EMITTANCE BLOW UP AND HALO-FORMATION

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Abstract

This is a preliminary result of the first systematic study on space-charge effects in the 3 GeV Ring of the Joint Project.

1 INTRODUCTION

A systematic study on the halo-formation predicted in the 3GeV Booster Ring for the Joint Project has been performed. Orbits of interacting particles are examined by utilizing three independently developed computer codes of ACCSIM, SIMPSONS, and PATRASH. Sextupole fields for chromaticity correction are included in the tracking simulations. For a typical example, driving mechanisms of halo-formation are manifested. Absolute sizes of the halo are given as a function of the beam intensity.

The machine parameters are based on the early version of the 3GeV Ring lattice for the Joint Project. The lattice is characterized by (1) three-fold symmetry, (2) high γ_t, (3) dispersion free in the straight sections, (4) beta function with low symmetry and (5) half integer tune split. The operating tune has been chosen in the region far from the major structure resonances, where the lattice functions are stable under perturbations and give a relatively small beam size. Sextupole fileds for chromaticity is included in the argument here.

2 COMPUTER SIMULATION AND CODE BENCHMARKING

For the purpose to establish a tool capable of quantitatively estimating emittance blow up and halo-formation in a reliable manner, we have performed careful benchmarking between three computer codes that had been independently developed by employing different methods to treat the space-charge fields. History and characteristics of three codes are summarized in Table 1.

Table.1 History and characteristics of ACCSIM, PATRASH and SIMPSONS [1].

Code name	ACCSIM	PATRASH	SIMPSONS
Author & Year	F.Jones & TRIUMF G. since 1986	Y.Shimosaki since 1999	S.Machida since 1988
Freedom	2D/3D	2D	2D/3D
Space-charge fields calculation	Hybrid Fast Multipole Method	Hybrid Tree Method	PIC with multipole expansion
Linear optics	Thick lens	Thick lens	Thin lens
Run for benchmark	S.Igarashi	Y.Shimosaki	S.Machida

As benchmark tests, 2D simulations at the injection energy of 400MeV have been performed over 1000 turns as a function of beam peak current $I_{\rm peak}$ in the bunched beam. Saturation of simulation results against the simulation parameters such as longitudinal step size and number of macro particles had been checked by varying those parameters in the individual codes.

An initial 2D particle distribution was generated by the anti-correlated painting method without space-charge forces and other nonlinear magnetic fields for the simplicity. It is noted that the used distribution is asymmetric in a real space. For this reason, various unexpected phenomena have been observed.

Over an entire region of revolution, simulation results obtained by ACCSIM and PATRASH are practically in agreement with each other. The results obtained by SIMPSONS are slightly different from other results in several cases (see Fig.1). Even so, we can say that simulation results and reliable simulation codes are in our hands now. Of course we should use an appropriate codes in compliance with requests.

3 PHYSICS OF EMITTANCE BLOW UP AND HALO-FORMATION

Key mechanisms of emittance blow up and halo-formation are addressed in this section, which have been identified through the present benchmarking study.

Important features of space-charge effects are to induce a spread in the betatron tune and to cause nonlinear resonances originating from nonlinear field components. A typical tune footprint in a case of $I_{\rm peak}$ = 20A is shown in Fig.2. The edge of spread far from the bare tune (6.64, 6.27) places below half integer in the horizontal direction and integer in the vertical. Particles located there are subject to strong structure (lattice harmonic) resonances such as $mQ_y = 6m$ and $6Q_x = 39$ where m is an integer. In addition to these resonances, sum and difference resonances between both directions affect on the betatron motion. We focus our concern on two regions in temporal evolution of the emittance: (1) just after deposit of the initial beam (1-20 turns) in the horizontal direction (see Fig.1) and (2) gradual blow up region over 200 turns in the vertical (see Fig.3).

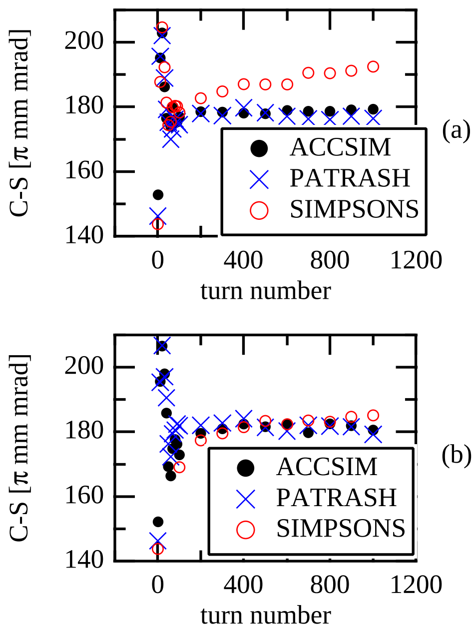

Figure 1: Time evolution of the horizontal 90% Courant - Snyder invariant (C-S) in the case of (a) (6.64, 6.27) and (b) (6.72, 6.35). I_{peak} = 20A.

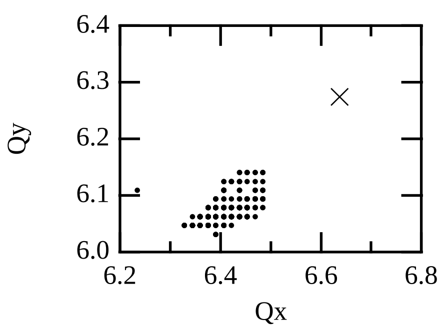

Figure 2: Footprints on the tune diagram. I_{peak} = 20A.

3.1 Early stage just after deposit of the initial beam for I_{peak}=20A

In order to confirm the mechanisms of the emittance blow up at early stage, Poincaré plot analysis for 18 test particles has been performed. A variety of beam dynamics features have been observed. Some seem to originate from the resonance with the lattice harmonic. The remained ones seem to be caused by the resonance with rapidly evolving higher order collective modes. The second order resonance in the horizontal direction, $2Q_x$ = 12.96~13.0, is quite clear from the Poincaré map for some particles. For the other particles, the coupling resonances of $2Q_x - Q_y$ = 6.9 and $3Q_x - Q_y$ = 13.49 are likely (see Fig.4). If these resonance were explained by the resonances with lattice harmonic only, they must be $6Q_x$ = 39, $6Q_x - 3Q_y$ = 21 and $6Q_x - 2Q_y$ = 27. However, such 6th, 8th and 9th order resonances are unlikely. To confirm the speculation, time evolution and frequency analysis of beam moments $<x^2>$, $<x^2y>$ and $<x^3y>$ should be useful. Their time evolutions are shown in Fig.5, where $<x^2y>$ is extremely large just at start and $<x^3y>$ stays at a large level until 60 turns. It is not clear if the resonance with either of both coherent modes is dominant. Further study on the frequency of these coherent modes will allow us to delineate more precise mechanism behind the observation.

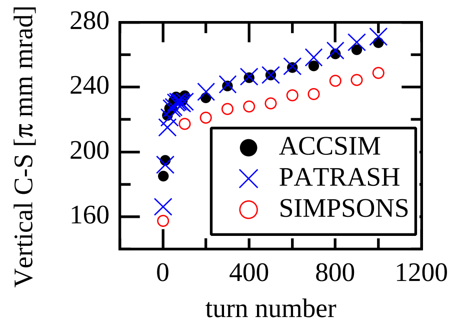

Figure 3: Time evolution of the 95% C-S. I_{peak} = 30A.

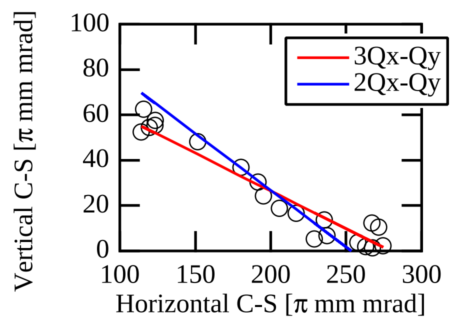

Figure 4: History of the C-S of a test particle on the emittanc space.

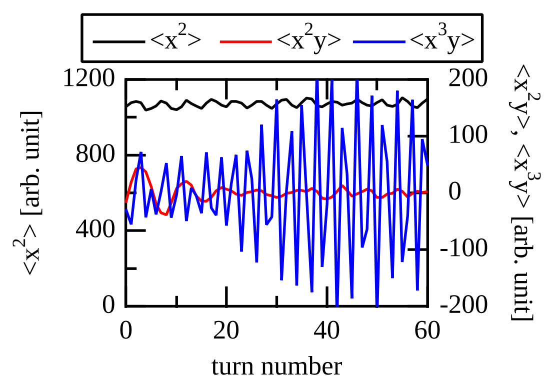

Figure 5: Time evolution of the beam momentum.

Further study in the wide range of the vertical tune, 5.75~6.55, has been done by SIMPSONS. Any cases show a similar drastic change in both emittances. This may suggest that this rapid change is not induced by any particular single resonance but pure evolution of any coherent mode not related to resonance of an individual particle takes a crucial role. At this moment, we can not conclude what mechanism causes the drastic change.

3.2 Gradual blow up region for I_{peak}=30A

Blow up of the vertical emittance over the entire region is notable, although the horizontal emittance achieves a steady state. The fact suggests that there are any driving mechanisms. The growth rate is almost constant there. Integer resonances of $mQ_y = 6m$ is suspicious, because the space-charge depressed tune Q_y is very close to 6.0. However, the depressed tune in the outer edge should be far from integer. Meanwhile, the result without sextupole fields has shown less blow up. What drives the blow up was mysterious for a while. Poincaré analysis of a finite number of test particles has been performed during 1000-2000 turns under the same condition.

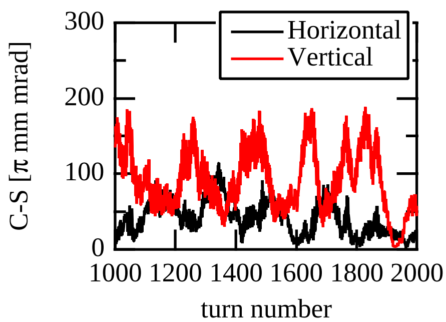

Fig.6 Exchange of emittance.

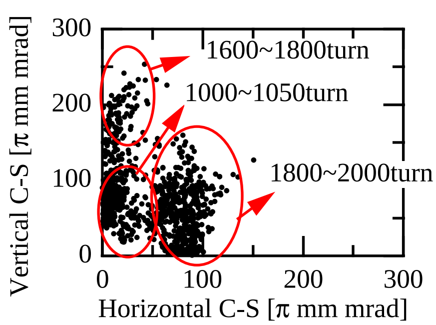

Fig.7 Time evolution of the emittance.

Apparent exchange of emittance can be seen from the Poincaré map for some particles, for example, as shown in Fig.6. On the other hand, the other particles indicate the emittance blow up for both directions. Those results for test particles suggest that the motion of an individual test particle is determined in a comprehensive manner. A coupling resonance becomes dominant during some time period; then the driving mechanism seems to be switched to another resonance. History of the motion plotted on the emittance space for most of test particles certainly indicates such changes in the driving mechanism as shown in Fig.7. This may be understandable in a speculation that a particle driven by a particular resonance gains or looses some emittance; as a result, the tune dependent of its emittance goes from the resonance to approach another resonance. On the other hand, a result of FFT analysis of tunes for test particle tells us that above coupling resonance does not originate from a resonance with lattice harmonic. A possible resonance is $2Q_x - Q_y = 6.6$. This suggests that higher order collective beam modes may be excited in this time period. However, time evolution of the beam moment $<x^2y>$ does not indicate a notable change.

4 DEPENDENCE ON BEAM INTENSITY

Time evaluation of the emittance in the horizontal direction has been shown as a function of peak intensity in Fig.8. It is notable that rapid blow up of the emittance at the early stage does not mitigate with lower peak current. The blow up rate of the 99% emittance is shown as a fuction of I_{peak} in Fig.9. A threshold current for blow up is not found.

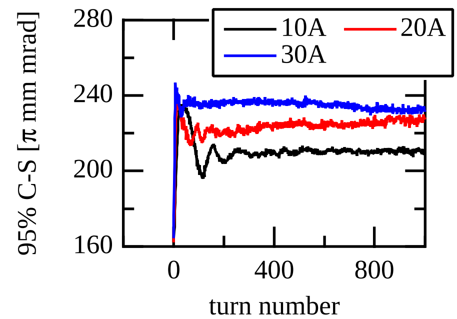

Fig.8 Time evolution of emittance as a function of I_{peak}.

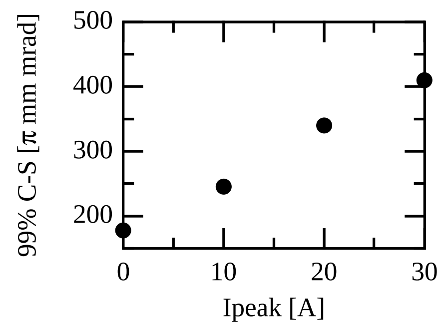

Fig.9 Edge emittance vs. I_{peak} in vertical direction.

5 SUMMARY

The physical aperture of the 3GeV Ring is limited to 324π mm mrad by the collimator system. Most of the halo particles diffusing beyond this value are scraped in the collimator region. What fraction of the painted beam is lost is a big concern. It has been one of motivation of the present study to predict its magnitude assuming the operating machine condition. A bare estimation, where the space-charge effects at the peak line density are considered assuming the proposed anti-correlated painting and operating tunes, tells us that emittance blow up and halo formation is not avoidable beyond I_{peak} = 20A and loss predicted there may be not tolerable. More quantitative estimation will be performed in the forthcoming study.

6 REFERENCES

[1] http://hadron.kek.jp/member/onishi/tdr/index.html