PRELIMINARY STUDY FOR THE HLS VARIABLE PULSE LENGTH STORAGE RING BY TWO HARMONIC CAVITIES*

Tong Zhang, Cong-Feng Wu[†], Lei Shang, Lin Wang, Wei-min Li,
NSRL, USTC, Hefei 230029, China

Abstract

The 4th harmonic cavity is successfully used in HLS II to increase the beam lifetime and suppress the beam instability now. In the future, a scheme of two higher harmonic cavities may be applied in Hefei light source for a variable electron pulse length storage ring (HLS VSR). With optimal RF system parameters, 45 ps long bunches and 6 ps short bunches may be stored simultaneously in the HLS storage ring. The ratio of the bunch number for 45 ps to the one for 6 ps is 1:2. Particle tracking calculations are performed to simulate the longitudinal phase space of the new system and to track the process of shortening bunches with Elegant Software. Moreover, a tracking simulation code for RF systems is developed in MALAB to study transient beam loading which affects bunch length, phase stability, and longitudinal muti-bunch oscillation for different fill patterns. In the end, the preliminary design of the two harmonic cavities for longitudinal bunch focusing is given.

INTRODUCTION

Over the years, many approaches have been studied for generating short pulses in storage rings, including laser slicing technique [1], crab cavity approach [2], low-α method [3].The short pulses from previous two methods are only available at few photon beamlines following the modulator or the defecting cavity. All the photon flux from above mentioned methods are relatively low, due to either utilization of only a small fraction of the electrons or strong perturbation of particle motion.

To overcome these limitations, BESSYII firstly presented the alternating bunch length scheme [4] by using two active harmonic cavities. With the frequencies of the cavities chosen to be n and n+1/2 times of that of the main RF cavity, long and short bunches are filled in the storage ring simultaneously. And the available beam current (dominated by bursting instabilities [5]) can be greatly increased for a higher radiation power from the insertion devices. Specially, various bunch fill patterns may be used to serve different needs of the high flux long pulse users and the time resolved experiments relying on single short bunches simultaneously in the new scheme.

In this following, we explore the feasibility of the alternating bunch length scheme for HLS II by using two harmonic cavities. And Elegant simulations are performed for the longitudinal phase space of the new system and the process of shortening bunches. The transient beam loading is also considered here, which have a strong influence on the longitudinal beam dynamics. Finally, the preliminary design of harmonic cavities is given.

ALTERNATING BUNCH LENGTH SCHEME

In an electron storage ring, the equilibrium bunch length is [6]

$$\sigma_l = c\delta_e\sqrt{\frac{\alpha E_0}{ce f_{rev} V'}}$$

Here δ_e is the rms energy spread, α is the momentum compaction factor, V' is the voltage gradient, f_{rev} is the revolution frequency. Bunch length can be shortened by decreasing momentum compaction factor α or increasing the voltage gradient. In this scheme, we focus on the increasing of the voltage gradient.

In the alternating bunch length scheme [6], two harmonic cavities are installed with a difference of $1/3\, f_0$, f_0 is the frequency of the main cavity. Therefore the 45 buckets are divided into three classes: Bucket_{3m}, Bucket_{3m+1} and Bucket_{3m+2}, $(m = 0,1,2, \ldots 14)$.

Here we keep the length of Bucket_{3m} located at $3mcT_0$ invariant, $T_0 = 1/f_0$. And with the synchrotron loss of Bucket_{3m+1} replenished completely by the main cavity, we obtain the main parameters of three cavities which are given in Table 1.

Table 1: Main Parameters of the New RF System

Cavities	Frequency (GHz)	Voltage (MV)	Phase
Original	0.204	0.25	3.0747
Harmonic	1.224	1.9	π
Sub Harmonic	1.292	1.8	0

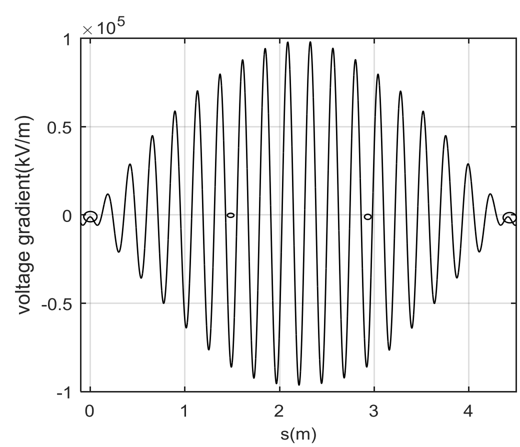

Figure 1: Total voltage gradient of the new RF system.

* Work supported by the National Science Foundation of China (11475167)
† cfwu@ustc.edu.cn

Figure 1 shows total voltage gradient for the chosen cavities as a function of longitudinal position. As can be seen , the Bucket_{3m} experiences a low voltage gradient which is equal to the one without the two harmonics while the total voltage gradient seen by Bucket_{3m+1} and Bucket_{3m+2} are nearly 100 times larger than Bucket_{3m}. Therefore, we can get long bunch at 45ps, the first short bunch at 6 ps, the second short bunch at 6 ps.

TRACKING RESULTS

A long term of particles tracking for 5000 particles with 15000 turns (nearly 3 damping times) at the same initial length 20mm is performed by using Elegant[7] to track the process of shortening bunches. The results are shown in Fig. 2.

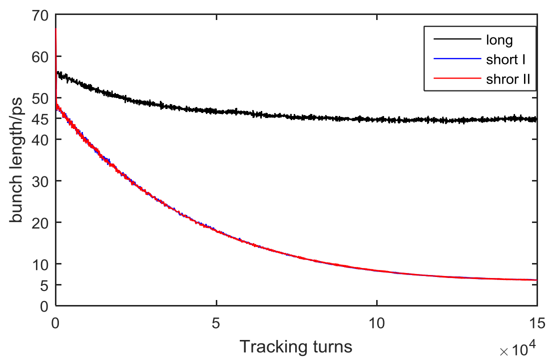

Figure 2: Results of 3 damping times tracking for length variation. Long, short I and short II bunches length variation are indicated in black, blue, red. The blue line coincides with the red one approximately. The final bunch length after 3 damping times are 45ps, 6ps and 6ps.

TRANSIENT BEAM LOADING

We developed a tracking code [8] written in MATLAB which uses one macro-particle per bunch for evaluating the transient beam loading. The cavity-bunch interaction is calculated by the means of phasor addition and active cavities are in the compensated condition with generator current in phase with the voltage. Assuming two normal conducting (NC) harmonic cavities are installed in the new RF system.

For the subharmonic cavity has $1/3\, f_0$ difference with harmonic frequency, the variation range of amplitude and phase of the 1292MHz cavity are large comparing with the other two cavities. The variation in phase and amplitude of the new RF systems mean that the time-behavior of the total voltage is different at each bucket position. In our scheme, Bucket_{3m} will be filled with long bunches, Bucket_{3m+1} and Bucket_{3m+2} filled with short bunches. The short bunches are formed under the high voltage gradient, so the relative effect of variation in voltage is expect to be small. At the buckets of long bunches however, the contributions of the two harmonic cavities are supposed to cancel each other, thus relative variations are amplified. With the bunch filled pattern of $I_{3m} = I_{3m+1} = I_{3m+2} =$ 6.67mA , the synchrotron phase position, the synchrotron frequency f_s and the bunch length is shown in Fig. 3.

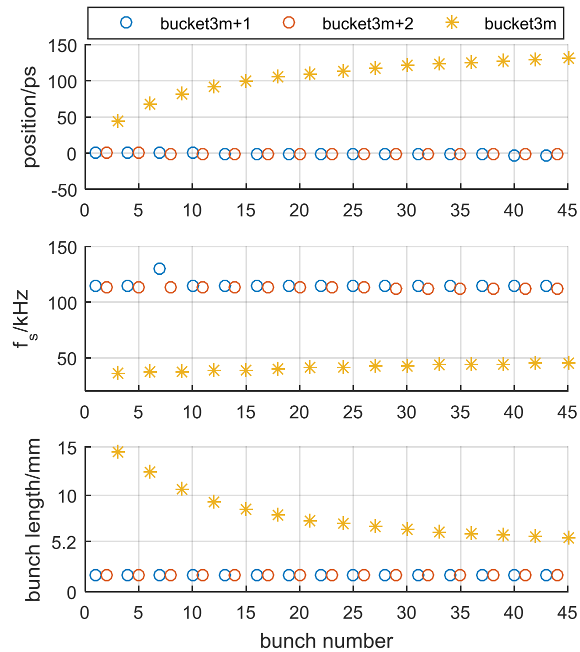

Figure 3: Synchrotron phase position (top), synchrotron frequency (center), and bunch length (bottom).

As can be seen, the influence of the transient beam loading on long bunches are more obvious than that on the short bunches, the majority of Bucket_{3m+1} become shortened.

For alleviating the effects of transient beam loading on the long bunches, a new filled pattern is considered, $I_{3m} =$ 16mA, $I_{3m+1} = 0$, $I_{3m+1} =$ 4mA. The bunch length for the fill pattern is shown in Fig.4. In this fill pattern, the condition of the long bunches is improved.

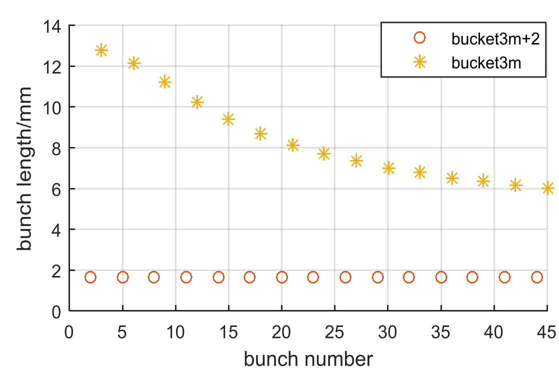

Figure 4: Bunch length in the new pattern.

PRELIMINARY CAVITY DESIGN

The voltage of main cavity in HLS II is relatively low, and the voltages of tw o harmonic cavities, nearly 2 MeV, are not high. Both NC and SC technologies can be used in the design of harmonic cavity. In this paper, we focus on the NC. The preliminary structure based on the BESSY II's cavity [9] is given in Fig.5.The main RF parameters are shown in Table.1.

ISBN 978-3-95450-147-2

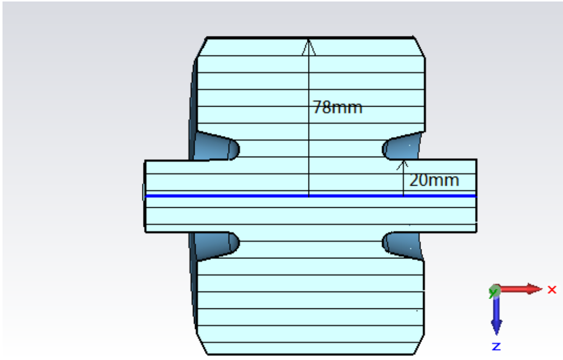

Figure 4: Bunch length in the new pattern.

CONCLUSION

With optimal RF parameters,15 long bunches and 30 short bunches can be stored in the HLS VSR simultaneously. The transient beam loading is significant in the new scheme, especially for long bunch. An uneven fill pattern may be beneficial to it. For better performance, study on superconductivity is in progress.

REFERENCES

[1] Zholents A A *et al.*, *Phys.Rev.Lett.,* 1996,76:912.

[2] Zholents *et al.*, *Nucl. Instrum. Methods Phys. Res.*, Sect.A, 1999,425:385.

[3] Feikes J et al. , in *Proc. EPAC'2004*, pp.1954-1956

[4] G.Wüstefeld *et al.*, in *Proc. IPAC'11*, pp.2936-2938

[5] G.Stupakov *et al.*, *Phys. Rev.*, STAB 5,054402(2002)

[6] ZHU Liang-Jing *et al.*, *Chin. Phys.*, C, 2015 ,3 9(7): 077001

[7] Borland M. elegant: A Flexible SDDS-Complaint Code for Accelerator Simulation. Advanced Photon Source LST-287， September 2000

[8] M.Ruprecht *et al.*, in *Proc.IPAC'15*, pp.141-143

[9] Marhauser F *et al.*, in *Proc.EPAC'2000*,pp.1972-1974