STUDY OF ROBINSON INSTABILITIES WITH A HIGHER-HARMONIC CAVITY FOR HLS PHASE II PROJECT

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Abstract

In the phase II project of Hefei Light Source, a fourth-harmonic "Landau" cavity will be operated in order to suppress coupled-bunch instabilities and increase the beam lifetime of Hefei Storage Ring. Instabilities limit the utility of the higher-harmonic cavity when the storage ring is operated with a small momentum compaction. Analytical modeling and simulations show that the instabilities result from Robinson mode coupling. In the analytic modeling, we operate an algorithm to consider Robinson instabilities. To study the evolution of unstable behavior, simulations have been performed in which macroparticles are distributed among the buckets. Both the analytic modeling and simulations agree for passive operation of the harmonic cavity.

INTRODUCTION

In the phase II project of Hefei Light Source, a fourth-harmonic "Landau" cavity will be operated in order to suppress coupled-bunch instabilities and increase the beam lifetime of Hefei Storage Ring. Instabilities limit the utility of the higher-harmonic cavity when the storage ring is operated with a small momentum compaction. Analytical modeling and simulations show that the instabilities result from Robinson mode coupling. In the analytic modeling, we operate an algorithm to consider Robinson instabilities. To study the evolution of unstable behavior, simulations have been performed in which macroparticles are distributed among the buckets. Both the analytic modeling and simulations agree for passive operation of the harmonic cavity.

ANALYTIC MODELING

For HLS II, we use the parameters shown in Table 1. The harmonic cavity impedance and Q factor are estimated respectively for 4th harmonic cavities. We have modified an algorithm to consider Robinson instabilities for a given fundamental rf voltage, ring current, and harmonic cavity tuning angle.

The analytical results are shown in Figure 1.

In Fig. 1(a), uncoupled dipole and quadrupole Robinson instabilities are predicted. When tuning in the cavity with currents below 80mA, a dipole Robinson instability is predicted to onset before optimal bunch lengthening is attained. For currents exceeding 100mA, a quadrupole Robinson instability is predicted to onset after optimal bunch lengthening is obtained.

In Fig. 1(b), dipole-quadrupole mode coupling is included in the analysis. Compared to FIG. 1(a), we conclude that when tuning in the cavity with currents nearby 100mA and optimal bunch lengthening is just obtained, coupled-dipole instability and coupled-quadrupole instability are predicted to onset.

In Fig. 1(c), coupled bunch instability is included. We see that when tuning in the cavity with currents below the current value of the optimal bunch lengthening, coupled bunch instability is predicted to onset.

Table 1: The Machine Parameters for Hefei Light Source II Project

Beam energy [GeV]	0.8
Beam revolution frequency [MHz]	4.533
Harmonic number	45
Energy lost per turn without ID's [keV]	16.73
Beam emittance [nrad]	40
Injected current [mA]	250-500
Energy spread (rms)%	0.00047
Momentum compaction α	0.02
Nominal rms bunch length (mm)	14.8
Main rf frequency [MHz]	204
Main rf peak voltage [kV]	250
Third harmonic frequency [MHz], n=4	816
Harmonic rf voltage [MV], n=4	0.0625
Harmonic cavity Q (n=4)	18000
Harmonic cavity $R_S(M\Omega)$, n=4	2.5
Optimum lifetime increase (n=4)	2.58

SIMULATIONS

We have performed 500 000-turn simulations for 20 values of the ring current and 50 values of the harmonic-cavity tuning angle to study the evolution of unstable behaviour. In our simulations, 450 macroparticles are evenly distributed among the 45 buckets. Figure 2 shows simulation results in which ■ is plotted for mild instability, ● is plotted for moderate instability, ▲ is plotted for strong instability. There is a good agreement between the analytic predictions of Fig. 1(b) and the simulated instabilities observed in Fig. 2. The results show that tuning in the harmonic cavity strongly suppresses the parasitic coupled-bunch instability.

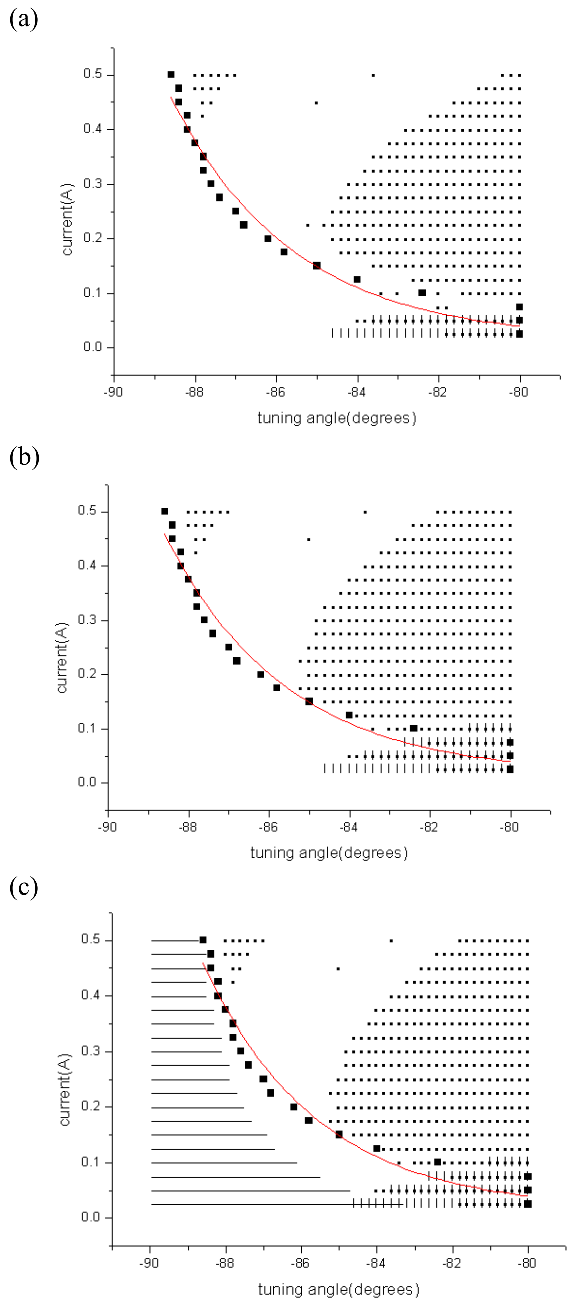

Figure 1: (a) Robinson in stabilities are predicted without consideration of mode coupling. A solid curve shows the parameters for optimal bunch lengthening, in which case the linear synchrotron frequency is zero. Vertical line: dipole instability; Spot: quadrupole instability. (b)Dipole-quadrupole mode coupling is included. Vertical line: coupled-dipole instability; Spot: coupled-quadrupole instability. (c)Coupled bunch instability is included. Horizontal line: coupled bunch instability.

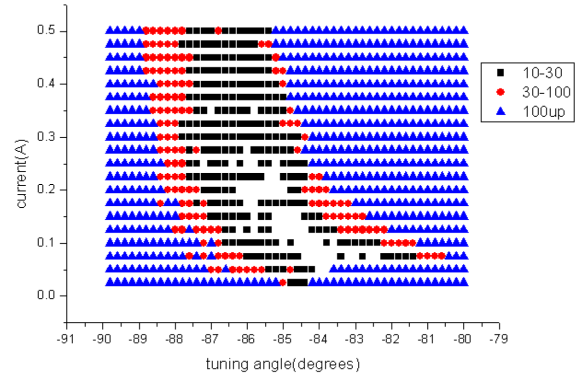

Figure 2: Results of 500 000-turn simulations of 450 macroparticles. ■: mild instability, where the energy spread exceeds its natural value by (10–30)%; ●: moderate instability, where the energyspread has increased by (30–100)%; ▲: strong instability, where the energy spread has increased more than 100%.

The simulated instability growth and saturation for a current of 125mA and harmonic-cavity tuning angle $-79.8°$ is shown in Fig. 3. The amplitude of σ_t oscillations is much greater than that of the beam centroid, consistent with analytic prediction of a coupled-quadrupole instability.

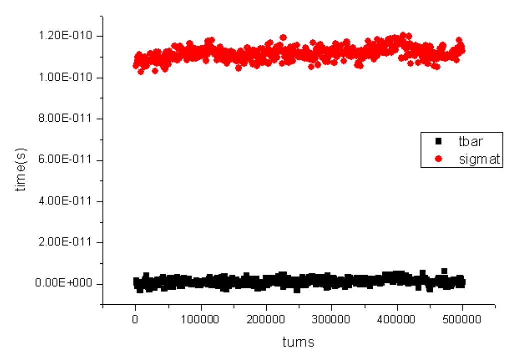

Figure 3: Simulation of coupled-quadrupole Robinson instability for a ring current of 125 mA and Landau-cavity tuning angle of $-79.8°$ ●: bunch length σ_t : bunch centroid <t>.

CONCLUSION

We have studied Robinson instabilities with a higher-harmonic cavity using analytic modelling, simulations. In our analytic model, we estimate the currents and tuning angles when instability is onset and the parameters for optimal bunch lengthening are also obtained. In our simulations, the results confirm that tuning in the harmonic cavity strongly suppresses the parasitic coupled-bunch instability. There is a good agreement between the analytic predictions and the simulated instabilities.

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