The 12th Symposium on Accelerator Science and Technology, Wako, Japan 1999

OBSERVATION OF QUADRUPOLE MODE FREQUENCY AND ITS CONNECTION WITH BEAM LOSS

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Abstract

Recent Simulation results imply that the number of particles in a high intensity synchrotron is limited by the resonance crossing of coherent mode oscillations, not by the incoherent one. In order to verify it, we are doing the experiments to measure tune shift of quadrupole oscillation and beam losses in several conditions in HIMAC synchrotron at NIRS. In this paper, we discuss the beam loss in dynamic resonance crossing, where the operating point is moving to cross the half integer resonance.

1 Introduction

It is believed that space charge effects limit the number of particles in a high intensity synchrotron. However, the detailed mechanism of beam loss is not clear. One model tells that the incoherent tune of an individual partcle is reduced by the space charge field to a major resonance line, and resonate with lattice field errors. Another model, proposed by Sacherer in 1960's[1], is that the coherent mode oscillations of a beam resonate with lattice field errors. The incoherent model is not self-consistent because it neglects the time evolution of distribution due to the space charge force.

Recent simulation results seem to support the latter model[2]. In order to verify this, we planned to measure the tune shifts of coherent mode oscillations and their connection with beam loss. We present our observation of the resonant behavior with approaching operating point to resonant condition.

2 Experiments

2.1 Accelerator and Its Equipments

All of our experiments are performed at Heavy Ion Medical Accelerator in Chiba (HIMAC) in National Institute for Radiological Science (NIRS), using 6MeV He^{2+} beam. We took the flatbase operation without RF. Beam and lattice parameters are listed in Table1. Laslett tune shift is -0.0446/10^{11}ppp, and that of coherent breathing mode oscillation is the 5/8 times of it. We chose the operating point of around (3.61,3.58), taking account of the observation of $\nu_{0y} = 3.5$ resonance. Around there, the bare tunes as the functions of defocusing field strength are well known experimentally, with $\delta\nu_{0y} = 0.01$ accuracy. They are

$$\nu_{0x} = 3.651 - 0.007588(I_{qd} - 84.48) \qquad (1)$$
$$\nu_{0y} = 3.280 + 0.05948(I_{qd} - 81.80), \qquad (2)$$

where I_{qd} is the current of defocusing quadrupole in the unit of A.

The stopband width of $\nu = 3.5$ line can be controlled by a pair of quadrupole magnets (QDS) at the opposite sides of synchrotron, excited in counterphase. The $B'L$ product of a QDS is expected 0.0156T at 1A of QDS current, which is calculated from the measurement for the same device with higher turn number of excitation coil. The maximum QDS current is ±10A, β_y is 3.22m there, and thus they expand the stopband width of

$$\frac{\Delta\nu_s}{2} = 0.011 I_{qds}. \qquad (3)$$

up to ±0.11.

Table 1
HIMAC BEAM AND LATTICE PARAMETERS

particle	6MeV/u He^{2+}
maximum peak current	$\sim 2\times 10^{11}$ppp
100% emittance	(264,10)πmm-mrad
momentum spread	0.1%
circumference	130m

2.2 Observation of Beam Loss in Resonance Crossing

We observed beam loss process with DC current transformer (DCCT), bringing the operating point gradually to a half integer resonance $\nu_y = 3.5$ and over, along the line described in eq.2. Four types of resonance crossing schemes, in Table.2, are attempted in several QDS strengths. In the table, time t is measured after master trigger, where beam is injected at t=40msec.

The DCCT waveform is in Figure 1. In the case that resonance is crossed downward (condition (a)(c)), the timing of resonant beam loss is not clear, while it occur instantaneously in upward case (condition (b)). For (a) and (b), we defined the "critical tune" by the position of the largest derivative of beam current, which is converted to the vertical bare tune by formula 2. In case (c), having no sudden drop of beam current, we defined it by the 60% loss of injected current. In condition (d), the injected beam current were too small to define the resonant time of about $t \sim$1sec. It may be because of the other resonance, $\nu_x + \nu_y = 7$, which is closer to the start point of (d) than that of (b).

Table 2
RESONANCE CROSSING SCHEMES

ID	ν_{0y} at t=0	$d\nu_{0y}/dt$
(a)	3.564	-0.05948(1/sec)
(b)	3.417	+0.05948(1/sec)
(c)	3.573	-0.05948(1/sec)
(d)	3.406	+0.05948(1/sec)

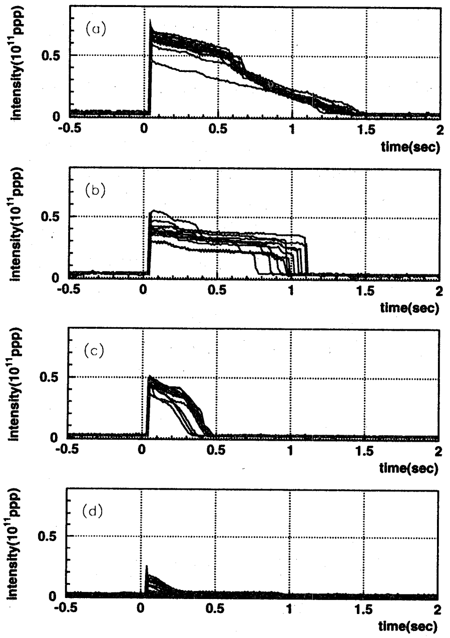

Fig. 1 The beam loss waveform when the vertical tune crosses 3.5 resonance line. Those about several stopband widths are superimposed. The symbol (a)$\sim$(d) correspond to those in Table 2.

Figure 2 and 3 show the critical tune as the function of QDS current. Linear dependence are seen in series (b) and (c). Its coefficients are -0.00153/A and +0.00166/A, while the half of stopband width expected from QDS field strength is 0.011/A. The reason of this disagreement is not clear. We plan to calibrate the field gradient of QDS.

Since there is no relation between QDS current and critical tune in (a), the sudden drop of current in (a) may be independent of half integer resonance.

The distance between critical tune and 3.5 means the uncorrectable stopband width, together with some space charge effect. What we are interested in is that which tune, coherent quadrupole mode or some kind of incoherent one, is responsible for half integer resonance. However, our experiment does not have enough accuracy to distinguish them, at the moment. The most serious problem here is the ambiguity to define "critical tune".

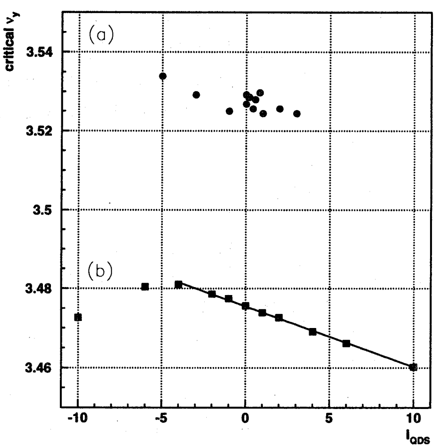

Fig. 2 Critical value of bare tune to half integer resonance (a)(b). For (b), it is approximately $-0.0015 I_{qds} + 3.476$ in the region $-5 < I_{qds}$.

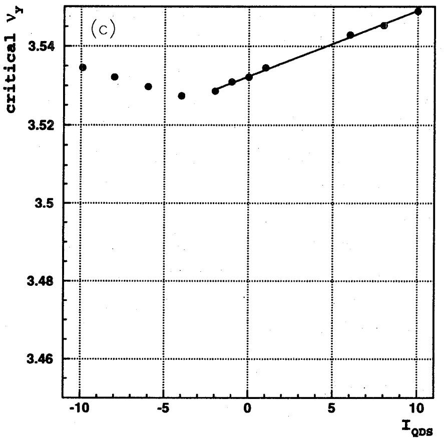

Fig. 3 Critical value of bare tune to half integer resonance (c). It is approximately $-0.00165 I_{qds} + 3.532$ in the region $-3 < I_{qds}$.

3 Multi-Particle Simulation

In order to understand the behavior of emittance blow up and beam loss in dynamic resonance crossing, upward and downward, we employed a multi-particle simulation. We discuss our simulation method and the first results here.

3.1 Simulation Method

Our simulation tracks the transverse motions of macroparticles. Axisymmetric focusing force are applied instead of alternating gradient focusing. Space charge field is also calculated on the assumption of axisymmetric charge distribution. Generalized perveance is determined by that of KV beam with the same rms beam sizes having 0.04 tune shift. Simulation parameters are in Table 3. Neither dispersion nor chromaticity is taken into account.

Focusing force is variable linearly, in order to approach the operating point to resonance line.

Table 3
SIMULATION PARAMETERS

lattice	12 FO cell/revolution
structure of a cell(length)	F(0.1)+O(0.9)
no. of multiparticle	10000
particle distribution	waterbag
no. of integration steps	100/cell
no. of radial grid points	$100/10r_{rms}$
aparture limit	$r \leq 6\times$(initial r_{rms})

3.2 Simulation Results

We simulated the dynamic resonance crossing. The operating points started at (a)3.491 and (b)3.508, and approached to 3.500 resonance with a speed of $0.7742/10^6$revolution, which is over 1000 times larger than our experiment. Lattice error fields are applied in 2 of 12 focusing section, as ±1% error of field strengths.

After crossing $\nu = 3.5$ line, almost all particles are lossed. Fig.4 shows the blow up of rms beam sizes and beam loss versus bare tune.

Unlike the results of our experiment (Fig.1), the behavior of beam loss does not differ between upward crossing case and downward one. In addition, the timing of beam loss seems to be sensitive to the aparture limit. Simulation with realistic speed to approach is in process.

4 SUMMARY

We observed the beam loss, approaching the operating point to half integer resonance, in HIMAC synchrotron. The beam loss behavior was quite different between the resonance crossing direction. The tune where the beam loss occur seemed to have linear dependence on stopband width. We are performing a multi-particle simulation in order to understand the beam loss behavior.

5 ACKNOWLEDGEMENT

We would like to thank the staff of Accelerator Engineering Company for the help of our experiment in HIMAC.

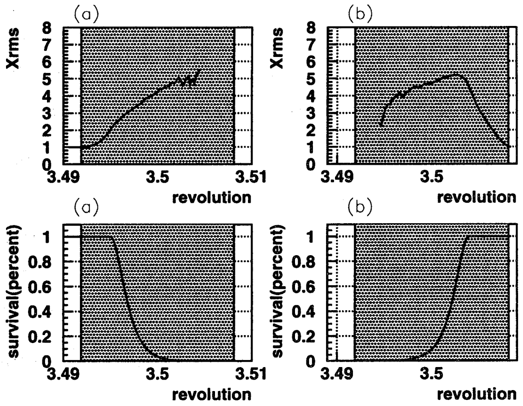

Fig. 4 Beam blow up and beam loss in dynamic resonance crossing. Hatched area shows the stopband.

References

[1] F.J.Sacherer, Ph.D.Thesis(1968).
[2] S.Machida, Proceeding of EPAC'98(1998).
[3] F.J.Sacherer, IEEE Trans.Nucl.Sci, 18(3)(1971).