THE 4TH HARMONIC CAVITY FOR HEFEI LIGHT SOURCE-II *

Cong-Feng Wu[†], Lin Wang, Chuan Li，Ke Xuan, J. Y Li, W. Xu, Jigang Wang, Guirong Huang,
Kai Jin, Dachun Jia, Sai Dong, Weiming Li, National Synchrotron Radiation Laboratory, USTC,
Hefei, Anhui, 230029, P. R. China
E. A. Rotov, G. Ya. Kurkin, Budker Institute of Nuclear Physics, 630090, Novosibirsk, Russia
R. A. Bosch, University of Wisconsin-Madison, 3731 Schneider Drive, Stoughton, Wisconsin
53589, USA

Abstract

A higher-harmonic cavity can be used to increase the beam lifetime and suppress coupled-bunch instabilities. In this paper, the physical calculations have been made and the optimum RF parameters of the higher-harmonic cavity have been gained for the Hefei Light Source II Project (HLS-II). Moreover, the 4th passive harmonic cavity has been developed and commissioned successfully. The experimental results showed that the factor of lifetime improvement is close to 1.4 and the stability has been improved efficiently.

INTRODUCTION

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 add a higher harmonic RF system to modify the shape of the RF bucket. The energy distribution is unaffected but the bunch is lengthened. The peak charge density is decreased and the lifetime is improved. The lifetime improvement factor is about 1.4 by using normal conductor harmonic cavity (passive) in experiment [1]. Meanwhile, the harmonic cavity increases the spread of the synchrotron frequency of the electrons, which results in Landau damping [2].

In light sources, higher harmonic cavities are used successfully at the NSLS VUV-ring, ALS, NSLS-II, MAX II, BESSY II and ALADDIN. 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 [3].

In this paper, we present the physical design and simulated instability results. The 4th harmonic cavity which is composed of normal conductor has been developed because of the limited space of HLS-II. It is a passive harmonic cavity with HOM damper. We measured the RF parameters of the harmonic cavity. Finally, the experimental results (on-line measurement) for the bunch length and the instabilities are presented after the new 4th harmonic cavity has been installed in the storage ring for HLS-II.

PHYSICAL CALCULATIONS AND THE CHOICE FOR OPERATION MODES

The RF parameters such as the impedances, Q factor and the RF voltage for the 4th harmonic cavities are obtained by optimum calculations [1] based on the longitudinal beam dynamics with the machine physical parameters and the RF parameters of the main RF cavity listed in Table 1. The parameters are also shown in Table 1. Specially, the maximum harmonic cavity voltage is required to be not less than 62.5keV. The optimum rms bunch length and the lifetime improvement factor are 129ps and 2.58 respectively in theory.

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. ◦ : 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 indicate that tuning in the harmonic cavity strongly suppresses the parasitic coupled-bunch instability.

Table 1: Physical Parameters of the HLS-II Storage Ring and RF Cavities

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 HC)	5-6
Nominal rms bunch length (mm)	14.8 (50 ps)
Main RF frequency [MHz]	204
Main RF peak voltage [kV]	250
Fourth harmonic frequency [MHz], n=4	816
Harmonic RF voltage [KV], n=4	62.5
Harmonic cavity Q (n=4)	18000
Harmonic cavity $R_S(M\Omega)$,n=4	2.5
Rms bunch length with HHC (n=4)	38．184（129ps）
Optimum lifetime increase (n=4)	2.58

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* Work supported by HLS-II Project

[†] email: cfwu@ustc.edu.cn

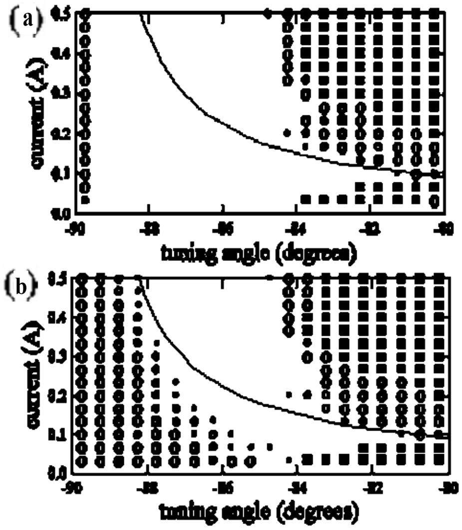

Figure 1: Modeling for the Hefei base lattice with worst-case parasitic coupled-bunch instability. with no HOM. (a) n=4, with no HOM. (b) n=4, with typical HOM.

The harmonic cavity voltage is changed by adjusting the position of the tuner (to tune) in the cavity. We use two operation modes (the fixed detuning and the fixed voltage) in commissioning. The tuner is controlled automatically by low-level circuit.

EXPERIMENTAL RESULTS

The experience with the main RF system indicated the importance of avoiding the HOMs of the cavities. The 4th harmonic cavity with HOM damper has been developed and RF parameters measurement are made. Fig. 2 is a photo of the harmonic cavity on the bench. Fig. 3 are the typical measured results. RF parameters and spectrum of higher-order modes are summarized in Table 2 and Table 3. From Table 2, we determine that the Q>20000, R_s>2700000 Ω and R_s of HOMs<1000 Ω in the frequency bandwidth of 816±2.6MHz. The above results state that the 4th harmonic cavity voltage (62.5keV) can be achieved.

Figure 2: Photo of the harmonic cavity on bench.

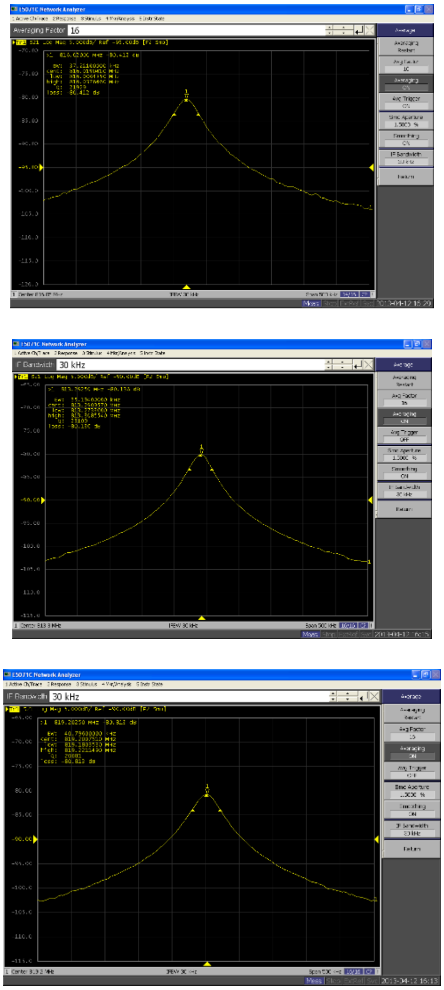

Figure 3: S parameters measured for the 4th harmonic cavity with the HOM absorber.

Table 2: RF Parameters in the Bandwidth for the 4^{th} Harmonic Cavity

f, MHz	Q	R_s, Ω
813.3	23109	3119715
813.4	22027	2973645
813.8	22877	3088395
814.2	22796	3077460
814.6	22495	3036825
815	22283	3008205
815.4	22220	2999700
815.8	22053	2977155
816	21929	2960415
816.4	21769	2938815
816.8	21415	2891025
817.2	21293	2874555
817.6	21032	2839320
818	20796	2807460
818.4	20618	2783430
818.6	20532	2771820
819	20216	2729160
819.2	20081	2710935

Table 3: Spectrum of Fundamental and Higher-order Modes

f, MHz	Q	R_s/Q, Ω	R_s, Ω
816	21000	135	2960415
2097	14000	0.05	700
2449	4500	0.1	450
2739	1200	0.04	48
2756	1500	0.02	30
2838	2300	0.3	850
2978	3000	0.14	420
3023	1500	0.002	3
3054	1000	0.0006	0.6
3059	1000	0.002	2

Figure 4 shows the 4th harmonic cavity installed in the storage ring for HLS-II. We measure the bunch length (by using the streak camera) as the harmonic cavity voltage is changed for the two typical beam currents. Where, the main rf cavity voltage is 200KeV. The results show that the beam length is increased obviously. From Table 4, Comparing the cavity voltages of 44kV and 10.9kV, the ratio of the bunch length is 115.998/89.091=1.302 for beam current of 75 mA of I_b=75mA. Table 5 shows that for the cavity voltages are 62kV and 6kV, the ratio of the length is 159.647/102.844=1.552 for beam current of I_b=300mA. So the lifetime is improved when the harmonic cavity voltage is increased. We may predict that the factor of lifetime improvement is about 1.4.

In addition, the oscillation amplitude and frequency change with the harmonic cavity voltage are given in Fig. 5 and Fig. 6 respectively. We conclude that the instability is decreased as the harmonic cavity voltage is raised. The experimental results is in accord with the theoretical analysis.

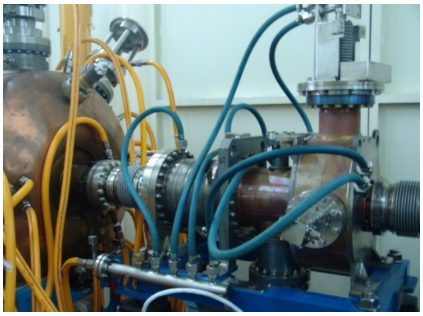

Figure 4: The 4th harmonic cavity installed in the storage ring for HLS-II.

Table 4: Relation of the Bunch Length to the Harmonic Cavity Voltage with I_b=75mA, V_{rf}=200kV

$\sigma_{z,,}$ ps	V_{hc}, kV
89.091	10.9
113.606	22
115.4	33
115.998	44

Table 5: Relation of the Bunch Length to the Harmonic Cavity Voltage with I_b=300mA, V_{rf}=200kV

$\sigma_{z,}$ ps	V_{hc}, kV
102.844	6
108.823	40
117.792	52.67
159.647	62

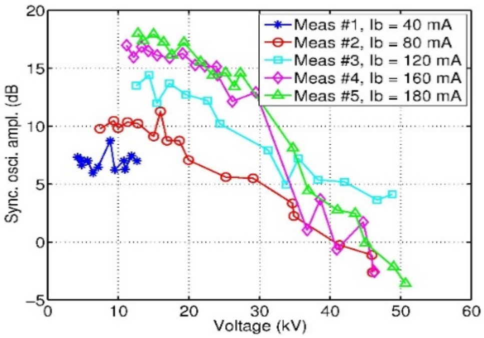

Figure 5: Oscillation Amplitude vs. harmonic cavity voltage.

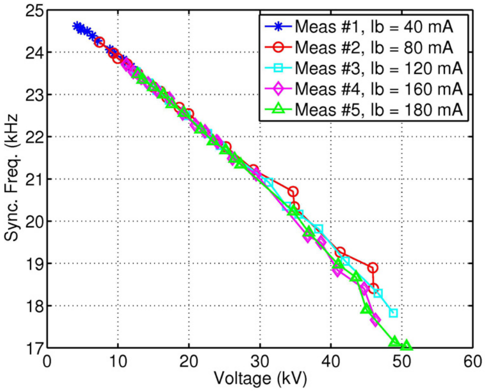

Figure 6: Oscillation Frequency vs. harmonic cavity voltage.

SUMMARY

The 4-th passive harmonic cavity for HLS-II is physically designed and developed. The observed gain in lifetime is about a factor of 1.4 with the passive harmonic cavity. The experimental results confirm that tuning in the harmonic cavity can suppresses the bunch instabilities.

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