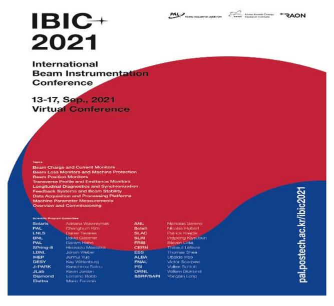

Observation and analysis of island phenomenon in the storage ring light source

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Abstract: In the previous experimental investigations and measurements using the radio-frequency (RF) phase modulation method to study the longitudinal beam characteristics of the Hefei Light Source-II (HLS-II), we found that the longitudinal bunch distributions under different modulation frequencies and amplitudes have great difference. In order to further explore island phenomenon and better under beam motion associated with external RF phase modulation, the streak camera is exploited to effectively observe the longitudinal bunch profile and distribution in single-bunch operation mode. In addition, the relationship between island size, bunch dilution effect and modulation frequency are also discussed in detail. This is meaningful for researching the impact of RF noise on longitudinal beam dynamics, beam manipulation, and machine maintenance and debugging.

INTRODUCTION

In accelerators, the study of the nonlinear longitudinal beam dynamics is of great physical significance and engineering value. This is particularly important for investigating and exploring the mechanism of beam instability, analysis of beam evolution, observation of longitudinal bunch characteristics, and beam manipulation. In the actual operation of accelerators and synchrotron radiation light sources, the particle motion is generally disturbed by RF noise, wakefields, power supply ripple, vibration, etc. There is no doubt that these disturbances will cause changes in beam motion and machine performance due to RF phase and voltage modulations. A part of the theoretical analysis and experimental measurements have been demonstrated that this RF modulation has significant advantages as that of suppressing the coupled bunch instability, improving the beam lifetime, and performing beam manipulation in phase space. Therefore, the RF phase modulation (RFPM) technique was preferred introduced into the HLS-II storage ring to deeply research longitudinal beam characteristics and effectively improve beam lifetime in recent research work. However, it is a pity that the exploration of nonlinear longitudinal beam dynamics is not comprehensive and ambiguous subjected to the RFPM error noise. Moreover, some clerical errors need to be corrected in reference. As a consequence, the motivation of this article is to further investigate the nonlinear beam dynamics in HLS-II based on the RFPM approach. The main research contents include the observation of resonance island phenomenon, characterization of island size, and study of bunch evolution.

THEORETICAL MODELLING AND ANALYSIS

◆ Hamiltonian formalism

$$\langle H \rangle_t = (\omega_s - \omega_m)J - \frac{\omega_s J^2}{16} - \frac{\omega_s a_m}{2}(2J)^{\frac{1}{2}}\cos\psi$$

◆ Multi-Gaussian equation

$$I(\tau) = I_0 + \sum_{i=1}^{n} I_i \exp\left[-\frac{\left(\tau - \overline{\tau}_i\right)^2}{2\sigma_i^2}\right]$$

➢ Hamiltonian Tori and fixed points' amplitude

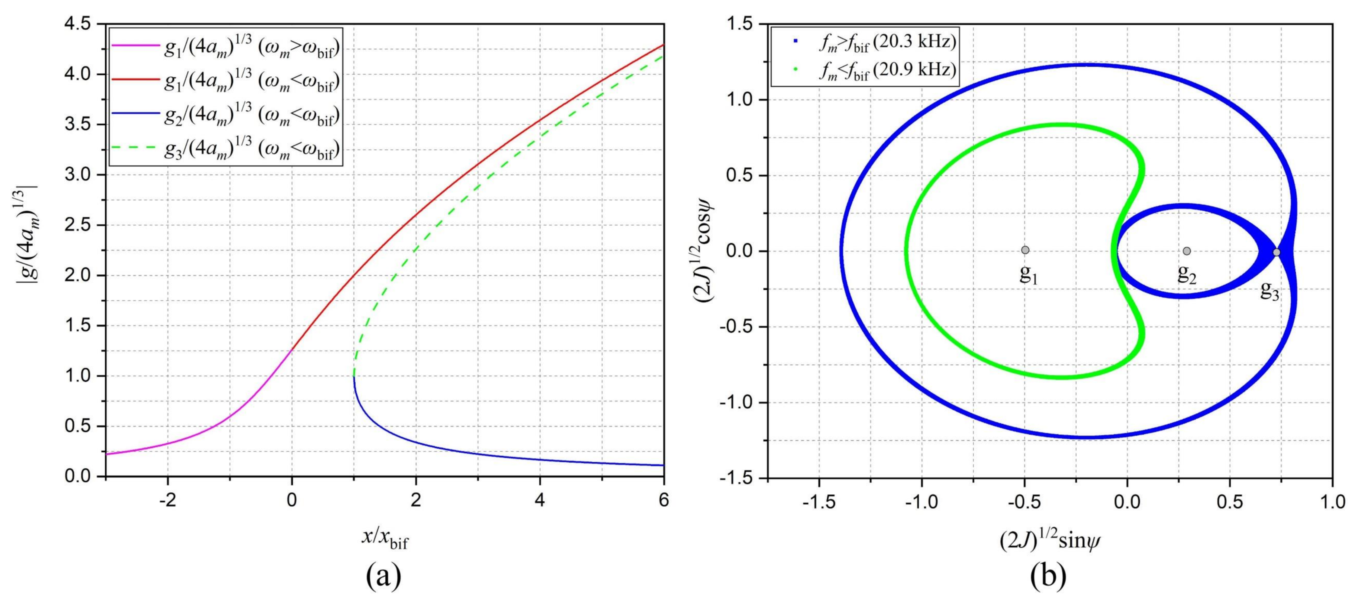

Fig. 1: The amplitudes of fixed points and Hamiltonian tori in phase space (a_m=0.02 rad, f_s=21.3 kHz, f_{bif}=20.6 kHz).

➢ Multi-Gaussian theoretical model

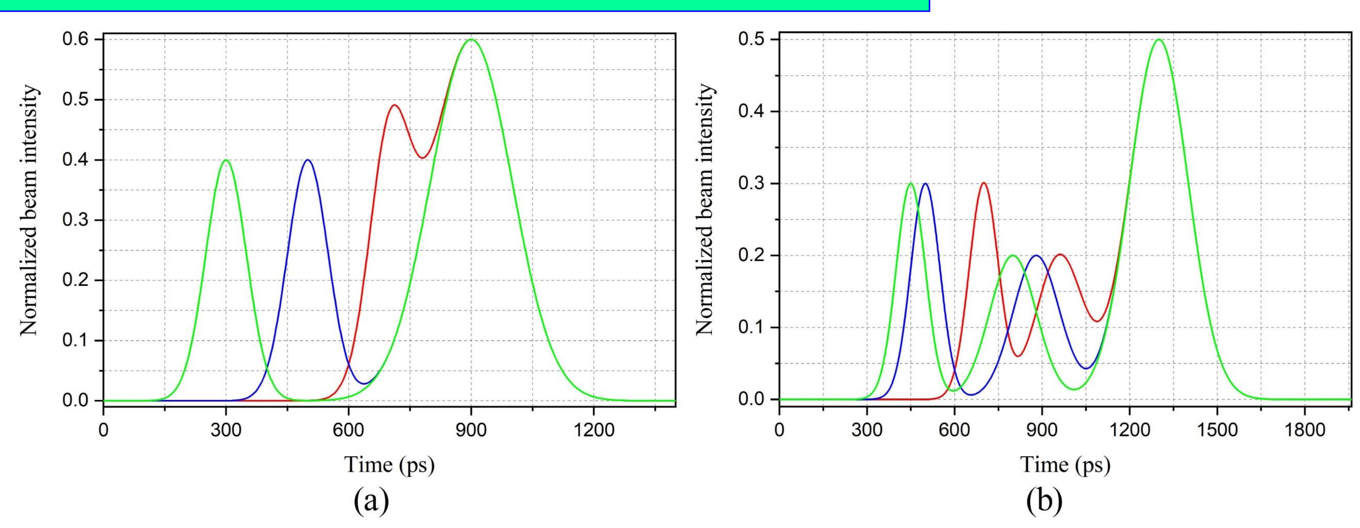

Fig. 2: Longitudinal bunch profiles of bi-Gaussian and multi-Gaussian models.

- ➢ The RF phase noise affects the particle motion trajectory and bunch dilution;
- ➢ Resonance islands occur by applying RFPM.
- ➢ Machine study and longitudinal beam dynamics exploration at the storage ring light source;
- ➢ Beam manipulation and suppress coupled bunch instability;

EXPERIMENTAL SETUP AND RESULTS

Experimental measurement system

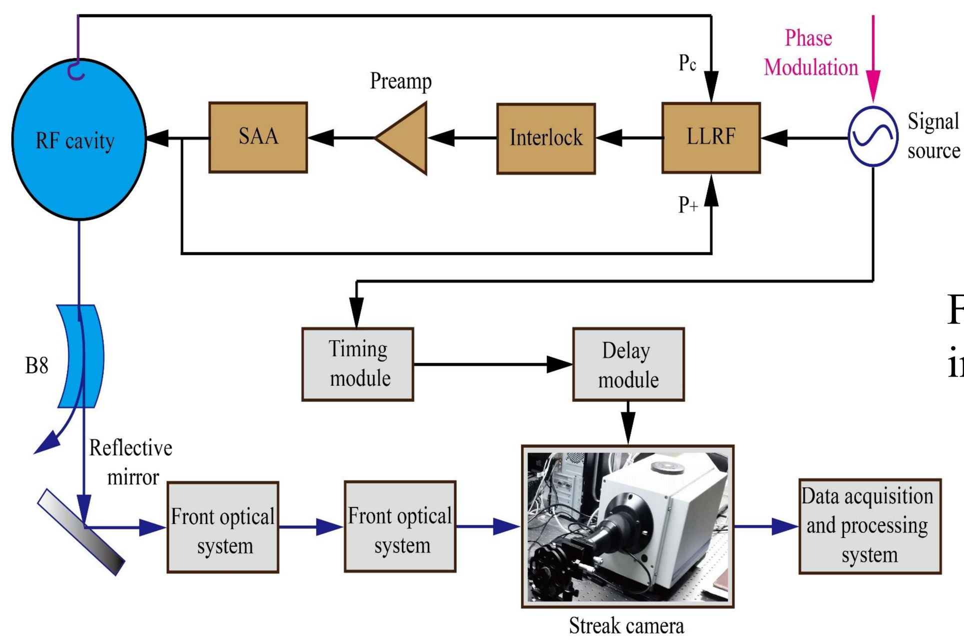

Fig. 3: Diagram of the experimental measurement system for RFPM.

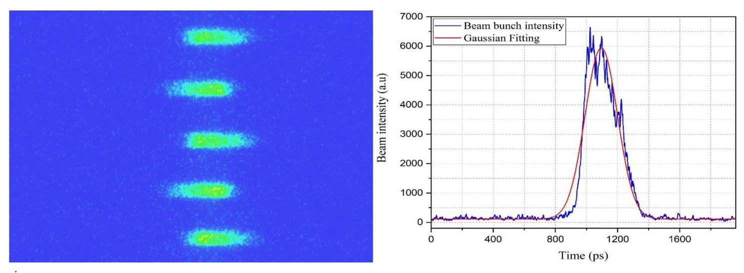

Fig. 4: Longitudinal bunch intensity image and profile in the absence of RFPM.

The RFPM experimental system mainly consists of a RF cavity system and a streak camera measurement system.

Longitudinal bunch intensity and distribution with RFPM

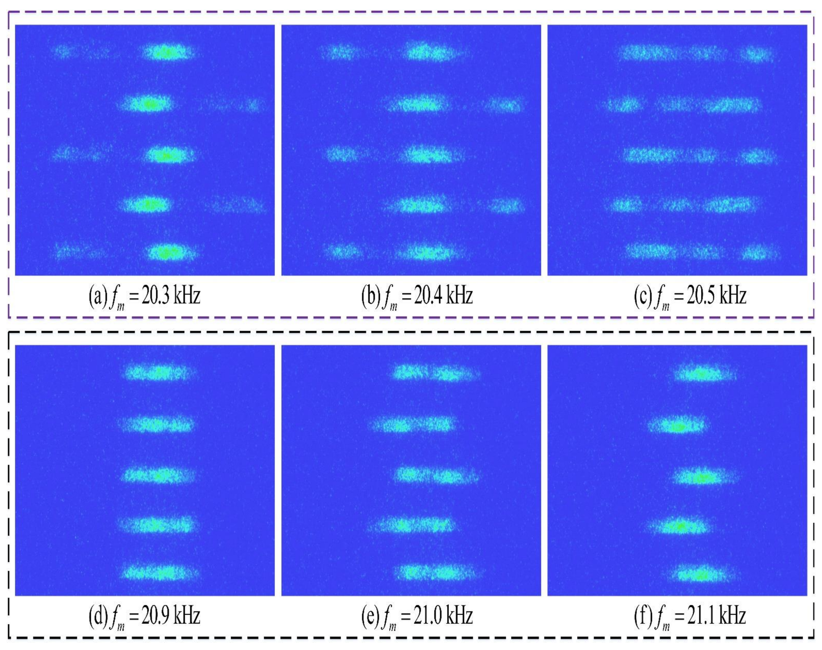

Fig. 5: Longitudinal bunch intensity image and profile in the absence of RFPM.

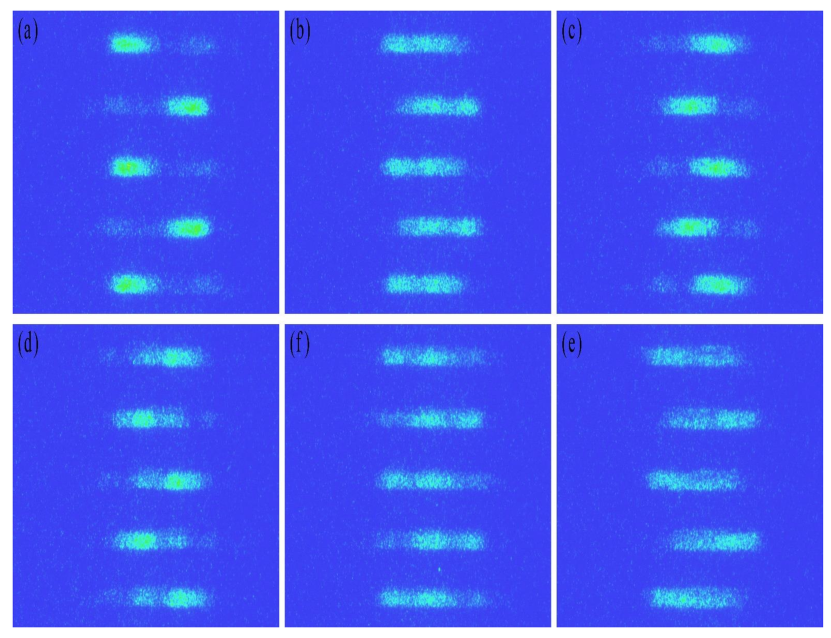

Fig. 6: Longitudinal bunch intensity image versus RFPM frequency.

Analysis of island phenomena and the beam dilution

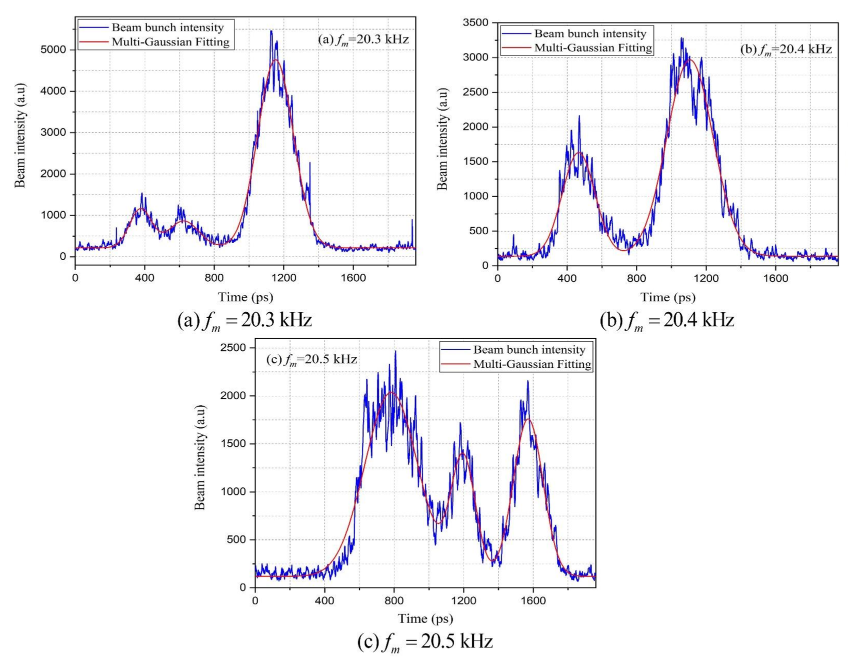

Fig. 7: Longitudinal bunch distributions and data-analysis below the bifurcation frequency.

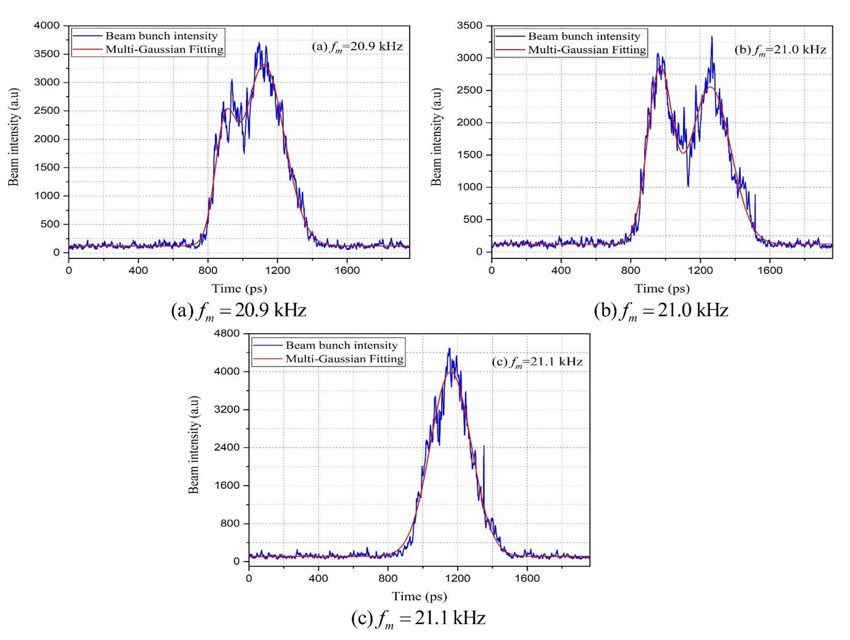

Fig. 8: Longitudinal bunch distributions and data-analysis above the bifurcation frequency.

CONCLUSION

In this paper, the RF phase modulation method is used for researching the longitudinal bunch distribution and nonlinear island phenomenon in HLS-II. It has shown that the formation of resonant island and beam dilution effect are dependent on the RF phase modulation frequencies and amplitudes. In addition, the multi-Gaussian thermotical model is developed to analyze the size of the resonance island and effectiveness of beam manipulation based on RF phase modulation. This is important for the analysis of the influence of RF noise, investigation of the longitudinal beam dynamics, exploration of the nonlinear island phenomena, maintenance and debugging of machine.

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