ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW029

PRELIMINARY STUDY OF BUNCH COMPRESSION IN THE HEFEI LIGHT SOURCE

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Abstract

Short electron bunch has interesting applications in the synchrotron radiation light sources, such as the production of powerful coherent THz radiation, time resolving spectrum analysis, etc. In this work, we are interested in acquiring the short bunch in the storage ring with a small circumference like Hefei Light Source. In this paper, we tried to approach the short bunch in two separate methods: by increasing the higher harmonic cavity voltage and by reducing the momentum compaction factor. The preliminary result and observations are shown and discussed.

INTRODUCTION

Hefei light source (HLS) is a dedicated 2^{nd} generation VUV light source, it consists of an 800 MeV electron storage ring, a linac injector, and a beam transfer line. It was designed and constructed over 30 years ago, and Phase II upgraded project was carried out 20 years ago. After the major renovation project started in 2010, a new full energy injector was implemented and the storage ring magnet lattice was reconstructed with new insertion devices (see in Table 1) [1], a new higher harmonic cavity was installed [2].

Table 1: Main Parameters of Upgraded HLS Storage Ring

Parameter	**Value**
Energy E_0	800 MeV
Circumferences C_0	66.13 m
Natural Emittance ϵ_n	36 nmrad
Beam Intensity	300 mA
RF frequency f_{RF}	204 MHz
Tune ν_x/ν_y	4.41/3.21
Momentum compaction factor α_c	0.0205

Short electron bunch in the synchrotron radiation light sources can be used to produce powerful coherent THz radiation due to the superposition of coherent radiation fields of the electrons inside the bunch [3], when the bunch length is smaller than the radiation wavelength. Except for the linac-based synchrotron radiation light source, various methods were developed to produce short electron bunch or short radiation pulse, for example, laser-slicing method, isochronous storage ring, crab cavity pair technique, etc [4–6].

The bunch length in the storage ring can be calculated:

$$\sigma_z = \left(\frac{c\alpha_c E T_0}{\left|\frac{\partial V}{\partial z}\right|} \right)^{\frac{1}{2}} \sigma_\delta \tag{1}$$

where α_c is the momentum compaction factor, E is the energy of the stored electron beam, $\frac{\partial V}{\partial z}$ is the gradient of accelerating electric field, σ_δ is the energy dispersion of the electron beam, which is determined by the equilibrium state of the synchrotron radiation damping and the quantum excitation. According to this formula, the bunch length can be compressed in two methods: 1) by increasing the gradient of the longitudinal accelerating electric field, and 2) by reducing the momentum compaction factor α_c.

In this paper, we will present our preliminary study of bunch compression in the HLS. One way is to tune the higher harmonic cavity (HHC), another is to operate the machine in a lattice with a very small momentum compaction factor. In the second method, we designed a lattice with α_c two order of magnitude smaller than the nominal operation lattice, and the bunch length was measured while approaching the dedicated lattice. The preliminary result and observations will be shown and discussed.

BUNCH LENGTH MEASUREMENT

The layout of the bunch length measurement system in the HLS is illustrated in Fig. 1. In this system, the synchrotron radiation is reflected, focused and filtered by the optical elements, and it is sent to the downstream camera. The longitudinal distribution of the synchrotron radiation is captured by the streak camera, and the bunch length can be calculated. The resolution of this system is about 2 ps [7].

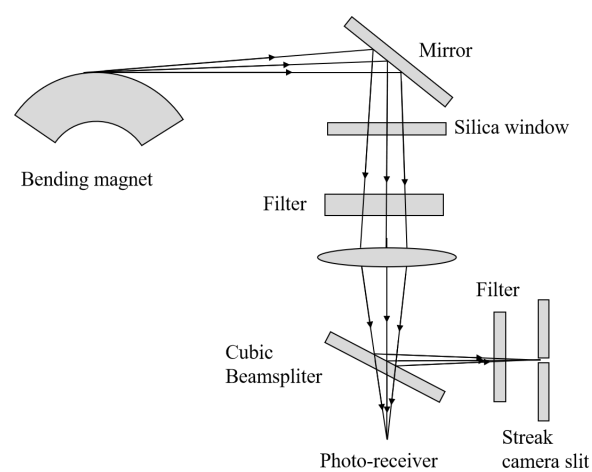

Figure 1: Layout of the bunch length measurement system.

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As shown in Fig. 2, the image data is selected for fitting (between the two yellow lines), hence to avoid unexpected perturbations, the summation of these data is shown in green dot-line. Gaussian fitting is performed, and bunch length is obtained by transferring the pixels to bunch length.

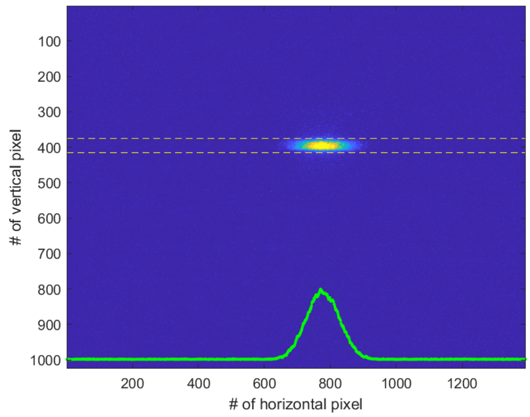

Figure 2: Image acquired by the streak camera. Data points between the yellow dash-lines are summed up as shown in the lower green dot-line.

BUNCH LENGTH COMPRESSION

Using Higher Harmonic Cavity

A passive 4^{th} HHC was installed in the HLS, which was initially implemented to lengthen the beam, but it can be used to shorten the bunch as well. According to the study in [2], the bunch length in HLS can be shortened by properly changing the tuning angle of HHC. Therefore, we performed this experiment in the HLS storage ring. By adjusting the tuning plug of HHC, the voltage of the HHC and bunch length were measured with the position of the tuning plug, as shown in Fig. 3.

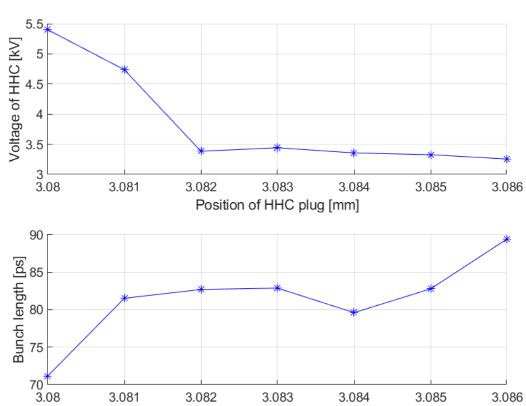

Figure 3: Measured voltage of the HHC and bunch length by tuning the plug of the HHC. Beam current is about 5 mA.

However, there was not a significant change of the bunch length during this process. The longitudinal distribution of the bunch while HHC plug was located at the position of 3.087 mm is shown in Fig. 4. It has deviated from the Gaussian distribution, and the bunch looks to be longitudinally shaped by the HHC [8], resulting from the change of phase due to beam energy dispersion.

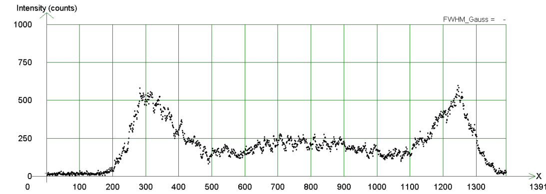

Figure 4: Longitudinal bunch distribution measured with HHC plug located at the position of 3.087 mm.

Implementing Low Alpha Lattice

Another approach is to operate the storage ring in a lattice with a small momentum compaction factor. As shown in Fig. 5, the momentum compaction factor is 1×10^{-4}, which is two orders of magnitude smaller than that of the nominal operation lattice in HLS. The main parameters of this lattice are shown in Table 2. By operating the storage ring magnets in this lattice after normalization, the injection scheme was found to be insufficient, and it was very difficult to store the electron beam in the storage ring with the new lattice.

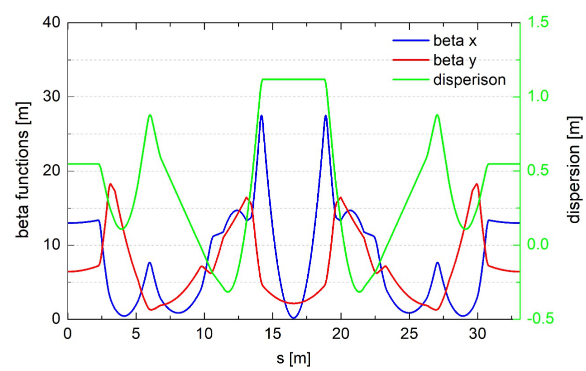

Figure 5: The lattice with α_c=1e-4.

Table 2: Main Parameters of the Low Alpha Lattice

Parameter	Value
Energy E_0	800 MeV
Circumferences C_0	66.13 m
Tune ν_x/ν_y	4.434/2.355
Momentum compaction factor α_c	1×10^{-4}

Therefore, we decided to approach this low alpha lattice step-by-step, starting from the nominal lattice, to find out the limitation of the beam current that can be stored in this new lattice. So we started from the nominal operation lattice, injected the electron beam to a typical current and then

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change the settings of the magnets towards the dedicated lattice. This process can be formulated as equation 2, where $\vec{\mathcal{K}}_{set}$ represents the setting of quadrupole magnets, $\vec{\mathcal{K}}_0$ are the strength of quadrupole in nominal operation lattice, and $\vec{\mathcal{K}}_{low\alpha}$ is the quadrupole strength of the dedicated lattice, the scaling factor x shows the relative position from the staring lattice and the dedicated one. In the process of approaching the low alpha lattice starting, x changes from 0 to 1.

$$\vec{\mathcal{K}}_{set} = \vec{\mathcal{K}}_0 + x\left(\vec{\mathcal{K}}_{low\alpha} - \vec{\mathcal{K}}_0\right) \tag{2}$$

By changing the scaling factor x from 0 to 1, the momentum compaction factor of the "transitional" lattice decreases. As shown in Fig. 6, the momentum compaction factor α_c decreases substantially (one order of magnitude) between 0.9 and 1. Therefore, the strength of magnets should be carefully changed in small steps in this region to avoid beam loss due to the sudden change of α_c.

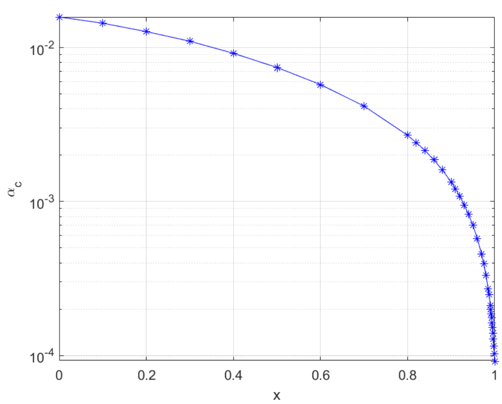

Figure 6: Change of momentum compaction factor with scaling factor x in Equation 2.

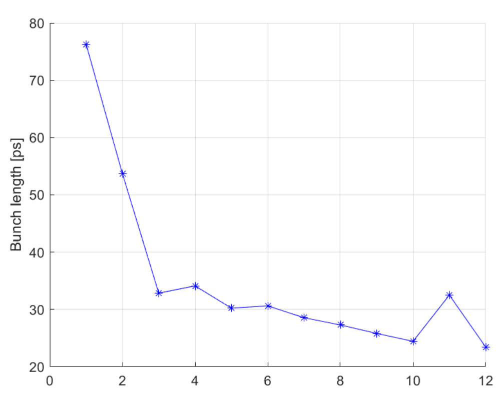

Figure 7: Measured bunch length while approaching the low alpha lattice.

It was observed as expected that the beam current is decreased during this process, as shown in Fig. 7. We observed some sudden decrease of the beam current while x was still small (close to the nominal lattice), where the beam could still be injected although not very sufficient. The injection was performed, but the highest current was limited. Hence the beam current was expected to be ultra-low in the region close to the dedicated lattice.

Therefore, we started this experiment with a relatively low beam current of 1.3 mA in a single bunch mode. And the final observation showed that the beam current in the storage ring was about 0.002 mA with the scaling factor x=0.992, which corresponding to a small value of momentum compaction factor $\alpha_c = 1.8 \times 10^{-4}$ in theory. And the bunch length was about 23 ps, which was significantly shorter than that of the nominal operation (about 88 ps).

DISCUSSION AND OUTLOOK

In this work, the short bunch was approached with two methods in the Hefei light source, the first method was to adjust the tuning plug of the HHC, and the second method was to approach the lattice with small momentum compaction factor. It was observed that the bunch was not significantly shortened by adjusting the tuning plug of the passive HHC. However, in approaching the low alpha lattice, the bunch length was significantly decreased with the reduced momentum compaction factor. To further study this topic, an upgrade is needed for the bunch length measurement system, so that to achieve better measurement resolution for ultra-low beam current. And the step monitor of the HHC tuning plug needs to be upgraded to improve the control resolution.

ACKNOWLEDGEMENT

This work was supported by the Fundamental Research Funds for the Central Universities (Grant No.WK2310000082 and WK2310000077), and the National Natural Science Foundation of China (Grant No. 11475167).

REFERENCES

[1] Wang Lin, Li Weimin, Feng Guangyao *et al.*, "The Upgrade Project of Hefei Light Source (HLS)", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper WEPEA043, pp. 2588–2590.

[2] Fan Hao, Wu Cong-Feng, He Duo-Hui, "Calculations for shortening the bunch length in storage rings using a harmonic cavity", *Chinese Physics C*, vol. 38, no. 8, p. 087004, 2014.

[3] Alexander Wu Chao, Karl Hubert Mess *et al.*, *Handbook of accelerator physics and engineering*, World scientific, 2013.

[4] David Robin, Etienne Forest, Claudio Pellegrini, Ali Amiry, "Quasi-isochronous storage rings", *Physical Review E*, vol. 48, no. 3, p. 2149, 1993.

[5] G Wüstefeld, A Jankowiak, J Knobloch *et al.*, "Simultaneous Long and Short Electron Bunches in the BESSY II Storage Ring", in *Proc. IPAC'11*, San Sebastian, Spain, Sep. 2011, paper THPC014, pp. 2936–2938.

[6] Michael Borland, J Carwardine, Y Chae *et al.*, "Planned Use of Pulsed Crab Cavities for Short X-ray Pulse Generation at the Advanced Photon Source", in *Proc. PAC'07*, Albuquerque, NM, USA, Jun. 2007, paper TUPMN091, pp. 1127–1129.

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[7] Baogen Sun, Baoyun Wang, Jigang Wang *et al.*, "Research and measurement of synchrotron radiation system for HLS," *Chinese Physics. C*, vol. 32(suppl.), pp.133–135, 2008.

[8] Fan Hao, Wu Cong-Feng, and Liu Guang-Chao, "Calculations of operating schemes for a passive harmonic cavity in HLS-II," *Chinese Physics C*, vol. 36, no. 9, p. 895, 2012.