transverse position.

Collimator Distance to the Beam Edge

During the electron cooling process, the beam emittance will be decreased from the machine acceptance to 35 pi.mm.mrad in the horizontal phase space [11]. The collimation efficiency for one electron loss process is simulated with the evolution of the horizontal beam emittance is showed in Fig. 4. The result shows that lower beam emittance which is cooled down by the electron cooling contributes to the higher catchability of the charge exchanged particles.

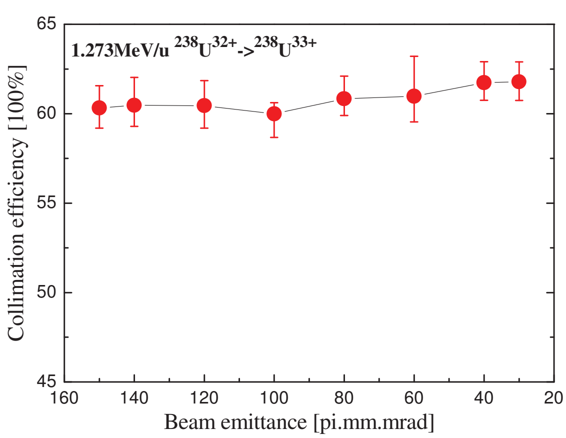

Figure 4: Collimation efficiency with beam emittance.

PROTOTYPE COLLIMATOR

Two prototype collimators have been designed and will be tested in the CSRm. The collimators are copper blocks with coated 20 um thick gold films. The collimators can be moved by means of a stepping motor with respect to the nominal position. The technical drawing of the movable collimator system is shown in Figure 5. This collimator system will be assembled at the beginning of next year and tested in the CSRm.

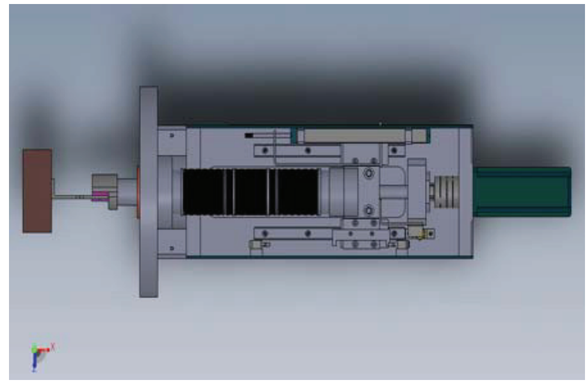

Figure 5: Picture of the movable collimator system.

CONCLUSION

In this paper, the beam losses driven by particle ionization process are simulated in the CSRm for the first time. Collimation system is designed to catch the charge exchanged particles as much as possible. The collimation efficiency is optimized under different collimator design. Two prototype collimators will be tested and installed in the space between two dipoles in the CSRm.

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