SIMULATION OF TWO-PLANE PAINTING MULTITURN INJECTION INTO BRING WITH SPACE CHARGE EFFECT

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Abstract

The new project HIAF is under design now in IMP (Lanzhou, China) [1]. One of the aim of the project is to accumulate up to 1×10^{11} ions U^{34+} in the booster ring (BRing) at the injection energy 17 MeV/u. Two-plan painting procedure in both horizontal and vertical spaces was proposed to fill out full acceptance of BRing. The space charge effect was estimated with the molecular dynamics technique which was effectively used for the crystalline beam simulation.

TWO-PLANE PAINTING

The aim of the two-plan painting at BRing is to reach the necessary beam intensity 1×10^{11} after an injection procedure (Table 1). The transverse emittance of the injected beam is 5 π mm mrad and the horizontal ring acceptance is about 200 π mm mrad. In this case, the maximum gain for one-plan injection is about 26 what is not enough to accumulate the necessary value of the particle number. In accordance with [2] the gain factor for two-plan painting procedure can be achieved a value up to 100.

Table 1: BRing parameters for Au^{34+}

Parameter	Value
Circumference, m	473
Rigidity, T m	1 – 34
Acceptance, hor/ver, π mm mrad	200 / 100
Longitudinal acceptance, $\Delta p/p$, %	±0.5
Injection energy, MeV/u	17
Injection intensity	1.5×10^{9}
Injection emittance, π mm mrad	5
Injected momentum spread, %	±0.5
Injection cycle number	90
Extraction energy, MeV/u	800
Extracted particle number	7×10^{10}

The two-plan painting can be realized with two groups of orbit bump for both horizontal and vertical, simultaneous injection in horizontal and vertical phase spaces using tilted septum (Figure 1). During injection procedure the septum position is coming to the reference orbit and the septum angle remains constant.

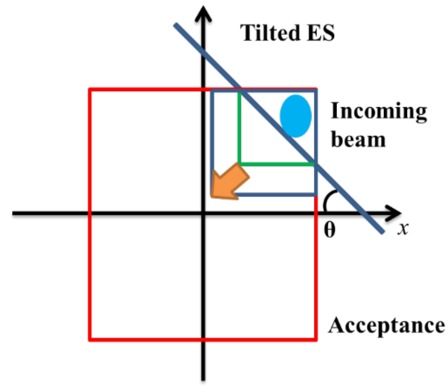

Figure 1: Scheme of injection in horizontal and vertical phase spaces using tilted septum.

The optimization of two-plan painting procedure was carried out with WinAgile [3], ORBIT [4] and BETACOOL [5] programs. The injection efficiency was optimized with the following input parameters: lattice functions at injection point, betatron values, septum angle, septum position, etc.

On Figure 2 is presented simulation results with BETACOOL for designed parameters (Table 1). Left picture is the particle distribution in the transverse plan, right picture is horizontal phase space after 90 cycles of the injection. The particle losses on the septum and transverse acceptance are taken into account. The dependence of the transverse emittances and particle number during injection procedure are presented on Figure 3.

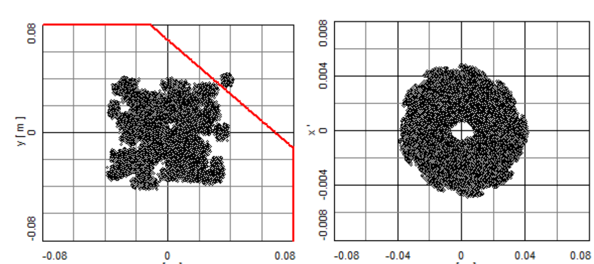

Figure 2: Particle distribution for transverse plan (left picture) and horizontal phase space (right picture) after 90 cycles of injection procedure.

Results of simulation with BETACOOL program have a good agreement with results of ORBIT program and show that without space charge effect the particle number can reach a necessary value 1×10^{11}.

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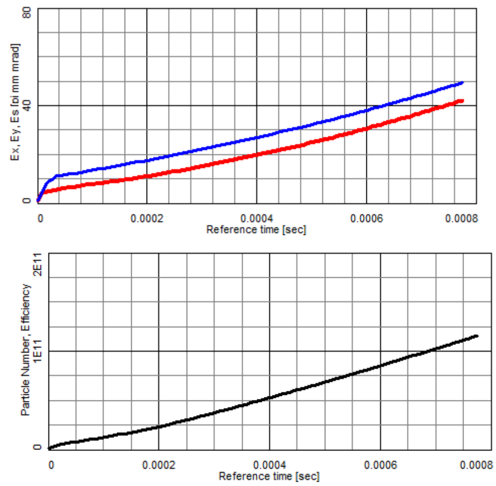

Figure 3: Transverse emittances (top picture) and particle number (bottom picture) during injection procedure. Injection efficiency 85%.

For the optimization of the working point the injection efficiency can be plotted on the tune shift diagram (Figure 4). The different colours corresponds to the particle number after injection procedure for different values of betatron tunes. The minimum injection efficiency is defined by the crossing of structure resonances.

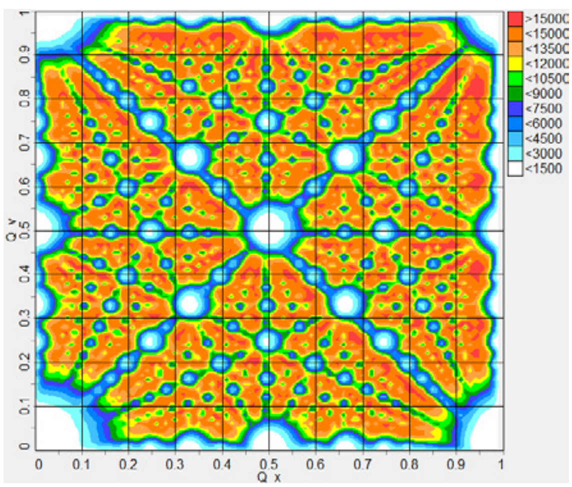

Figure 4: Injection efficiency on tune shift diagram, BETACOOL simulation without space charge effect.

SPACE CHARGE EFFECT

For the investigation of the space charge effect during injection procedure the Molecular Dynamics (MD) algorithm was applied in BETACOOL program which is successfully used for the crystalline beam simulation [6]. MD algorithm simulates direct Coulomb interactions under following assumptions:

- Particles have periodical distribution in longitudinal direction – cannot be used for bunched beam.
- No interactions with the electric field of chamber wall – only Coulomb interaction between particles.
- Very close interactions between particle does not take into account – no intrabeam scattering.

Horizontal (vertical) coordinates of particles are changed after (i+1) turn of transformation matrix as [7]:

$$\begin{bmatrix} x \\ x' \end{bmatrix}_{i+1} = \begin{bmatrix} \cos\mu + \alpha\sin\mu & \beta\sin\mu \\ -\gamma\sin\mu & \cos\mu - \alpha\sin\mu \end{bmatrix} \times \begin{bmatrix} x \\ x' \end{bmatrix}_i , \quad (1)$$

where x and x' – particle coordinates, μ – phase advance, α, β, γ – Twiss parameters. Betatron tune shifts for horizontal (vertical) plan can be calculated from the transformation matrix for each particle:

$$\Delta Q = \frac{1}{2\pi}\arctan\frac{\sin\mu}{\cos\mu} . \quad (2)$$

Tune shift distribution of particles calculated with (2) after one turn in BRing is presented on Figure 5 (right picture). Result is in a good agreement with the theoretical estimation of tune shift about ΔQ~0.3. One rhombus red point is working point; another one is the centre of tune shift distribution after one turn.

For the optimization of the injection procedure with space charge effect the tune shift diagram (Figure 5, right picture) can be overlapped with the efficiency diagram (Figure 4). It permits to avoid the crossing of structure resonances during and after injection procedure.

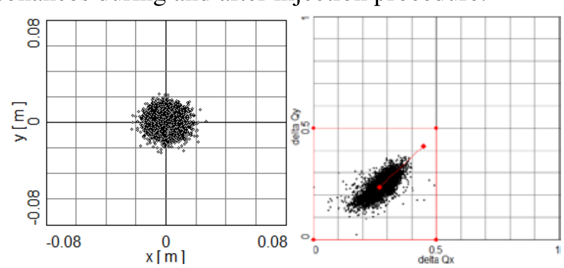

Figure 5: Numerical simulation of the tune shift due to space charge effect for Gaussian distribution. Left picture – particle distribution, right picture – tune shift distribution after turn.

The tune shift distribution after injection procedure (90 injection cycles) in BRing for designed parameters (Table 1) is presented on Figure 6 (left picture). One can see that for non-uniform distribution the tune shift much smaller in comparison with the theoretical estimation.

If the particle number increases in few times then the space charge leads to the relax of the particle distribution and the tune shift distribution seems more close to the theoretical estimation of the tune shift (Figure 6, right picture).

Injected efficiency for designed parameters of BRing (Table 1) is about 85% without space charge effect (Figure 7, zero value of particle number) and about 71% with space charge effect that is enough for HIAF project. Further increasing of the injected particle number leads to the decreasing of the injection efficiency (Figure 7) and fast increasing of the space charge effect (Figure 6, right picture).

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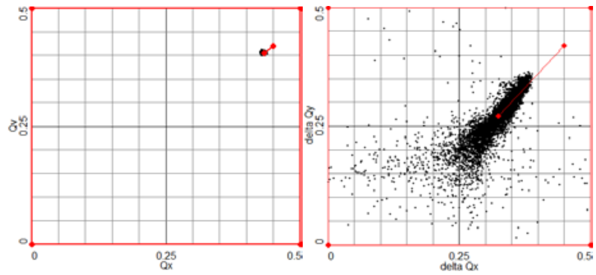

Figure 6: Numerical simulation of the tune shift due to space charge effect after two-plan painting multiturn injection, left pictures: N~10^{11} (ΔQ~0.08), right picture: N~5×10^{11} (ΔQ~0.4).

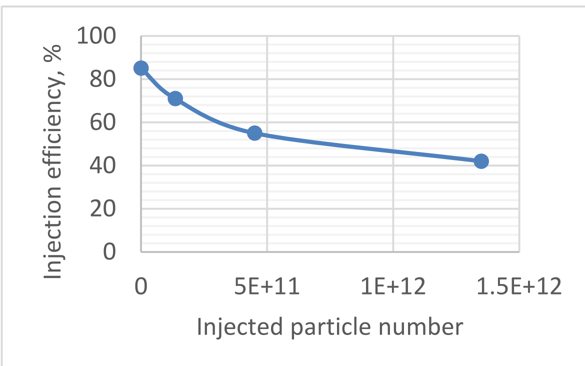

Figure 7: Dependence of injection efficiency on the total injected particle number. Zero particle number means no space effect (Figure 2).

The same effect with decreasing of the space charge effect was observed for the transverse shift of beam position (Figure 8). The area of the tune shift distribution is comparable with normal beam position (Figure 5) but shift of the tune shift distribution equal zero.

However, after a few hundred turns the particle distribution fill out all phase space around the reference orbit and the space charge comebacks to the normal value. Probably, if it possible to find way how to keep the beam in the non-uniform distribution for long time then the space charge effect can be significantly decreasing.

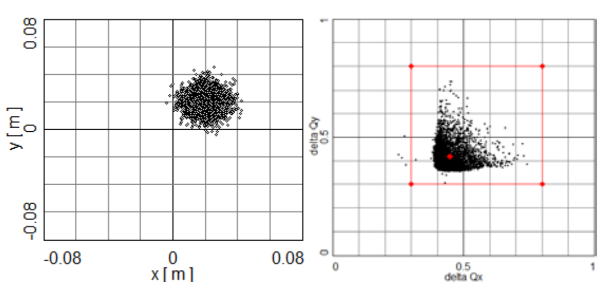

Figure 8: Numerical simulation of tune shift distribution (right picture) due to space charge effect with horizontal and vertical shifts (both are 2 cm) of the beam centre (left picture).

CONCLUSUTION

The using of Molecular Dynamics technique for the numerical simulation of the space charge effect can open new possibilities for the optimization of the intense beam dynamics in storage rings. From the present investigation can be formulated the following conclusions:

- Space charge has not large effect on injection procedure in BRing for designed parameters.
- Influence of space effect is significantly decreasing for non-uniform ion beam distribution.
- Large space charge leads to fast mixing (relax) of particles distribution and beam becomes uniform.

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