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TRACKING STUDY OF THE BIMODAL RF CAVITY FOR STORAGE RING LIGHT SOURCE*

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Abstract

Beam lengthening is an effective and commonly used method to improving the beamlife of storage rings. Based on the previously proposed design of a room temperature conducting bimodal RF cavity, we conducted relevant dynamic simulations. Tracking study on a simulated storage ring lattice with the beam energy of 2 GeV and the synchronous radiation energy of 357 KeV, the results show that, the bimodal RF cavity which contains an accelerating field and a third harmonic field can effectively lengthen beam length, the beam lengthening effect similar to the double RF system which consists of main RF cavity and third harmonic cavity.

INTRODUCTION

For advanced synchrotron radiation sources, the Touschek effect has a very large influence on the beamlife, which can be effectively reduced by introducing higher-order harmonic cavities, and the beamlife can be further improved. Bimodal RF cavity [1] is a special RF structure design, which can effectively run two resontant mode in one cell and integrate the higher order harmonic cavity and the mian rf cavity together, the beam length can be controlled accurately.

For advanced synchrotron radiation light, the storage ring RF system is usually composed of two types of RF cavity, respectively, the mian acceleration RF cavity (RFC), used to accelerate the bunch and compensate for the energy loss of electrons due to synchrotron radiation, according to demand can be designed as a 1-cell or multiple cell, another is a high-order harmonic cavity (HHC), which operates on the harmonic frequency for the acceleration cavity. That is, $f_{HHC} = nf_{RFC}$, high-order harmonic cavity and acceleration cavity operate at the same time, which can adjust the slope of voltage in the gap of the cavity, so as to change the stable phase width of the bunch in the RF field, and can control the length of the bunch to realize the lengthen or compression of the bunch. In the simulation, the main main work is about bunch lengthening of this case.

LATTICE FOR SIMULATION

The tracking simulation is performed using `elegant` code, developed by M. Borland in 2000, which has very powerful lattice design and beam dynamics simulation capabilities, and the code is still updated every year with new version [2, 3]. By tracking the phase change of the bunch in the simulation storage ring and stabilizing the beam length, the effect of the bimodal cavity can be analyzed. In order to adapt some parameters of the bimodal cavity, we presuppose a set of a lattice, some parameters of which are shown in Table 1. The lattice refers to the storage ring design of APS [4].

Table 1: Parameters of Lattice for Tracking

Energy	2.0 GeV
Circumference	1104 m
Radiation energy loss(dipole)	356.7 keV
Revolution frequency	271.554 MHz
Harmonic number	1841
Main voltage	573 keV
Main frequency	499.926 MHz
Harmonic voltage	166 keV
harmonic frequency	1499.778 MHz
Synchronous phase	3.0793 rad
Harmonic phase	−0.155 rad

The multi-bend achromat lattice of each unite consists of 11 quadrupole magnets, 7 sextupole magnets, and 4 bend magnets. The twiss parameter distribution of each cell is shown in Fig. 1. The length of each unit is 27.6 meters, and the entire storage ring is composed of 40 units. Different cavity

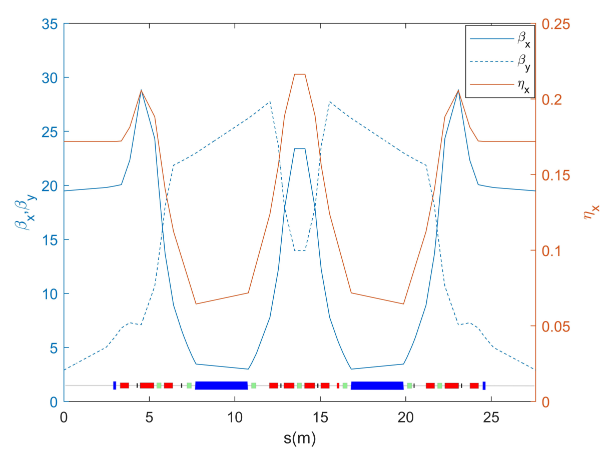

Figure 1: Lattice for tracking.

structure designs have different gaps, which will change the parameters of the cavity in the lattice, and these parameters

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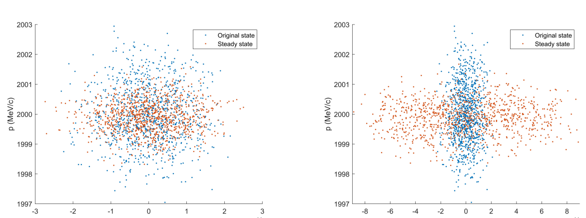
will be set differently in the simulation, but the total length of the lattice will not change.

As shown in Table 1, the operating frequency of the main mode is 499.926 MHz, and the operating frequency of the high-order harmonic mode is 3 times that of the main mode. For a bimodal cavity, there are two resonant modes of the field running in a cavity at the same time, the gap of the cavity is the same length, the R over Q of the main mode is 210, and the R over Q of the high-order harmonic cavity is 20, which is much lower than that of the independent 1-cell high-order harmonic cavity. Therefore, in the case of obtaining the same acceleration gradient, more harmonic power needs to be fed into the bimodal cavity.

SIMULATION AND RESULTS

In the tracked lattice structure, synchrotron radiation energy is generated when electrons pass through bend magnets, bend magnets is defined as 'CSBEND'. 'SYNCH-RAD' switch controls the synchrotron radiation of particles, and 'ISR' switch controls the quantum excitation to generate incoherent synchrotron radiation. The total energy loss per turn is 356.7 keV, and the relevant parameters of the RF cavity are set through the 'RFCA' command, which can independently set the operating phase and standing wave operation [5]. In `elegant` code, the RF cavity is divided into field and drift segment, bimodal cavity according to its operation characteristics, set as the bunch run in the two fields at the same time, and then through the drift segment, and if the two fields are in the two rf cavities structure, it is set as "field + drift tubes + field + drift tubes".

Each bunch is set to contain 1000 particles with Gaussian distribution. In the case that only a 1-cell of high-frequency cavity is operated in the simulated lattice and bunches full filled, the longitudinal distribution of the bunch in the initial state and the stable state is shown in Fig. 2(a). When a bimodal high-frequency cavity is operated in the lattice and bunches full filled, the longitudinal distribution of the bunch is shown in Fig. 2(b).



(a) Main RF cavity (b) Bimodal RF cavity

Figure 2: Particles distribution of tracking.

In Fig. 2, the blue dots represent the distribution of particles in the initial state, and the orange dots represent the distribution of particles in the stable state. As shown in Fig. 2(a),in case of operating a main RF cvaity, the longitudinal length of the bunch is basically consistent with the initial state. As Fig. 2(b) shows that the longitudinal beam length of the bunch is obviously extended when a 1-cell bimodal RF cavity is operated. The natural emittance of the bunch is reduced to a certain extent, this can be more clearly observed in Fig. 3.

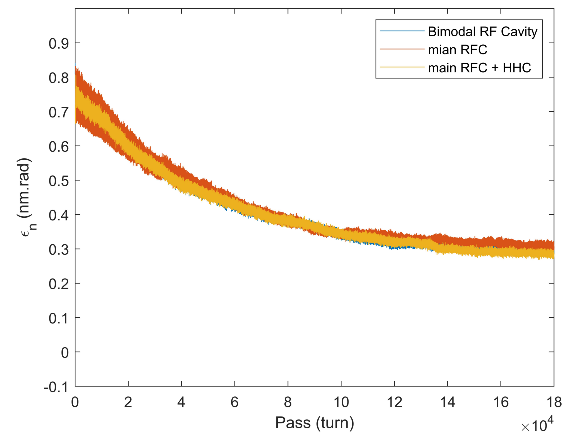


Figure 3: Natural emittance of three RF cavity operating modes.

As shown in Fig. 3, when opearting 1-cell main RF cavity, 1-cell bimodal cavity, and both 1-cell RF cavity and 1-cell higher harmonic cavity, the natural emittance of the bunch is reduced,and the effect is very similar in the three cases, because the RF cavity does not change the transverse size of the bunch, and the emittance of the bunch is reduced due to the lattice strong focusing structure.

By tracking and simulating the continuous movement of a given Gaussian bunch in the lattice, the beam length finally reaches a stable state after enough revolutions (time of flight), which is shown in Fig. 4.

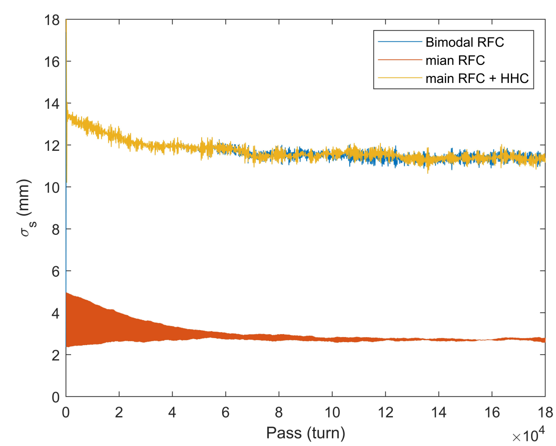


Figure 4: Bunch length of three RF cavity operating modes.

When the 1-cell main RF cavity mode is operated, the stable beam length is 2.7 mm. The stable beam length is almost the same when the 1-cell bimodal cavity and the combination of the 1-cell main RF cavity and the 1-cell 3rd harmonic cavity are adopted. The RF cavity does not set

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at the best phase, because the beam load effect leads to the beam cluster is not in the best working phase, and this part of the phase deviation should be taken into account when calculating the working phase of the RF cavity [6].

The intra-bema scattering effect is an important factor affecting the stability of the bunch and the lifetime of the beam. When considering the IBS effect and the beam load effect, the optimal beam length and Touschek lifetime when the full bunch is filled can be further obtained, and the calculation results are shown in Table 2.

Table 2: Comparison of RF Cavity and Bimodal Cavity

Parameters	**RF Cavity**	**Bimodal Cavity**
Energy	2000 MeV	2000 MeV
Charge	5.0 nC	5.0 nC
$\epsilon_{n,s}$	0.73 nm	0.46 nm
σ_s(with IBS)	6.67 mm	22.58 mm
Touschek lifetime	7.33 hour	21.93 hour

As shown in Table 2,the results show that the stable beam length σ_{rfc} = 6.67 mm in the case of only the main RF cavity and no higher harmonic cavity, and the stable beam length σ_{bic} = 22.58 mm in the case of the bimodal RF cavity operate optimal phase. In both cases,the touschek lifetime of the beam τ_{rfc} = 7.3 h and τ_{bic} = 21.93 h, and the lifetime of the beam can be treble by using a bimodal RF cavity.

CONCLUSION

According to the design parameters of part of the bimodal cavity, we have tracked it through a group of lattice structures. The bimodal RF cavity can stably lengthen bunch, reduce the intra-beam scatting effect, and effectively increase the touschek beamlife, which is very close to the working effect of the double RF system. Considering that there are many factors that can affect the operating frequency and phase of the RF system, the gain of the bimodal cavity to the bunch can be further improved by further optimization.

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