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STUDY OF BEAM INSTABILITIES WITH A HIGHER-HARMONIC CAVITY FOR THE HALS*

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Abstract

Hefei Advanced Light Source (HALS), a diffraction-limited storage ring is on the design. In HALS project, a passive higher-harmonic cavity may be added in order to increase the beam lifetime of the storage ring. When the storage ring is operated with a small momentum compaction, instabilities limit the utility of the higher-harmonic cavity. In this paper, we run an algorithm (analytic modeling) to consider the Robinson instabilities for normal and superconducting cavity respectively. The Robinson instabilities are predicted with and without mode coupling. Coupled-bunch instability induced by resonant interaction with parasitic longitudinal mode is also considered. The analytic modeling may be used to give rf-cavity parameters that are more conducive to stability. The results show that the storage ring can operate at a higher beam current and the parasitic higher-order mode of the fundamental cavity has less impact on the beam by using superconducting harmonic cavity.

INTRODUCTION

The beam energy of Hefei Advanced Light Source (HALS) is about 2.5GeV, and the beam emittance is aimed at about 50 pm-rad. Because of small momentum compaction for the diffraction-limited storage ring lattice, the bunch lengths are usually short. The intense intra-beam scattering and Touschek effects will cause evident emittance growth and lifetime reduction. The low-emittance lattice also increase the susceptibility to Robinson instabilities. Here, a passive higher-harmonic cavity is used to increase Landau damping of synchrotron oscillation and lengthen the bunch, thereby suppressing Robinson instabilities and increase the Touschek lifetime.

In this paper, we operate an algorithm to analyze the Robinson instabilities and coupled-bunch instabilities for normal and superconducting cavity respectively in the HALS. The analysis results will help us to determine the rf-cavity parameters that are useful for beam stability in HALS.

ANALYTIC MODELING

We use the parameters of HALS shown in Table 1 and Table 2 to consider Robinson instability for a given rf voltage V_{T1}, ring current I, and harmonic cavity tuning angle ϕ_2. We also calculates whether resonant interaction with a real parasitic impedance R_3 at frequency ~ ω_{CB} will excite a dipole coupled-bunch instability. Then we calculates whether the dipole coupled-bunch modes with longitudinal mode numbers of ± 1 will cause a dipole coupled-bunch instability. The Robinson instability theory can be seen in reference [1]. The calculation procedure refers to the reference [1, 2].

The analytical results are shown in Fig. 1.

Table 1: The Machine Parameters for HALS

Parameter	Value
V_{T1} (fundamental cavity peak voltage)	500 kV
β_1 (fundamental cavity rf coupling coefficient)	2.6
Q_1 (fundamental cavity quality factor)	20000
R_1 (fundamental cavity shunt impedance)	3.2 MΩ
α (momentum compaction)	3.42×10^{-5}
T_0 (recirculation time)	2.24×10^{-6} s
N (number of bunches)	224
E (beam energy)	2.5 GeV
σ_E/E (natural electron energy spread)	5.39×10^{-4}
V_s (synchronous voltage)	217.6 kV
τ_L (longitudinal radiation damping time)	0.0332 s
Q_3 (HOM quality factor)	700
R_3 (HOM impedance)	6000Ω
ω_{CB} (HOM angular frequency)	7.536×10^9 rad/s

Table 2: The RF Parameters of Harmonic Cavity

Parameter	Normal	Superconducting
ν (harmonic cavity harmonic number)	3	3
β_2 (harmonic cavity rf coupling coefficient)	0	4
Q_2 (harmonic cavity quality factor)	11000	1×10^9
R_2 (harmonic cavity shunt impedance)	1.65 MΩ	1.25×10^{11}MΩ

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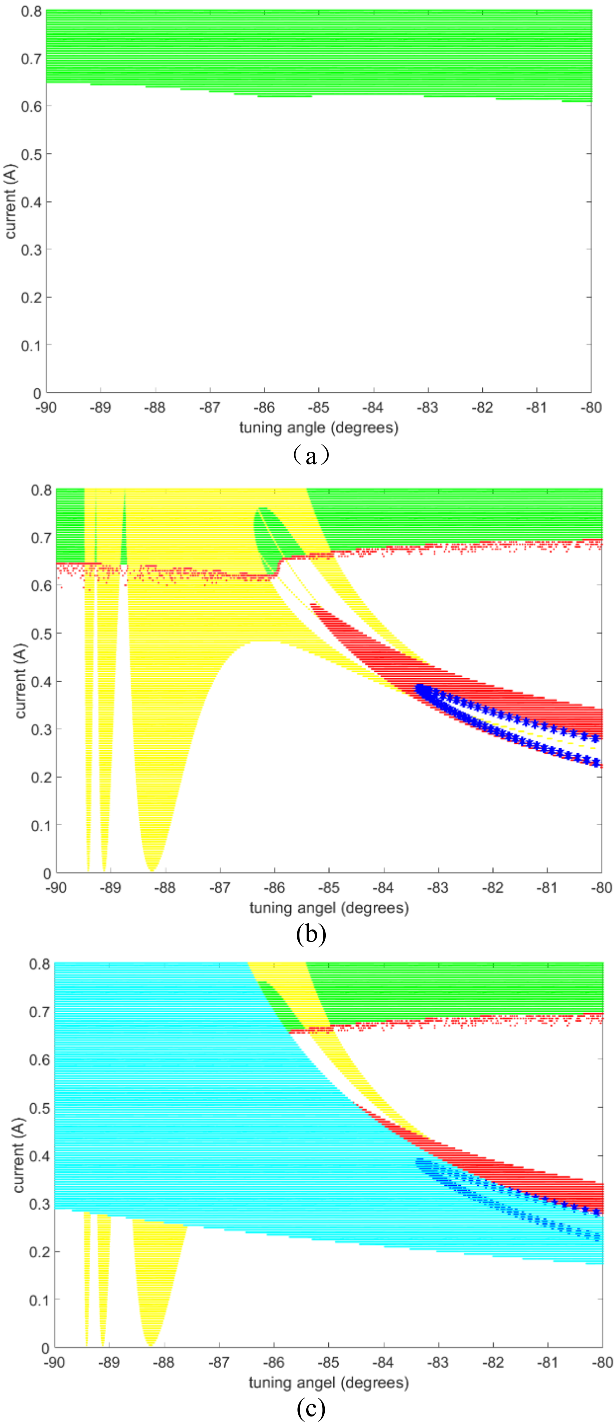

Figure 1: (a) Instabilities are predicted without consideration of mode coupling. A symbol is plotted when instabilities is predicted for a given ring current and Landau-cavity tuning angle. Green point: zero-frequency instability. (b) Dipole-quadrupole mode coupling is include. Green point: zero-frequency coupled instability. Red point: fast mode-coupling instability. Blue *: coupled-quadrupole Robinson instability. Yellow point: instability for dipole coupled-bunch oscillations with longitudinal mode numbers of ±1. (c) Included the resonant interaction with a longitudinal mode. Cyan point: parasitic mode coupled-bunch instability.

In Fig. 1(a), the zero-frequency instability is predicted. The instability occurs when the currents exceeding 610 mA. In Fig. 1(b), the threshold currents of zero-frequency coupled instability is slightly increased in the larger tuning angle side compare with the zero-frequency instability. While another instability (suspect fast mode-coupling instability) occur when the currents is less than the threshold currents of zero-frequency coupled instability. This instability is plotted because the algorithm used to compute the coupled-dipole and coupled-quadrupole Robinson frequencies does not converge, which may indicate a fast instability. When currents is below 560 mA, a fast mode-coupling instability is predicted. When current is below 410 mA, the coupled-quadrupole instability is predicted. The instability for dipole coupled-bunch oscillations with longitudinal mode numbers of ±1 occurs because the harmonic cavity has a low value of Q or is detuned far from the frequency $\nu\omega_g$, where ω_g is the rf generator frequency. The parasitic mode coupled-bunch instability is shown in Fig. 3(c). The values of R_3 and ω_{CB} represent a typical higher-order mode of the fundamental rf cavity. Passive operation of the harmonic cavity is stable in the blank area in Fig. 1(c).

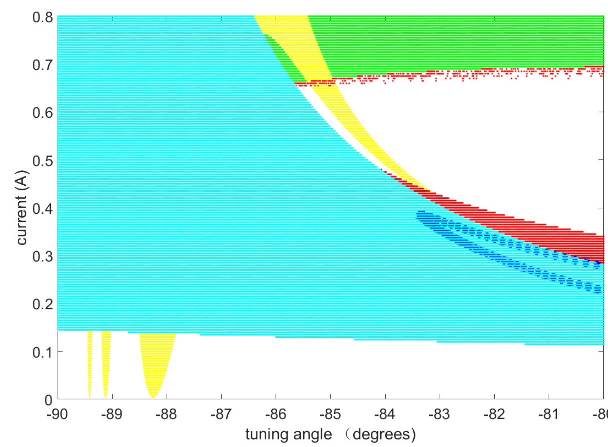

Figure 2: Instability are predicted with a HOM parasitic impedance R_3=12000 Ω.

When the higher-order mode is not damped sufficiently, it will has a more serious impact on the beam. For R_3=12000Ω, the analytical results are shown in Fig. 2. The parasitic mode coupled-instability is predicted in a larger area. The results manifest that the HOM must be damped strongly in order to reduce parasitic mode coupled-bunch instability.

We also analyze a superconducting harmonic cavity used the rf parameter in Table 2. The results are shown in Fig. 3. In Fig. 3, the plot range of the tuning angle is only from – 90° to – 89.9°. In Fig. 3(a), the zero-frequency instability is predicted in the range of I >740 mA and tuning angle < – 89.96°. The quadrupole Robinson instability is happened at low current I ~20 mA from tuning angle – 89.926° to – 89.914°. In Fig. 3(b), the zero-frequency coupled instability area become smaller compare with the uncoupled zero frequency instability. The plotted fast instability include the fast mode-coupling instability and the suspect fast mode-coupling instability. The parasitic mode coupled-bunch instability is given in Fig. 3(c). This parasitic

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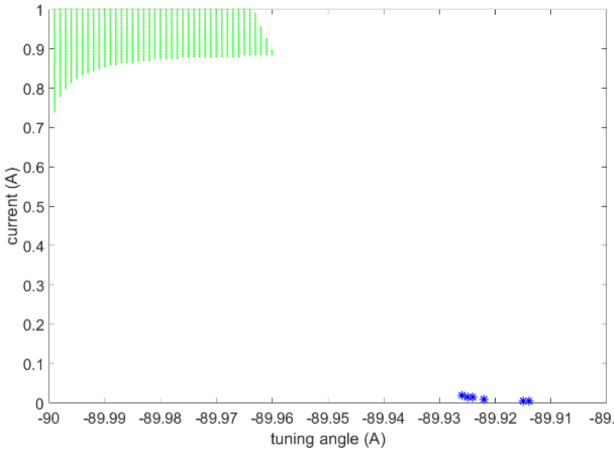
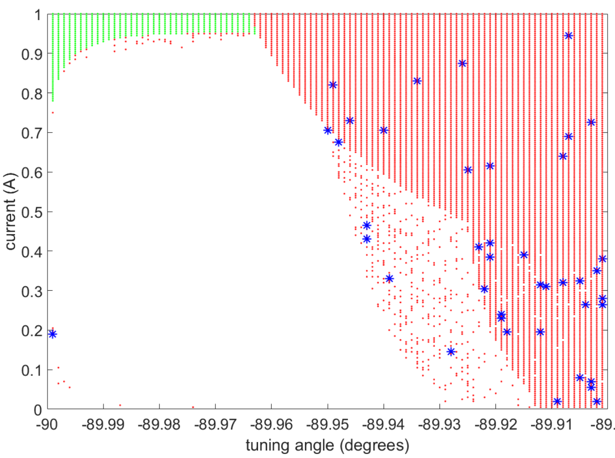
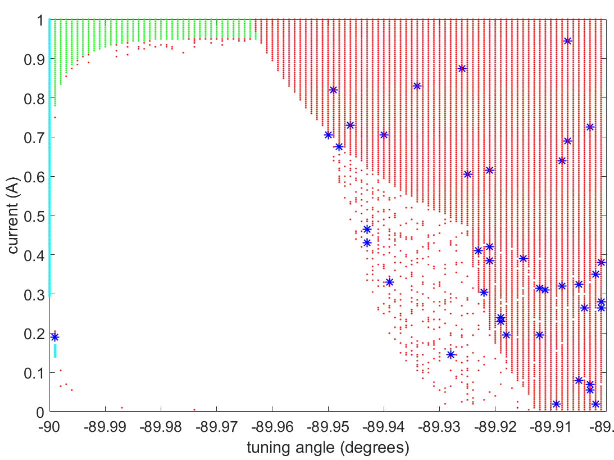
higher-order mode has a small influence on beam instability.



(a)



(b)



(c)

Figure 3: Instabilities are predicted for the HALS lattice with a passive superconducting harmonic cavity. The plotted symbols has the same meaning as in the Fig. 1. In Fig. 3(a) Blue *: quadrupole Robinson instability.

Passive operation of the superconducting harmonic cavity is stable probably in tuning angle < – 89.98° and at ring current < 900 mA. Compare with normal harmonic cavity, superconducting harmonic cavity is less affected by the longitudinal cavity mode and can stable operate in a higher beam current.

For R_3=12000Ω, the analytical results are shown in Fig. 4. The results show that the impact of the parasitic higher-order mode on the beam is slight.

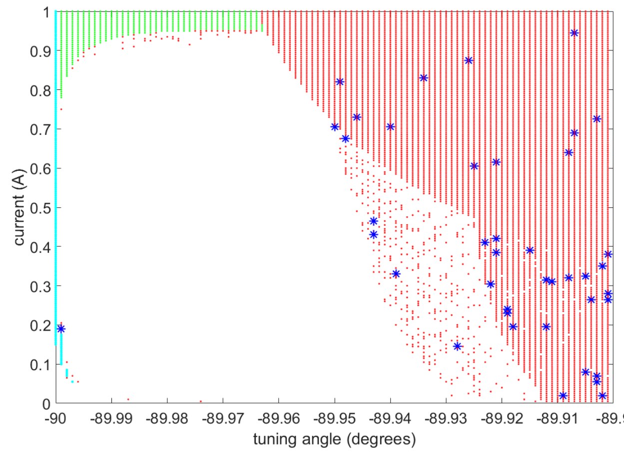


Figure 4: Instability are predicted with a HOM parasitic impedance R_3=12000Ω.

DISCUSSION

We have studied instabilities when a normal and superconducting harmonic cavity is utilized respectively with the HALS lattice, whose momentum compaction is small. The results show that by using superconducting harmonic cavity, the storage ring can operate at higher beam current and the parasitic higher-order mode of the fundamental cavity has less impact on the beam. The stable operation area was obtain. We can change the rf parameters of the rf cavities to get a larger stable operation area. The analytic modeling can help us to get rf parameters, which are better for stable operation at higher beam current. We will study instabilities when the superconducting fundamental cavity with the higher harmonic cavity are utilized in the future.

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