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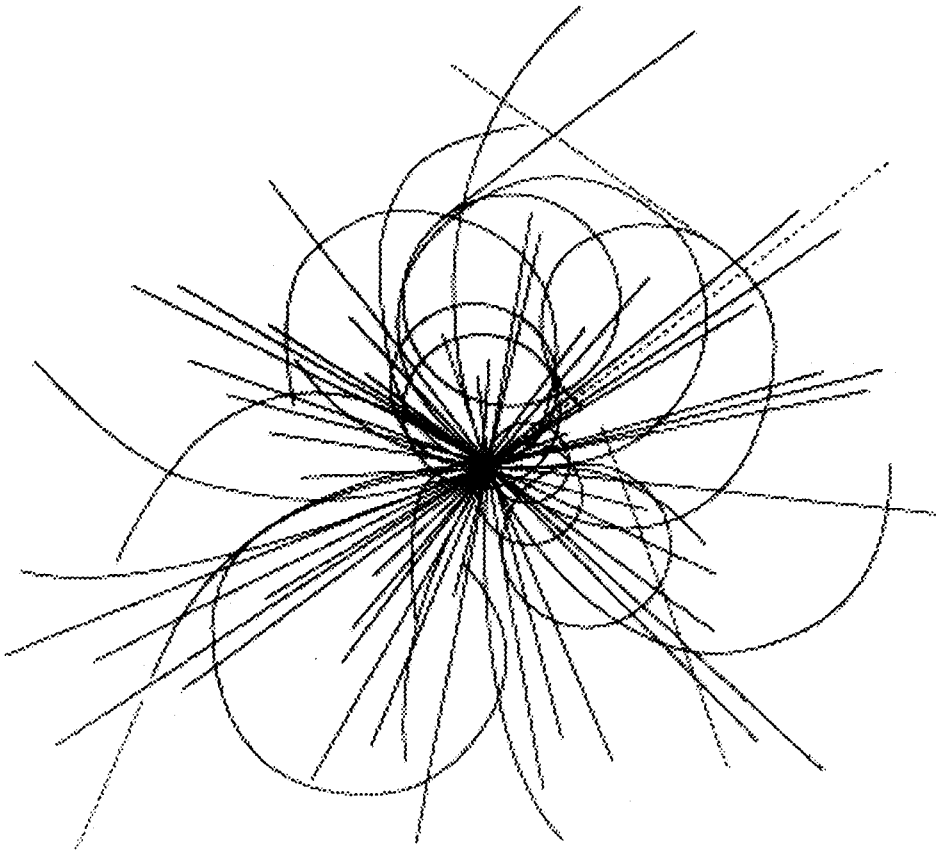

Superconducting Super Collider Laboratory

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Simulation of the Injection Damping and Resonance Correction Systems for the HEB of the SSC*

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*To be presented at the Computational Accelerator Physics Conference February, 1993.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE–AC35–89ER40486.

SIMULATION OF THE INJECTION DAMPING AND RESONANCE CORRECTION SYSTEMS FOR THE HEB OF THE SSC*

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ABSTRACT

An injection damping and resonance correction system for the High Energy Booster (HEB) of the Superconducting Super Collider (SSC) was investigated by means of multiparticle tracking. For an injection damping study, the code Simpsons is modified to utilize two Beam Position Monitors (BPM) and two dampers. The particles of 200 Gev/c, numbered 1024 or more, with Gaussian distribution in 6-D phase space are injected into the HEB with certain injection offsets. The whole bunch of particles is then kicked in proportion to the BPM signals with some upper limit. Tracking these particles up to several hundred turns while the damping system is acting shows the turn-by-turn emittance growth, which is caused by the tune spread due to nonlinearity of the lattice and residual chromaticity with synchrotron oscillations. For a resonance correction study, the operating tune is scanned as a function of time so that a bunch goes through a resonance. The performance of the resonance correction system is demonstrated. We optimize the system parameters which satisfy the emittance budget of the HEB, taking into account the realistic hardware requirement.

INTRODUCTION

Injection dampers are needed in the High Energy Booster (HEB) of the Superconducting Super Collider (SSC) to remove a large coherent betatron oscillation, which has resulted from unavoidable injection offsets, rapidly to prevent excessive emittance growth.

In concept, a damper system consists of a Beam Position Monitor (BPM) whose position signal is amplified to provide a transverse electric field across a damper, a pair of deflection plates, located about $N + 0.25$ (or 0.75) betatron period downstream of the BPM. (N is an integer.) On successive passes, the oscillation amplitude is reduced until the noise limit of the system is reached.

In practice, the tunes must be changeable in a certain scale, and the damper might not be able to be put at the expected position to get the exact fractional phase advance corresponding to 0.25 (or 0.75) betatron period. So, two BPMs separated by 0.25 betatron period and two dampers are used for one transverse direction.

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Because of errors in magnets, betatron resonances of several orders are excited. The way to correct these resonances is well known and it can be done by calculating the bandwidth of a resonance. In real machines, however, one needs to adjust the corrector iteratively by looking at beam behavior because not all the error information, especially concerning random errors, is obtainable. The purpose of the simulation study is to look at the emittance growth and beam loss using macro-particles in the lattice with and without the resonance correction system.

SIMULATION METHOD

We modified the code Simpsons[1] to incorporate the damper system for injection orbit errors and to evaluate performance of the resonance correction system. The code Simpsons is a fully 6-D multiparticle tracking program with acceleration. (In the following study, the particle momentum is fixed to the injection value.) It uses time as the independent variable instead of longitudinal position which is commonly taken by the other programs. One of the advantages of this is that we can change machine parameters such as tune and chromaticity as a function of time just like real machines, which makes it a lot easier to simulate resonance crossing as shown later. The table of quadrupole strength at several times, for example, is read into the code and interpolated at the time when a tracking particle passes the element. Usually, we track only one bunch (although there are 2160 bunches in the HEB) and assume the remainder of the bunches behave identically.

For the damper system simulation, the transverse charge center of macro-particles should be determined every turn. The position of one or two beam position monitors (BPMs) is specified in the lattice beforehand. Because time is the independent variable, all the macro-particles are not necessarily passing BPMs in the same time interval. There is a counter at each BPM which counts the number of particles passing through and a recorder which accumulates the transverse position of particles. When the counter counts the total number of macro-particles, a displacement of the transverse charge center is calculated as the average of all the positions.

Once the beam position is determined at the BPMs, one or two dampers, which locate downstream of the BPMs, are ready to give horizontal and vertical dipole kicks when a particle is passing there. The strength of dipole kicks is determined linearly depending on the beam position at the BPMs, but with a certain maximum strength which should not be exceeded. The sign and amplitude of the linear coefficient is chosen according to the phase advance between the BPMs and dampers.

To check the performance of the proposed resonance correction system, we observed the rms emittance and beam loss due to the resonance crossing. The bandwidth of individual resonance is estimated first, and the strength of correctors is calculated so that the bandwidth is reduced. The simulation of both lattice with and without correctors is then performed. The strength of quadrupoles which are used for tune adjustment is linearly scanned near resonances as a function of time.

With the damping systems applied we have options to turn on one set (one BPM and one damper) only or both sets, or we may set the voltage across the damper to a different value. Figure 6 shows the emittance growths with different cases. The emittance slightly increases as only one set is used with 1-kV voltage. When the voltage is increased to 3 kV, or two sets are turned on with 1-kV voltage at each damper, the emittance keeps its average unchanged but with a small fluctuation. In Figures 7-10 one can see how the beam centroid is damped by differently operated damping systems.

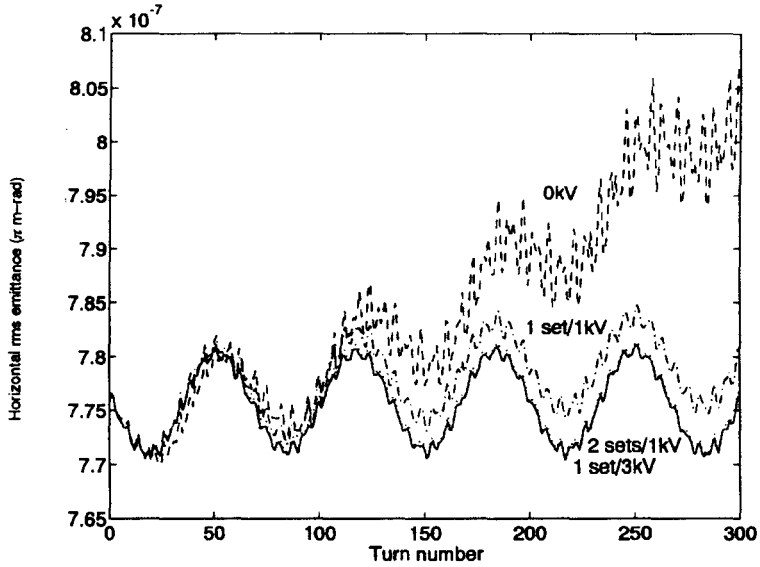

Fig. 6. Emittance Growth With Various Dampers.

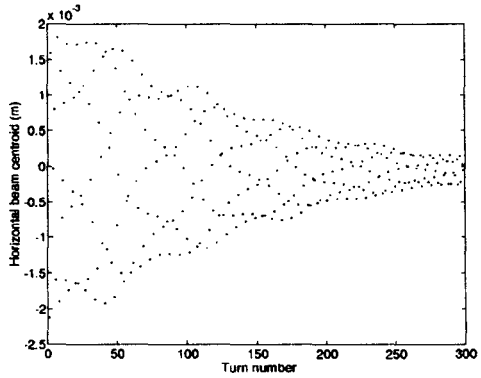

Fig. 7. One Set of Dampers With 1-kV Voltage.

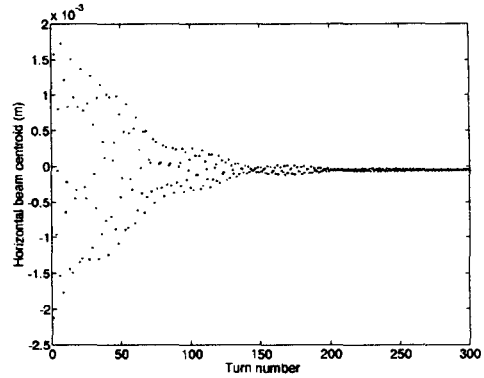

Fig. 8. Two Sets of Dampers With 1 kV on Each.

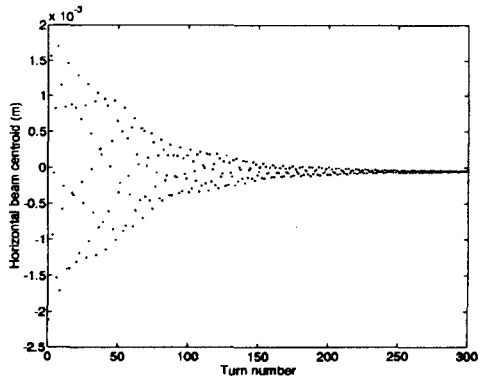

Fig. 9. One Set of Dampers With 3-kV Voltage.

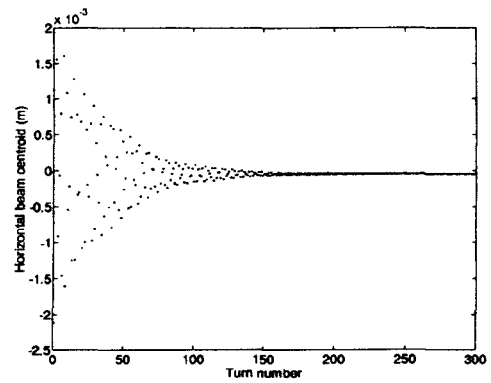

Fig. 10. Two Sets of Dampers With 3 kV On Each.

The fluctuation of the emittance shown in Figure 6 is partly due to the lack of the particles being tracked. By increasing the number of the particles tracked from 1024 to 2048 and 4096 individually, the amplitude of the fluctuation is reduced, which can be seen in Figure 11. The residual oscillation is due to the difference resonance, which cannot be removed.

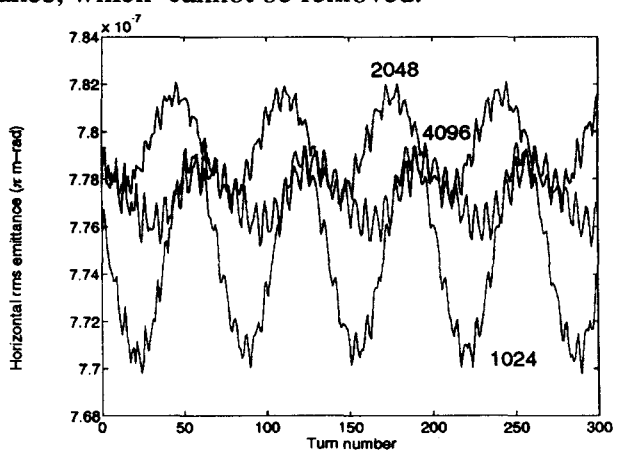

Fig. 11. Emittance Fluctuation With Various Particles.

RESONANCE CORRECTION

The working point of the HEB is (39.42, 38.41) in tune space, which is close to half integer resonance lines. Therefore, a half integer corrector is designed to correct the strong half integer resonance lines.

The corrector consists of eight quadrupole magnets, four of them for resonance line $2\nu_x = 79$ and other four for resonance line $2\nu_y = 77$, respectively. Each of the four magnets is assigned into two groups powered by two adjustable power supplies and those groups of magnets form two orthogonal vectors in phase space to

INJECTION DAMPING SYSTEM

In general, the centroid oscillation amplitude reduction per turn ΔX is proportional to, $\sqrt{\beta_b \beta_k}\,\theta$ where β_b and β_k are the beta-function at the BPM and the corresponding damper, θ is the kick strength of the damper, when the centroid oscillation itself is larger than a certain amount. Figure 1 shows the beta-functions at one straight section of the HEB. Four BPMs, two horizontal and two vertical, are set into two cells of a dispersion suppressor in such a way that each BPM is right beside either a focusing or defocusing quadrupole to assure that each one has been located at the position with a local peak beta-function. The beta-function at each BPM and damper, and the fractional betatron period corresponding to the phase advance between a BPM and damper pair are shown in the Table I.

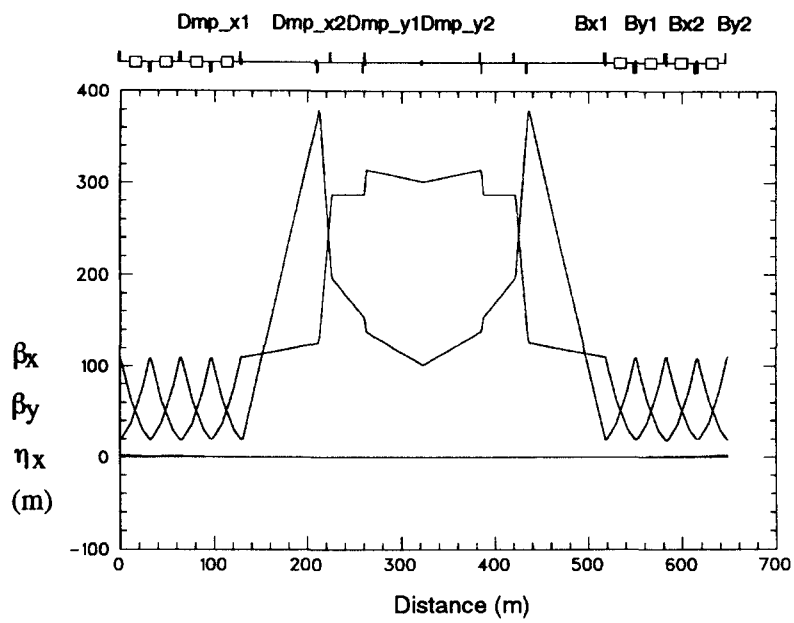

Fig. 1. The Injection Damping Systems in the HEB of the SSC.

Table I Beta–functions and phase advances/2π.

	β_x (m)	β_x (m)	$\Delta\nu_x$ to BPM_x1	$\Delta\nu_x$ to BPM_x2	$\Delta\nu_y$ to BPM_y2	$\Delta\nu_y$ to BPM_y2
BPM_x1	120.3					
BPM_x2	95.8					
BPM_y1		102.0				
BPM_y2		110.2				
Damper_x1	98.2		0.05	0.78		
Damper_x2	297.8		0.23	0.96		
Damper_y1		348.4			0.81	0.57
Damper_y1		101.3			0.95	0.71

The maximum voltage across the damper is set up from 1 kV to 3 kV with the assumption of that each damper is 1-meter long and has a 50-millimeter gap between two deflection plates. The initial beam offsets are determined as 2 mm in horizontal and 1.5 mm in vertical, which are the maximum possible values from the transform line coming to the HEB. The normalized emittance of the injection beam is 0.8 mm–mrad in each transverse phase space.

In order to simulate an injected beam, 1024 particles were assigned with a Gaussian distribution in 6-D phase space and then tracked through the ring. The centroid position and the emittance of these particles were calculated after each turn.

Without a damping system, the phase space occupied by a bunch of particles will dilute, which can be seen in Figures 2 and 3. As a result of this, the emittance will increase and then be saturated as the beam dilutes completely, which is shown in Figure 4. In Figure 5 the centroid of the beam oscillates for thousand turns and then gradually comes back to the closed orbit due to the dilution.

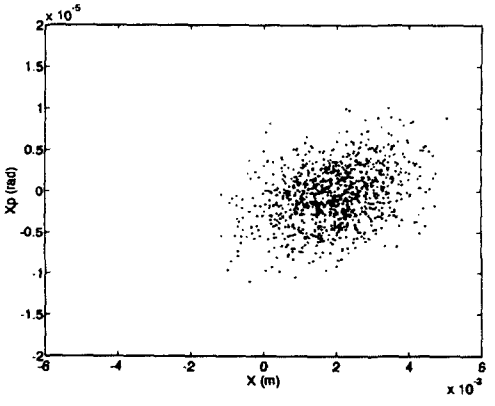

Fig. 2. Horizontal Phase Space at 0 Turn.

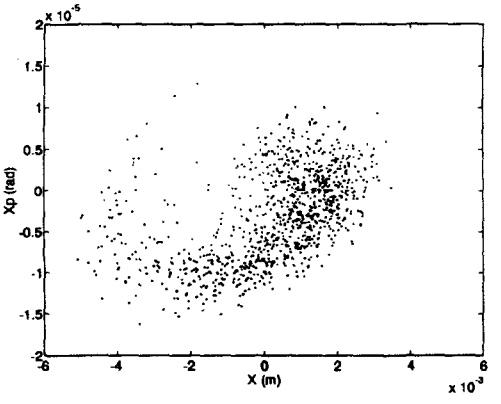

Fig. 3. Horizontal Phase Space at 2000 Turns.

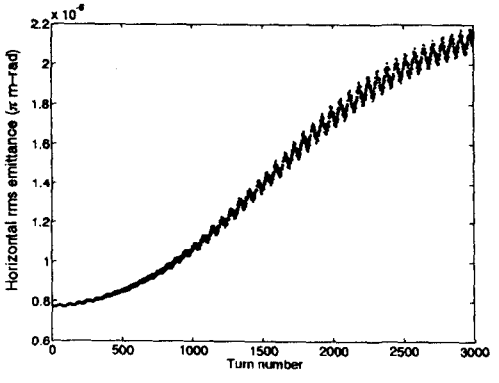

Fig. 4. Emittance Growth Due To Injection Offset.

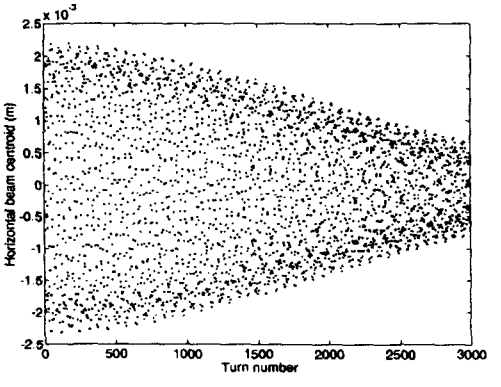

Fig. 5. Beam Centroid Moving Due To Dilution.

generate harmonics. All of the two magnet sets in each group are wired in series and placed in position with 90° phase advance. Such correctors are able to generate any desired amplitude and phase for harmonics without tune shifts.

The Simpsons, 6-D dynamic simulation code, is used to test the correction scheme. The Simpsons is set up in a tune scan mode to examine the effects of half integer crossing.

In the simulation, the working point is linearly moving from (39.424, 38.414) to (39.543, 38.533) in 10 msec. At about 6 msec, the working point crosses the half integer; 1024 particles are used to calculate emittance. Emittance growth is occurring at half integer crossing while correct circuits are turned off (Figures 12, 13). A smooth half integer crossing is also shown in Figures 12 and 13 for a well-corrected HEB.

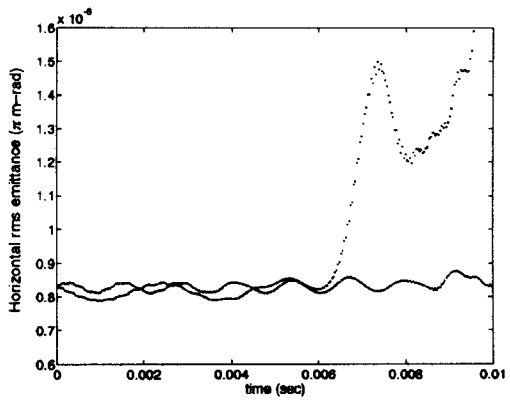

Fig. 12. Horizontal Emittance With and Without Correction.

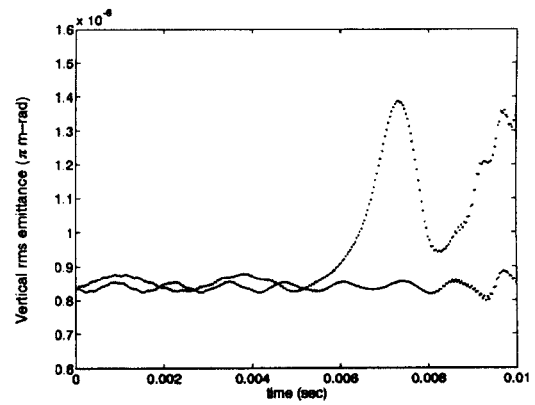

Fig. 13. Vertical Emittance With and Without Correction.

SUMMARY

To verify two design issues in the HEB of the SSC; injection damper and resonance correction systems, we modified the multiparticle tracking code Simpsons and examined the beam emittance growth under several conditions. The location of damper and BPM are chosen with practical constraints, not assuming any ideal situation. One damper and one BPM system turns out to be effective but required voltage for the damper is probably on the margin of the technical feasibility. Two dampers and two BPMs in a system do not require such high voltage but the improvement in terms of beam performance is not significant. The resonance correction for two half–integer resonance, $2\nu_x = 79$ and $2\nu_y = 79$, works well with four correctors for each.

ACKNOWLEDGEMENT

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REFERENCE

1. S. Machida, *Computational Accelerator Physics Conference 1993.*