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, the simulated results confirm that tuning in the harmonic cavity may suppress the parasitic coupled-bunch instabilities. The higher-harmonic cavity has been designed and the calculated factor of lifetime improvement is larger than 2.5.

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 intrabeam (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 and the lifetime improves. 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 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 indicated 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 the higher harmonic cavity with HOM damper for HLS II.

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INSTABILITY

For HLS II, we use the parameters shown in Table 1. The harmonic cavity impedance and Q factor are estimated respectively for 3rd and 4th harmonic cavities. The instability results from 500000-turn simulations of 100 particles per bunch are shown in Figure 1. The curve shows the parameters for optimal bunch lengthening. ∘ : mild instability, where the energy spread exceeds its natural value by (10-30)%; **o**: 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. The results show that tuning in the harmonic cavity strongly suppresses the parasitic coupled-bunch instability. The calculated optimum lifetime improvement factors are 2.98 and 2.58 for 3rd and 4th harmonic cavities.

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 lifetime [hours] (before 3HC)	5-6
Nominal rms bunch length (mm)	14.8(about50 ps)
Main rf frequency [MHz]	204
Main rf peak voltage [kV]	250
Third harmonic frequency [MHz], n=3,4	612, 816
Harmonic rf voltage [MV], n=3,4	0.083, 0.0625
Harmonic cavity Q (n=3,4)	20000, 18000
Harmonic cavity $R_S(M\Omega)$, n=3,4	2.7, 2.5
Rms bunch length with HHC (n=3,4)	149ps, 129ps
Optimum lifetime increase (n=3,4)	2.98, 2.58

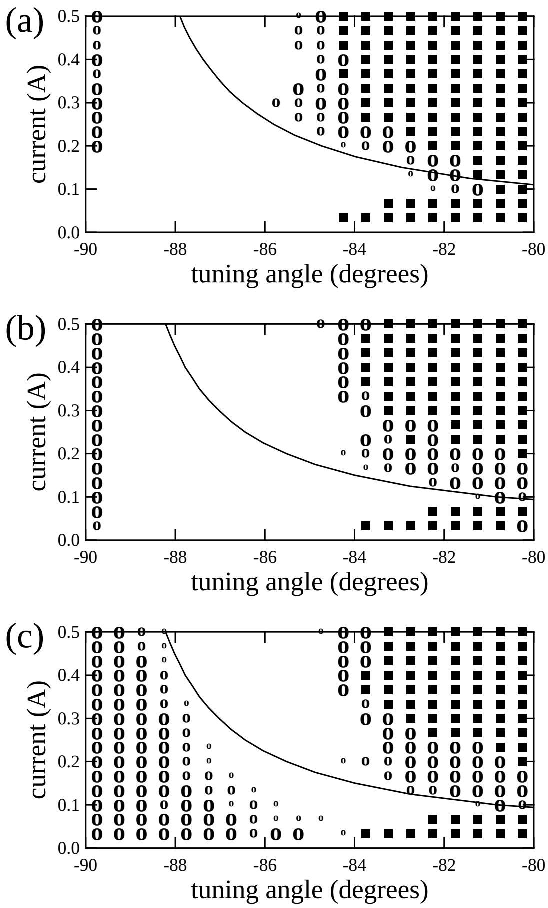

Figure 1: Modeling for the Hefei base lattice with worst-case parasitic coupled-bunch instability. (a) n=3, with no HOM. (b) n=4, with no HOM. (c) n=4, with typical damped HOM.

DESIGN

Because of the limited space of HLS-II, the 4th harmonic cavity based on Duke's RF cavity [3] with HOM damping by the SiC duct (ε'=30, ε''=21) has been simulated (shown in Figure 2) and the fundamental and HOM parameters are presented in Table 2. The shunt impedance is equal to 3.6 MΩ. We find that the HOM quality factors are decreased significantly by the HOM damper.

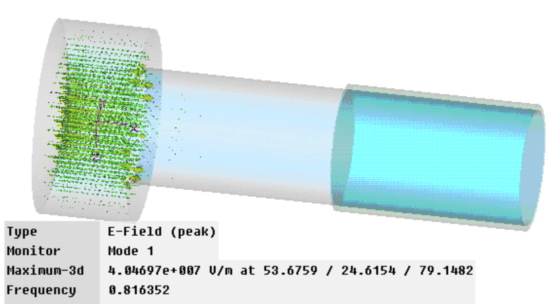

Figure 2: The model of the 4th harmonic cavity with the HOM absorber.

We also designed a third harmonic cavity according to the KEK-PF RF cavity (shown in Fig. 3) [4]. The cavity absorbs HOMs by two SiC ducts. But the simulations show that some HOMs below the cutoff frequency of the beam pipe are trapped in the cavity. However they are coupled efficiently by three couplers with rod-shaped antenna [5]. Figure 4 shows the cavity with SiC ducts and three coaxial couplers. Comparing Table 3 and Table 4, we think that the HOMs are damped effectively.

Table 2: The RF Parameters of the 4th Harmonic Cavity

mode	Frequency (MHZ)	Q value (without damper)	Q value (with damper)
TM, m=0, mode1	815.9	23305	23300
TM, m=0, mode2		39194	1.6
TM, m=1, mode1		28497	104
TM, m=1, mode2		30841	56
TM, m=1, mode3		34800	13
TE, m=0, mode1		58440	58400
TE, m=0, mode2		59490	1.6
TE, m=1, mode1		28497	58
TE, m=1, mode2		30841	56
TE, m=1, mode3		34800	12

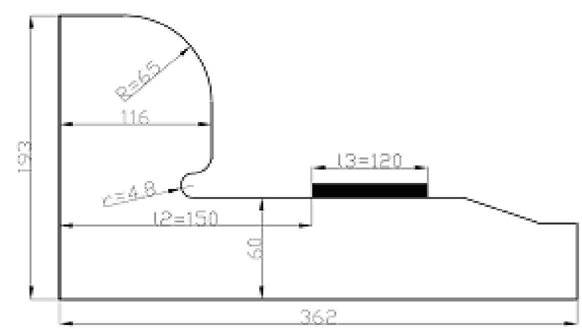

Figure 3: Cross-sectional view of the 3rd harmonic cavity. The dark colored part is the SiC absorber.

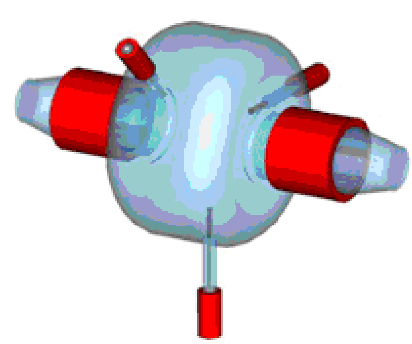

Figure 4: The 3rd harmonic cavity with SiC absorbers and three couplers.

Table 3: The RF Parameters for the 3rd Harmonic Cavity without any Absorber

Longitudinal mode			Transverse mode		
Mode	**Frequency(MHz)**	**Q factor**	**Mode**	**Frequency(MHz)**	**Q factor**
M 1	611.673	41360	D 1	804.432	42928
M 2	932.381	35153	D 2	959.784	46465
M 3	1384.07	47290	D 3	1175.64	34039
M 4	1519.537	61268	D 4	1353.105	45192
M 5	1620.935	42509	D 5	1455.723	73427
M 6	1974.653	42195	D 6	1509.237	
M 7	1996.947	39212	D 7	1569.244	

Table 4: The RF Parameters for the 3rd Harmonic Cavity with SIC Ducts and Three Antennas

Longitudinal mode		Transverse mode	
Mode	**Q factor**	**Mode**	**Q factor**
M 1	37476	D 1	400
M 2	16	D 2	1552
M 3	315	D 3	110
M 4	3293	D 4	23
M 5		D 5	
M 6	1.2	D 6	
M 7	1.2	D 7	

CONCLUSION

A factor of 2.98 and 2.58 of lifetime improvement with passive third and fourth harmonic cavities are obtained in theory. The simulated results confirm that tuning in the harmonic cavity may suppress the parasitic coupled-bunch instabilities. The higher harmonic cavities for HLS-II are designed and the results show that higher order modes are damped efficiently while having low influence on the fundamental mode.

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