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Effect of Phase Modulation on the Transverse Beam Size and Emittance of the HLS-II Ring

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Abstract: In this paper, the radio-frequency (RF) phase modulation method is exploited to investigate the variations in the transverse beam size and emittance at Hefei Light Source (HLS-II). Meanwhile, a certain quantitative analysis was performed on the stability and practicability of the beam transverse profile measurement systems. The experiments show that the RF phase modulation method can effectively explore the robustness and stability of beam transverse profile measurement systems over the range of 20.0-22.5 kHz, which is close to the first-harmonic of the synchrotron frequency. It is concluded that when the modulation amplitude of the external phase perturbation is less than 0.04 rad, this optical system can be capable of maintaining reliable and stable working status. This is also useful for analyzing the influence of RF phase noise on the subsequent beam measurement and diagnostics, which including the deterioration of beam quality, emittance blowup, beam jitter, and beam loss.

INTRODUCTION

In the synchrotron radiation (SR) storage ring light sources, it is crucial to real-time high-accuracy monitor the variations of the transverse beam size and emittance. With this in mind, HLS-II is equipped with two transverse beam profile measurement systems as that of the synchrotron light imaging system and interferometric system to precisely measure the beam size, emittance, and energy spread on the basis of the actual measurement requirement. In previous machine experiments, a RF phase modulation method is developed to improve beam lifetime and explore longitudinal beam characteristics in the HLS-II storage ring. However, we found that the transverse beam size and emittance are affected by the parametric resonances resulting from the introduced phase perturbation.

Therefore, it is necessary to deeply research and elaborate the variations of beam transverse profile and beam emittance subjected to the external RF phase modulation. It has considerable physical and engineering guiding significance in the operation, commissioning, and beam manipulation of the HLS-II storage ring and our future Hefei Advanced Light Facility (HALF). Considering that the preliminary machine measurement are carried out in the single-bunch operation mode, we mainly focused on investigating the stability and feasibility of the beam transverse profile measurement systems by use of the changes on the transverse beam size and emittance. Furthermore, the dependence curve of the beam energy spread as a function of the RF phase modulation frequency is further analyzed under different modulation amplitudes.

THE MEASUREMENT PRINCIPLE

◆ Horizontal beam emittance and energy spread

$$\varepsilon_x = \frac{\sigma_{x,B7}^2\eta_{x,B8}^2 - \sigma_{x,B8}^2\eta_{x,B7}^2}{\beta_{x,B7}\eta_{x,B8}^2 - \beta_{x,B8}\eta_{x,B7}^2}$$

$$\delta = \left(\frac{\sigma_{x,B8}^2\beta_{x,B7} - \sigma_{x,B7}^2\beta_{x,B8}}{\beta_{x,B7}\eta_{x,B8}^2 - \beta_{x,B8}\eta_{x,B7}^2}\right)^{1/2}$$

◆ Vertical beam emittance

$$\varepsilon_y = \sigma_y^2 / \beta_y$$

◆ Hamiltonian formalism

$$\langle H_1\rangle_t = (\omega_s - \omega_m)J - \frac{\omega_s J^2}{16} - \frac{\omega_s a_m}{2}(2J)^{\frac{1}{2}}\cos\psi - \omega_s$$

➢ Hamiltonian Tori via different modulation amplitudes

- ➢ The modulation amplitudes are 0.02, 0.03, and 0.04 rad, respectively;
- ➢ The modulation frequency is 20.0 kHz;
- ➢ The phase noise has a great impact on the particle motion trajectory and bunch volume as a result of . parametric resonance;
- ➢ Investigating the beam characteristic parameters which including transverse beam size, emittance and energy spread related to phase modulation;
- ➢ Possessing outstanding importance on machine research and beam dynamics analysis at the HLS-II storage ring;

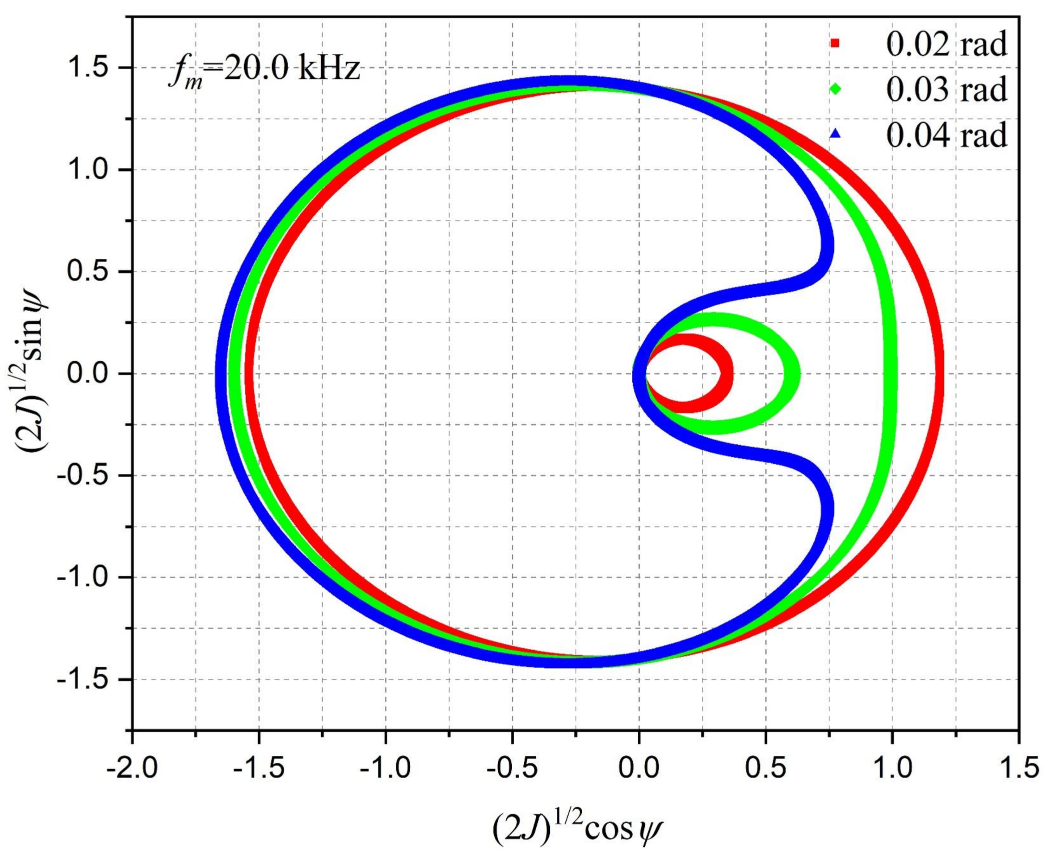

Fig. 1: The particle trajectories under different RF phase modulation amplitudes (f_s=21.3 kHz, f_m=20.0 kHz).

EXPERIMENTAL SETUP AND RESULTS

Experimental measurement system

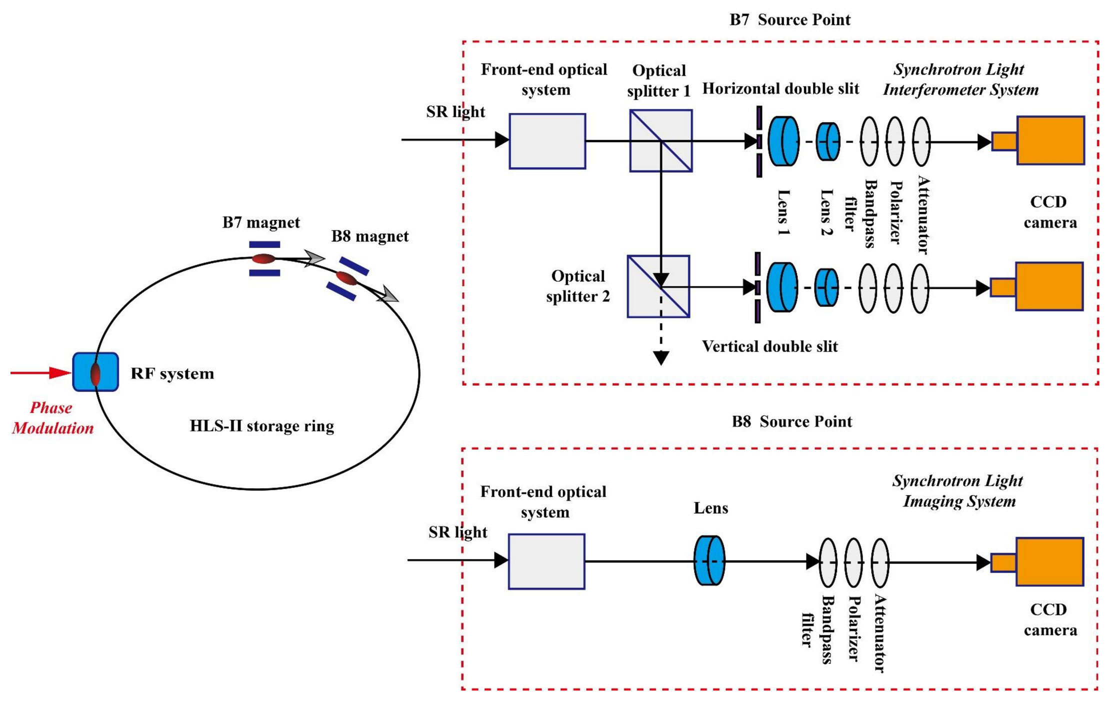

Fig. 2: Schematic diagram of the experimental measurement system.

- RF system, SR interferometer system (B7), SR imaging system (B8);
- Horizontal interferometer and vertical interferometer;
- optical attenuator, lens, polarizer, band-pass filter, attenuator, CCD camera;
- Front-end optical system;

Transverse beam size and emittance

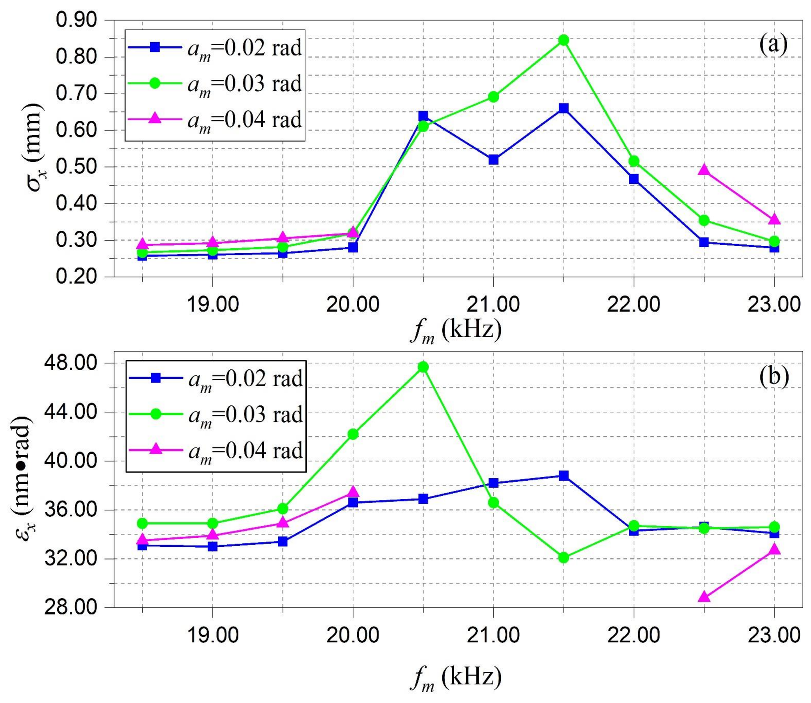

Fig. 3: Horizontal beam size and emittance versus f_m.

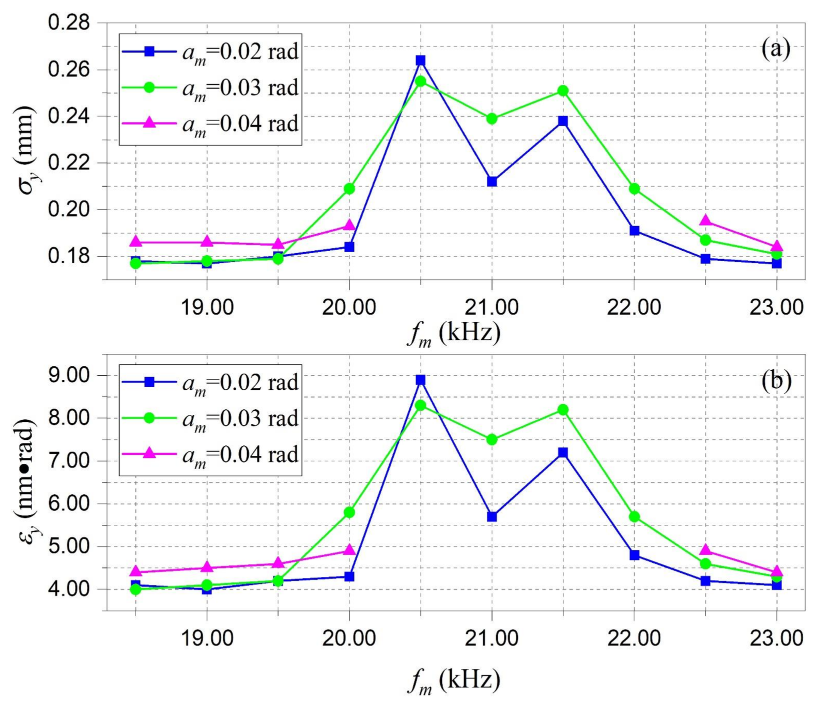

Fig. 4: vertical beam size and emittance with f_m.

Beam energy spread

- ◆ There is a severe blowup on beam energy spread in the range of 20.0-22.5 kHz;
- ◆ This RF phase modulation approach has a great impact on beam performance;
- ◆ Avoiding large modulation amplitude, beam stability;
- ◆ Exploring RF dynamical system, noise analysis;

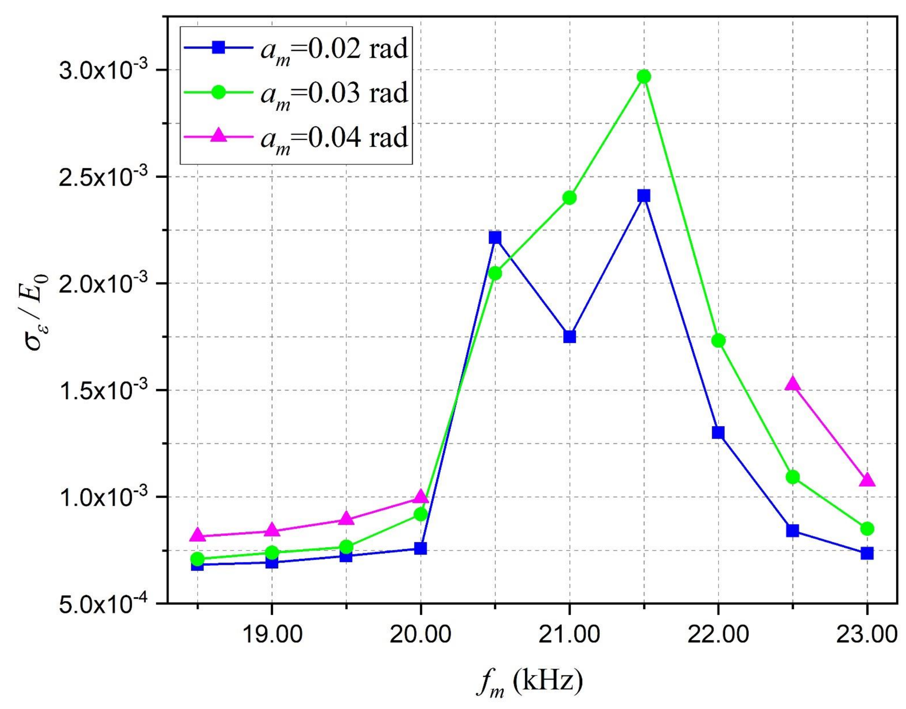

Fig. 5: The beam energy spread variation curve via f_m at different modulation amplitudes.

CONCLUSION

In general, it is desirable to explore and discuss the stability, feasibility and practicability of the beam transverse profile measurement systems on the HLS-II storage ring by means of the RF phase modulation method. It has demonstrated that these beam transverse profile measurement systems can be effective of maintaining measurement reliability in the case of the modulation amplitude of the external phase noise is less than 0.04 rad within the range of 20.0-22.5 kHz. At the same time, this phase modulation approach is of great significance to the operation, machine research and beam diagnosis of the HLS-II storage ring. Furthermore, it can provide feasible suggestions and ideas for researching the physical phenomena such as emittance dilution, beam jitter, and beam loss in the synchrotron storage ring light sources.

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