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Preliminary study of the higher-harmonic cavity for HLS-Ⅱ [*]

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Abstract: A higher-harmonic cavity will be used to increase the beam lifetime and suppress coupled-bunch instabilities for Hefei Light Source-Ⅱ. In this paper, results simulated by the particle-tracking model confirm that tuning in the harmonic cavity may suppress the parasitic coupled-bunch instabilities. The factors calculated for lifetime improvement are larger than 2.5. The 3rd and 4th harmonic cavities have been designed. In particular, the absorbers and antenna couplers are applied in harmonic cavities to damp the higher order modes. Finally, the 4th harmonic cavity similar to the Duke's RF cavity will be used for HLS-Ⅱ.

Key words: harmonic cavity, instabilities, lifetime improvement, HOMs damping

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1 Introduction

To users of synchrotron radiation, the beam lifetime is one of the most important aspects of a synchrotron light source. In low to medium energy storage ring light sources, the lifetime is usually dominated by large-angle Touschek scattering. One proven method for increasing the Touschek lifetime without compromising the transverse beam brightness is to reduce the peak charge density of an electron bunch. This requirement can be met by adding a higher harmonic RF system to modify the shape of the RF bucket. The energy distribution is unaffected but the bunch lengthens and the peak charge density decreases. Meanwhile, the harmonic cavity increases the spread of the synchrotron frequency of the electrons, which results in Landau damping [1].

In light sources, higher harmonic cavities are used successfully at the NSLS VUV-ring, ALS, NSLS-Ⅱ, MAX Ⅱ, BESSY Ⅱ and ALADDIN. A passive higher harmonic cavity will be used to increase the beam lifetime and suppress coupled-bunch instabilities in the Hefei Light Source Ⅱ Project (HLS-Ⅱ). When all RF buckets are filled equally, the transient beam loading may be neglected. However, unwanted side-effects such as Robinson instabilities should be avoided [2].

The experience with the main RF system indicates the importance of avoiding the HOMs of the cavities. That can be accomplished by reducing the Q-factor of the most harmful HOMs by the addition of a special absorbing load or a damping antenna.

In this paper, we present the simulated instability results and the preliminary design of a higher harmonic cavity with a HOM damper for HLS-Ⅱ.

2 Instability

For HLS-Ⅱ, we use the parameters shown in Table 1. The harmonic cavity impedance and Q factor are calculated respectively for the 3rd and 4th harmonic cavities. Based on the particle-tracking model in Reference [2], the instability results from 500000-turn simulations of 100 particles per bunch are shown in Fig. 1. The curve shows the parameters for optimal bunch lengthening. o: mild instability, where the energy spread exceeds its natural value by (10–30)%;

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Table 1. The machine parameters for the HLS-Ⅱ Light source Ⅱ project.

beam energy/GeV	0.8
revolution frequency/MHz	4.533
harmonic number	45
energy lost per turn/keV	16.73
beam emittance/nrad	40
injected current/mA	250–500
energy spread	0.00047
momentum compaction	0.02
nominal lifetime/h	5–6
nominal bunch length/mm	14.8 (about50 ps)
main rf frequency/MHz	204
main rf peak voltage/kV	250
harmonic voltage/MV (n=3,4)	0.083, 0.0625
harmonic cavity Q (n=3,4)	20000, 18000
shunt impedance (n=3,4)	2.7, 2.5
bunch length with HHC (n=3,4)	149 ps, 129 ps
lifetime improvement factor (n=3,4)	2.98, 2.58

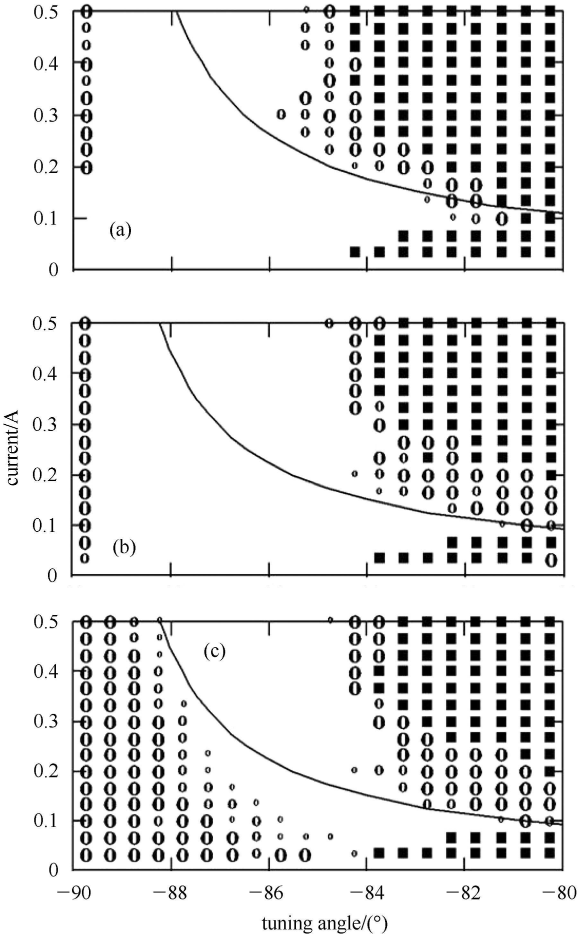


Fig. 1. Modeling for the HLS-Ⅱ base lattice with the worst-case parasitic coupled-bunch instability. (a) n=3, with no HOM. (b) n=4, with no HOM. (c) n=4, with a typical damped HOM.

0: moderate instability, where the energy spread exceeds its natural value by (30–100)%; **O**: strong instability, where the energy spread has increased more than 100%; ■: lost macroparticles. From Fig. 1(a) and (b), we find that the 4th harmonic cavity almost has the same performance as the 3rd harmonic cavity for stability. Comparing Fig. 1 (b) with (c), it can be concluded that the higher order modes contribute to the instabilities. However, tuning in the harmonic cavity can strongly suppress the parasitic coupled-bunch instability. In addition, the calculated optimum lifetime improvement factors from the model [2] are 2.98 and 2.58 for the 3rd and 4th harmonic cavities respectively.

3 Simulation and design

According to the KEK-PF-shaped RF cavity [3], a number of simulations have been made and the 3rd harmonic cavity has been designed (shown in Fig. 2). The cavity absorbs HOMs by two SiC ducts. The simulations show that some HOMs below the cutoff frequency of the beam pipe are trapped in the cavity. However they may be coupled efficiently by three couplers with rod-shaped antenna similar to the ones

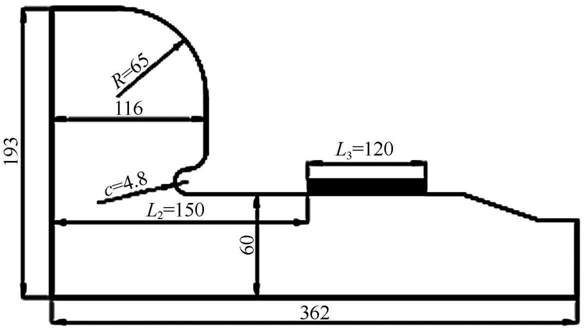


Fig. 2. Cross-sectional view of the 3rd harmonic cavity. The dark colored part is the SiC absorber.

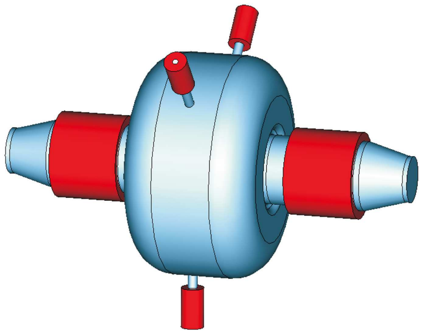


Fig. 3. The 3rd harmonic cavity with SiC absorbers and three antennas.

Table 2. The RF parameters of the 3rd harmonic cavity.

mode	undamped	damped		
longitudinal	Q	R_{eff}/Ω	Q	R_{eff}/Ω
M1	43060	3.214E6	16273	1.2E6
M2	49270	1.038E5	3.38	0.073
M3	70560	4.956	4.75	0.0297
transverse	Q	$R_{\text{eff}}/(\Omega/\text{m})$	Q	$R_{\text{eff}}/(\Omega/\text{m})$
D1	43670	4.440E5	2.64	12.39
D2	43990	5.099E6	2.59	4.5
D3	41590	5.043E4	2.93	3.53

in Ref. [4]. Fig. 3 shows the cavity with SiC ducts and three coaxial couplers. Based on Table 2, we think that the HOMs are damped efficiently.

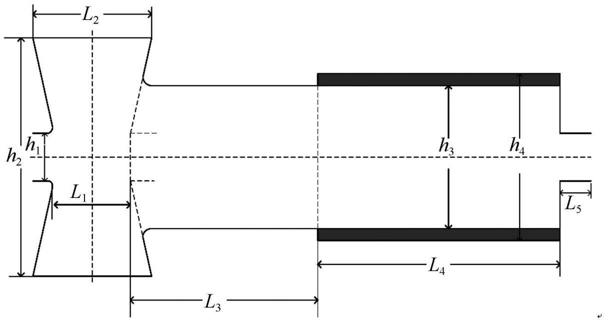
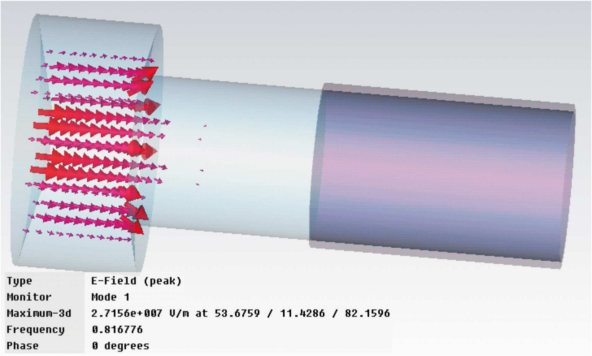


Fig. 4. Cross-sectional view of the 4th harmonic cavity (L_1=81.76 mm, L_2=136.17 mm, L_3=410 mm, L_4=274 mm, h_1=80 mm, h_2=277.07 mm, h_3=165 mm, h_4=181 mm, L=795 mm).

Due to the space limitation of HLS-II, the 4th harmonic cavity based on Duke's RF cavity [5] with HOM damping by the SiC duct (ε'=30, ε''=21) is considered in Fig. 4. The cavity has been simulated. As shown in Fig. 5, the accelerating field is trapped in the main cavity and the HOM absorber has less effect on the accelerating mode. The fundamental mode and HOMS parameters are presented in Table 3. The shunt impedance is equal to 3.6. We find that the HOMs quality factors decreased obviously with a HOM damper. The calculated wake fields induced by the beam, which have large effects on the quality of the beam, are suppressed in the damped cavity (Fig. 6).



Type E-Field (peak)
Monitor Mode 1
Maximum-3d 2.7156e+007 V/m at 53.6759 / 11.4286 / 82.1596
Frequency 0.816776
Phase 0 degrees

Fig. 5. The electric field of the accelerating mode for the 4th harmonic cavity with the HOM absorber.

Table 3. The RF parameters of the 4th harmonic cavity.

mode	undamped	damped		
longitudinal	Q	R_{eff}/Ω	Q	R_{eff}/Ω
M1	25632	1.740E6	25157	1.724E6
M2	41317	1.069E5	15	30
M3	40064	1.109E5	23	1.525
M4	34169	7.240E4	8	24
M5	25020	3.750E4	11	45
transverse	Q	$R_{\text{eff}}/(\Omega/\text{m})$	Q	$R_{\text{eff}}/(\Omega/\text{m})$
D1	23938	1.830E6	2862	3.666E4
D2	28726	1.180E6	140	167
D3	40127	6.600E6		
D4	35050	1.812E5	5	33

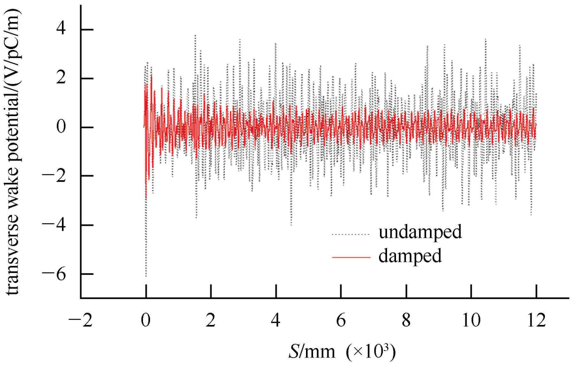


Fig. 6. Transverse wake potential for the undamped and damped cavity (sigma=15 mm, r=20 mm).

4 Discussion and conclusion

The lifetime improvement factors calculated are obtained respectively as 2.98 and 2.58 by using the passive third and fourth harmonic cavities. The simulated results obtained by the particle-tracking model confirm that tuning in the harmonic cavity may suppress the parasitic coupled-bunch instabilities. The 4th harmonic cavity almost has the same performance as the 3rd harmonic cavity for stability and the higher order modes contribute to the instabilities.

The 3rd harmonic cavity with a similar shape to the KEK-PF RF cavity damps the higher order modes by means of SiC ducts and three rod-shaped antenna. However, the off-centred damper is at an asymmetrical position to the electric field pattern of the accelerating mode, and there would be some coupling with the accelerating mode [6]. On the other hand, some HOMs such as TM011 have a small frequency shift with the varying of the antenna's blank-flange length. Thus a feedback method may be needed for this kind of mode [7].

Based on the above discussions, the 4th harmonic cavity similar to Duke's RF cavity will be used for HLS-II and the simulation results show that higher order modes are damped efficiently while having a low influence on the fundamental mode.

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