 ISBN 978-3-95450-180-9

MULTIPLE BUNCH LENGTH OPERATION MODE DESIGN AT HLS-II STORAGE RING*

Weiwei Gao#, College of Mathematics and Physics, Fujian University of Technology
Fuzhou 350118, China
Wei Li, Lin Wang, NSRL, University of Science & Technology of China, Hefei, 230029, China

Abstract

In this paper we design a simultaneous three bunch length operating mode at the HLS-II (Hefei Light Source II) storage ring by installing two harmonic cavities and minimizing the momentum compaction factor. The short bunches (2.6 mm) presented in this work will meet the requirement of coherent THz radiation experiments, and the long bunches (20 mm) will efficiently increase the total beam current. Therefore, this multiple-bunch-length operating mode allows present synchrotron users and THz users to carry out their experiments simultaneously. Also we analyzed the physical properties such as the CSR effect, RF jitter and Touschek lifetime of this operating mode.

INTRODUCTION

Short pulse electron bunches have been used for decades to satisfy the complex requirements of time resolved experiments. Some of the short electron bunches have been used for producing coherent THz radiation in rapid reaction kinetics experiments. In particular, the combination of THz pump and x-ray probe experiments will offer the opportunity for scientists to separately study the atomic, electronic, and magnetic response of materials. Therefore, generation of coherent THz radiation at a synchrotron radiation facility is a meaningful subject of study.

Previously, the low momentum compaction factor lattice was the preferred scheme for obtaining short electron bunches, because the bunch length is proportional to the square root of the momentum compaction factor [1], as shown in Eq. (1).

$$\sigma_\tau^2 = \frac{2\pi C_q}{(mc^2)^2}\frac{\alpha R}{J_\tau \rho_0}\frac{E_0^3}{e\dot{V}_0} \tag{1}$$

Recently, workers at the BESSY-II storage ring proposed a new method for achieving a multiple-bunch-length operating mode by installing harmonic cavities [2]. Based on the BESSY-II proposal we present a scheme for a multiple-bunch-length operating mode at HLS-II, which combines the harmonic cavity and low alpha methods.

* Work supported by NSFC (11305170)
# gaomqr@mail.ustc.edu.cn

MULTIPLE-BUNCH-LENGTH OPERATING MODE DESIGN

Low Alpha Lattice Design

In this section we describe the designation work of a reasonable low alpha lattice using a genetic algorithm, which was reported in our previous work [3]. In this optimization, the four groups of quadrupole strengths of one superperiod are varied to obtain a satisfactory low alpha lattice. The first constraint of our optimization is that both the horizontal and vertical betatron functions should be constrained to smaller than 30m. The second constraint is that the maximum dispersion function is restricted to 0.8m. The two objectives are to minimize the momentum companion factor and the beam emiitance. Since that if two lattices with the same momentum compaction factor, we prefer the one with lower emittance. After ascertaining the constraints and objectives, the optimization result gives us a clear picture of HLS-II' lattice properties. The result shows that if the polarity of the four groups of quadrupoles remain the same as in the present HLS-II lattice, the momentum compaction factor will be able to reduced to 10^{-3} when satisfying the above constraints. In addition, the momentum compaction factor can be further reduced (to approximately 10^{-6}) when the polarities of the last two groups of quadrupoles are changed. Synthesizing the injection process and other technologies, we choose a lattice whose momentum compaction factor is 0.0039 and retain the quadrupole polarities of the original HLS-II lattice. The main twiss parameters of this new low alpha lattice are shown in Table 1.

Table 1: Twiss Parameters of the Low Alpha Lattice

Emittance	87nm-rad
Tunes	5.72/2.58
Natural chromaticity	-20.29/-15.95
Momentum compaction factor	0.0039

The one cell betatron functions and dispersion function of the low momentum compaction factor lattice are drawn using ELEGANT program [4], and shown in Fig. 1. In addition, we also studied the nonlinear properties of the newly designed low momentum compaction factor lattice. The dynamic aperture tracking with 1000 turns is shown in Fig. 2.

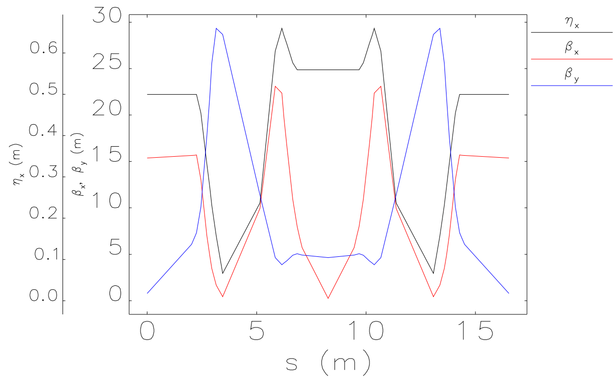

Figure 1: Twiss functions of the low alpha lattice.

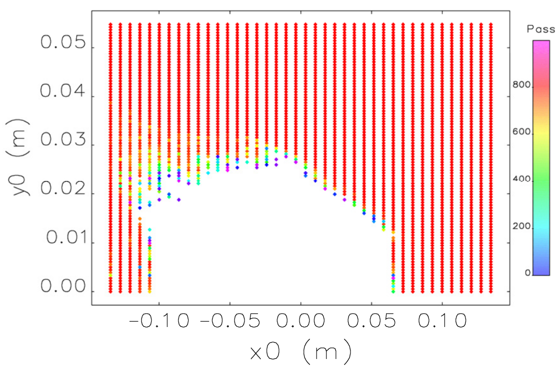

Figure 2: Dynamic aperture of the low alpha lattice, 4000 particles tracked with 1000 turns.

Multiple-Bunch-Length Operation Design at the Low Alpha Lattice by Harmonic Cavities

For the sake of economy, we use the original RF cavity of HLS-II. Hence, the designation of the new harmonic RF cavity parameters must be based on the original RF cavity. The frequency of the first harmonic cavity is chosen to be (N+i/3)×f_{rf} and that of the second harmonic cavity is chosen to be (M+i/3)×f_{rf}, where f_{rf} is the frequency of the basic RF cavity, M and N are two integers, and i can be chosen to be either 1 or 2. If the harmonic numbers are fixed, only the phase and voltage of the two harmonic cavities (four variables) can be varied to obtain the expected bunch lengths when satisfying the synchrotron radiation loss and stable buckets at the three bucket positions. In other words, the constraint conditions are larger than the variable numbers. Hence, we cannot restrict the beam length at the three places. Instead, we let the bunch length equal the value that we expect to obtain at one position, and along with the synchrotron radiation compensation at the three places are viewed as four constraints. After solving these equations, we obtain the initial phase and voltage of the two harmonic cavities. If the beam size at another two positions cannot satisfy our plan, that is, they are either too long or too short then we will change the harmonic numbers M, N, and i. Finally, we obtain three reasonable bunch lengths by installing two relatively low frequency harmonic cavities. The three cavity's parameters are listed in Table 2.

Table 2: Main Parameters of the Basic RF Cavity and Two Harmonic Cavities

Cavity	Basic RF	Harmonic RF-I	Harmonic RF-II
Voltage	250kV	186kV	184kV
phase	176.17deg	-79.0338deg	81.2895deg
Frequency	204MHz	747.9864MHz	679.9932MHz
Harmonic number	45	165	150

The sum voltages of the three RF cavities as a function of the longitudinal position are shown in Fig. 3.

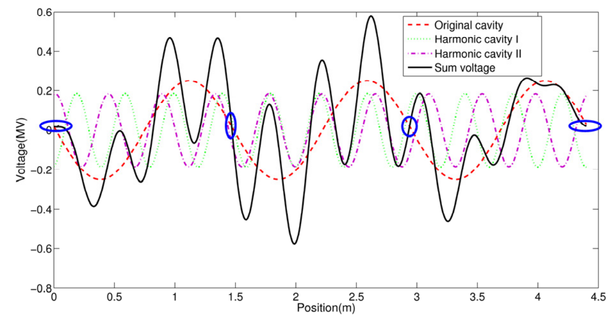

Figure 3: Accelerating voltage vs. position. Dotted red line is the voltage of the original RF cavity, dotted green line is the voltage of harmonic cavity I, dotted purple line is the voltage of harmonic cavity II, and solid black line is the sum voltage of the basic cavity and harmonic cavities.

After installing two harmonic cavities at the relatively low momentum compaction factor lattice, the longitudinal phase space and the beam size evolution process are simulated by ELEGENT program. A Gaussian-distributed beam with 5000 particles per bunch is tracked for 150, 000 turns (about three damping times). The longitudinal phase space of the long and short bunches are plotted in Fig. 4.

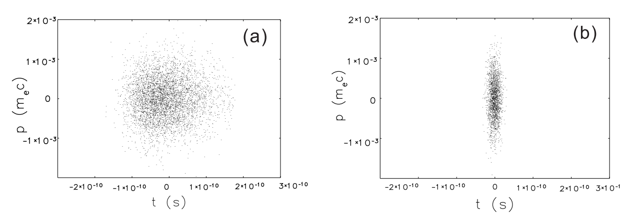

Figure 4: Tracking longitudinal phase space; plot (a) is the phase space of the long bunch (66 ps) and plot (b) is that of short bunch (8.7 ps).

CSR INSTABILITY ANALYSIS

The microwave instability induced by the coherent-synchrotron-radiation (CSR) effect of a beam is analyzed in this section. We calculate the CSR microwave instability threshold current of the long bunch beam (20 mm) using Eq. (2)[5], where α is the momentum compaction factor, σ_δ the energy spread, I_A the Alfvén current, σ_z the bunch length, and h the harmonic number. The result shows that the single beam current threshold of the long bunch is 8.6 mA.

$$I_{th} > \frac{3\sqrt{2}\alpha\gamma\sigma_\delta^2 I_A \sigma_z}{\pi^{3/2} h} \tag{2}$$

When the bunch length is shorter than 10 mm at HLS-II, the CSR bursting instability threshold current satisfies a simple scaling law with respect to the bunch length Therefore, we calculate the beam current threshold using Eq. (3) for the short and the medium bunches, where $\partial V_{rf} / \partial z$ is the sum voltage gradient and f_0 the revolution frequency. Based on the bunched beam theory, the scaled current $\xi^{th}(\chi) = 0.5 + 0.34\chi$, and the impedance of free space $Z_0 = 120\pi\Omega$. As a result, we find that the CSR microwave instability threshold of the short and medium beams is 1.62 mA, and 1.82 mA, respectively.

$$I_{th} > \frac{4\pi\xi^{th}(\chi)\sigma_z^{7/3} f_0}{c^2 Z_0 \rho^{1/3}} \sum \frac{\partial V_{rf}}{\partial z}. \tag{3}$$

RF JITTER ANALYSIS

In this section we analyzed the RF jitter on the short beam bunch and simulated by ELEGANT program. The results are depicted in Fig. 5. The phase jitter applied in this simulation are 0.1 deg, and the voltage error is 0.01% of the rms voltage.

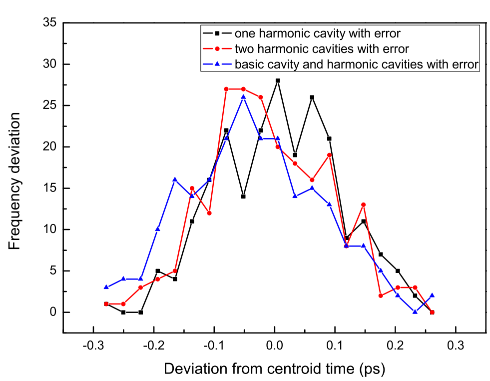

Figure 5: RF jitter analysis, the black line is the result harmonic cavity I with jitter, red line is the result both two harmonic cavities with jitter, blue line is all of the three cavities with jitter.

TOUSCHEK LIFETIME SIMULATION

The Touschek lifetime is another important issue for the short bunch beam. Thanks to the 15 long bunches, the Touschek lifetime is impressive for our designed machine. We also use the ZAP program to simulate the relation between Touschek lifetime and the total current, the result is depicted in Fig. 6. From this figure we see that when the total beam current is about 200mA, the Touschek lifetime can reach to 2 hours.

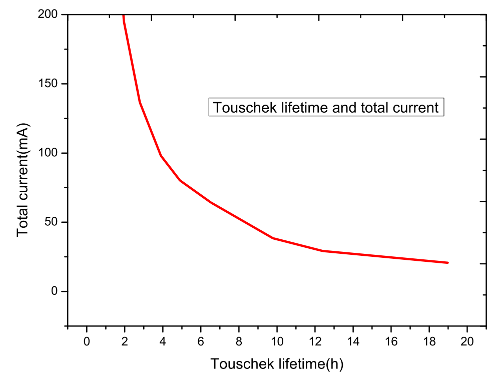

Figure 6: The Touschek lifetime with different beam current.

CONCLUSION

In this paper, we obtain a multiple-bunch-length operating mode for a storage ring using a hybrid low alpha and harmonic cavity method. The newly designed low alpha lattice has excellent linear and nonlinear properties. The old RF cavity of HLS-II was used and the newly added two harmonic cavities' harmonic numbers are the $11/3$-th harmonic and the $10/3$-th harmonic of the original RF cavity. After installing two harmonic cavities at the low alpha lattice, we achieve three kinds of bunch lengths. The short bunch can radiate at the coherent THz range and the long bunch can increase the total beam current for normal users. We also analyzed the CSR effect of this operating mode and show that the total beam current will reach 180 mA. Since the frequency and voltage are relatively low, this operating mode does not need to use multicell superconducting RF cavities. Hence, this operating mode is technically feasible.

REFERENCES

[1] M. Sands, "The physics of electron storage rings an introduction," SLAC-121.

[2] G. W¨ustefeld, A. Jankowiak, J. Knobloch, M. Ries, "Simultaneous long and short electron bunches in the BESSY-II storage ring," Proceedings of IPAC2011, San Sebastián, Spain (2011) 2936–2938.

[3] W. W. Gao, L.Wang, W. Li, "Simultaneous optimization of beam emittance and dynamic aperture for electron storage ring using genetic algorithm," *Phys. Rev. ST Accel. Beams* 14 (2011) 094001.

[4] M. Borland, User's manual for elegant program version 29.1.0.

[5] Y. Cai, Theory of microwave instability and coherent synchrotron radiation in electron storage rings, SLAC-PUB-14561.