APPLICATION AND DEVELOPMENT OF THE STREAK CAMERA MEASUREMENT SYSTEM AT HLS-II*

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Abstract

The dual-axial scan streak camera plays an important role in the super-fast optical measurement and the beam diagnosis of the accelerators. Indeed, the development of the synchrotron light measurement system by virtue of the streak camera provides an effective tool and research platform for accelerator physics and super-fast optical phenomenon. In this paper, the configuration of the streak camera measurement system is roughly described. And the experimental researches are simultaneously performed, including the bunch lengthening, the potential-well distortion, the longitudinal bunch oscillations, and the beam evolution during the single bunch operation mode in the HLS-II storage ring. Moreover, the effects of the RF modulation on the beam lifetime and longitudinal bunch beam dynamics are carried out.

INTRODUCTION

It is well-known that the streak camera [1–4] is a powerful diagnostic and measurement instrument with remarkable merits of high temporal and spatial resolution, good stability to measure ultra-fast light phenomena. As a consequence, it has been widely employed in accelerator, super-fast optics, and laser-plasma physics. Generally, the bunch length in the synchrotron radiation (SR) light source is on the order of tens to hundreds of ps, whereas below 10 ps down to the magnitude of fs in linear accelerator and free electron laser. For this reason that, the streak camera is usually applied for observing longitudinal distribution of the bunch and measuring bunch length owning to the accurate and intuitive measurement compared with other beam diagnostic tools. At present, it is regarded as an indispensable measurement device by many laboratories at home and abroad.

Similar to many storage ring light sources, our OPTOSCOPE streak camera purchased in 2006 was primary implemented for measuring bunch length and longitudinal bunch distribution of the Hefei light source (HLS) and upgraded HLS-II [5, 6]. However, it is worthwhile to note that a part of extended applications based on the streak camera were also carried out, such as the observation of potential-well distortion, bunch lengthening phenomena, and longitudinal beam oscillations [5], the investigation of radio-frequency (RF) modulation effect [7, 8], and the study of beam instability [7, 8], etc. In this paper, we are aim to review and summarize the current important applications of the streak camera in the HLS-II. The major machine parameters of the HLS-II ring are summarized in Table 1.

Table 1: Machine Parameters of the HLS-II Storage Ring

Parameter	Symbol	Value
Beam energy	E	0.8 GeV
Circumference	C	66.13 m
Energy loss	U_0	16.73 keV
Beam current	I	360 mA
Nat. rms energy spread	σ_ε/E_0	4.7×10^{-4}
Mom. comp. factor	α	0.0158
Nat. emittance	ε_0	~40 nm•rad
Beam lifetime	τ	7-8 h
Nat. rms bunch length	σ_τ	~50 ps
Cavity gap voltage	V_c	123 kV
RF frequency	f_{rf}	204.030 MHz
Harmonic number	h	45
Revolution frequency	f_{rev}	4.534 MHz
Synchrotron frequency*	f_s	20.0-21.5 kHz

*actual measured value.

EXPERIMENTAL SETUP AND RESULTS

Streak Camera Measurement System

In order to accurately measure the machine parameters and observe the bunch beam evolution during commissioning and operation of the HLS-II ring, the streak camera measurement system is well-established and mounted on beamline8 (B8), as shown in Fig. 1.

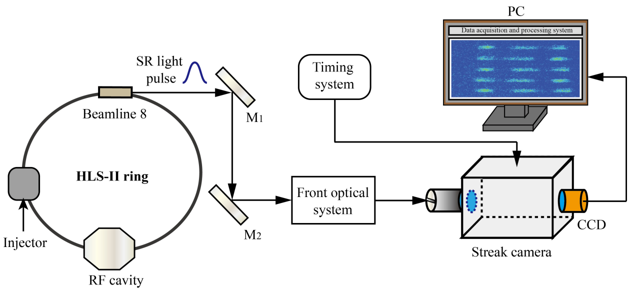

Figure 1: Schematic layout of the streak camera measurement system.

As shown in Fig. 1, this streak camera measurement system is mainly composed of a SR light extraction system, a front-end optical system, a timing system, and a data acquisition and processing system. The SR light extraction

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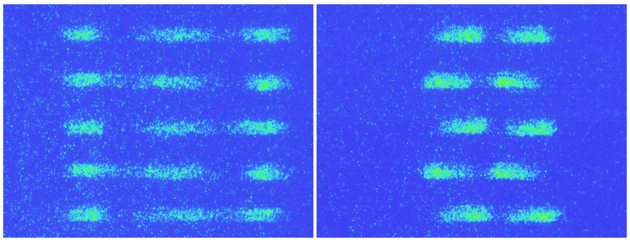
system mainly consists of a pair of mirrors M1, M2 that is used to extract SR light emitted along the tangential direction at B8 to the optical platform. Subsequently, the SR light signal is processed by the front-end optical system and then incident onto the streak camera. After that, the imaging light pulse can be obtained from the back-end CCD, so as to realize the acquisition of the light information to be measured. Moreover, the streak camera is connected to a personal computer (PC) to process and acquire experimental data. Here, it is noted that the timing system is used for the rigorous timing trigger control.

RF Modulation Effect

In view of the above-mentioned streak camera experimental measurement device, we have carried out a series of related longitudinal beam dynamics researches on the HLS-II ring. The measurement results of RF modulation are shown in the Fig. 2.



(a) $f_m = 20.5$ kHz, *three islands* (b) $f_m = 21.5$ kHz, *two islands*

Figure 2: Observations of RF modulation phenomena.

Figure 2 illustrates the island phenomena observed at different modulation frequencies in the case of 0.02 rad modulation amplitude. By introducing the phase modulation mechanism into the RF system, which is available for diluting the electron bunch density, and thereby mitigating particle collisions and simultaneously effectively improving beam lifetime. For Fig. 2(a), when the modulation frequency is 20.5 kHz, the single bunch is divided into three sub-bunches due to the beam dilution effect. With regard to Fig. 2(b), as the modulation frequency is adjusted to 21.5 kHz, two sub-bunches are monitored by a streak camera. It is clear that the RF noises with different frequencies have diverse impacts on the beam status, and are accompanied by longitudinal bunch beam oscillations. To visually and distinctly observe island phenomena, we further gave the corresponding longitudinal bunch profiles under different modulation frequencies, as plotted in Fig. 3.

Bunch Length Measurement

Furthermore, in the processes of common machine study, operation, and maintenance, we measured the significant parameters of bunch length and longitudinal bunch distribution of the HLS-II by means of this streak camera measurement system, as shown in Fig. 4.

As expressed in Fig. 4, the blue represents measured full-width at half height (FWHM) bunch length with standard deviation error bars as a function of beam current, while the red line for the nonlinear fitting curve. It can be seen from Fig. 4 that the bunch length gradually elongates as increasing the beam current, and the standard deviation error is in the range of a few ps. Of course, it is apparent that the bunch lengthening effect is very significant.

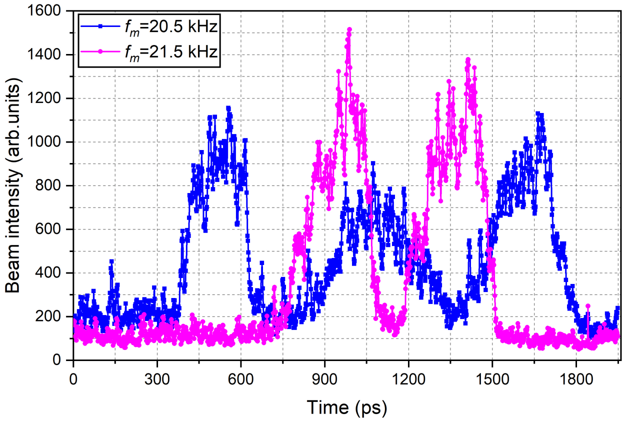
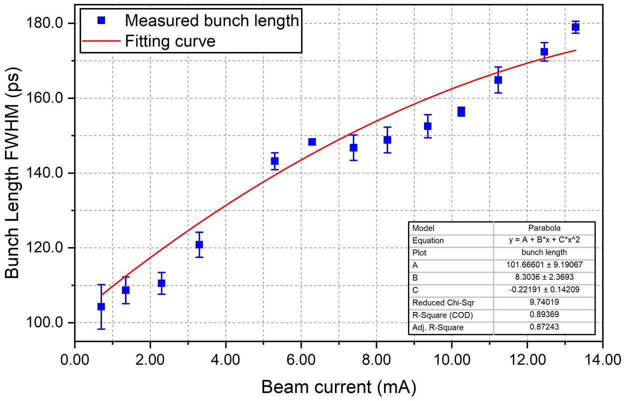


Figure 3: Longitudinal bunch profiles at different modulation frequencies.



Model	Parabola
Equation	y = A + B*x + C*x^2
Plot	bunch length
A	101.66601 ± 9.19067
B	8.3036 ± 2.3693
C	-0.22191 ± 0.14209
Reduced Chi-Sqr	9.74019
R-Square (COD)	0.89369
Adj. R-Square	0.87243

Figure 4: Bunch length via different beam currents.

Potential-well Distortion

In the actual measurements, we found that there are more severe potential-well distortion phenomena as the bunch length stretches, as distinctly depicted in Figs. 5 and 6.

Figure 5 shows the images of the longitudinal bunch distributions with the beam currents of 1.35, 3.30, 6.29, 9.36, and 12.35 mA, respectively. It is observed that the potential-well distortion and the shift of bunch centroid become more and more obvious with increase of beam current, as marked by the red arrow in Fig. 6. This leads to violent asymmetry and unevenness between the head and tail of a bunch. To the best of our knowledge, this longitudinal beam instability is mainly caused by the wakefields, which can degenerate the longitudinal distribution of a bunch from the original near-Gaussian to an asymmetric Gaussian. This main reason is originated from the change of impedance of the entire ring due to the addition of some insertion devices and vacuum components since the HLS was upgraded in 2014. As a result, the physical phenomenon of the potential-well distortion is more significant than before.

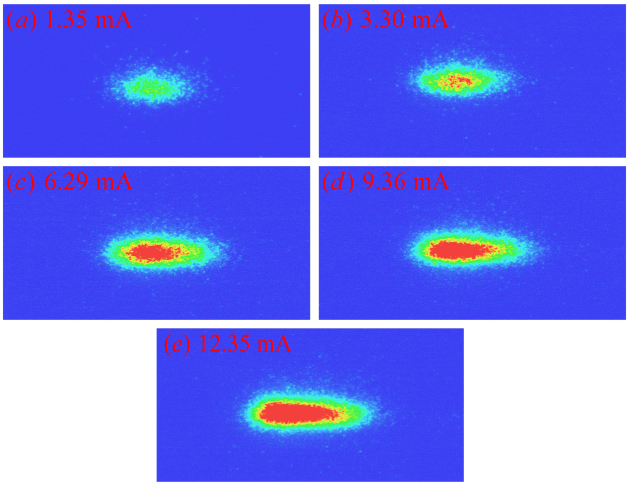


Figure 5: Observation of potential-well distortion under different beam currents.

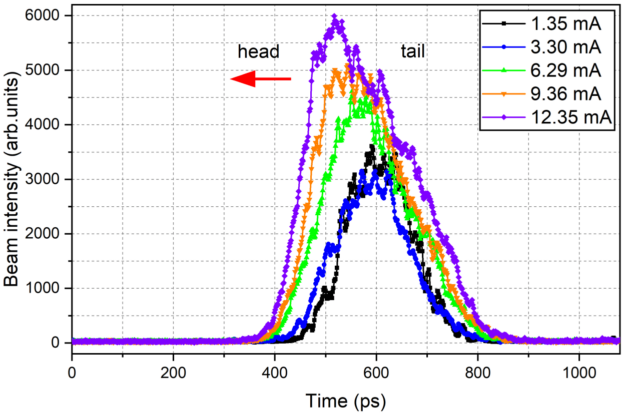


Figure 6: Longitudinal bunch distributions with beam currents.

Discussion and Summary

In summary, we have performed some related longitudinal beam dynamics studies on the HLS-II based on the streak camera measurement system. For instance, observations of bunch lengthening, potential-wall distortion, and longitudinal bunch oscillation, investigations of RF modulation and beam instability, etc. This has important physical significance in deeply understanding the performance of the HLS-II, improving the beam quality, and constructing the Hefei Advanced Light Facility (HALF) in the future. In follow-up research, we will further develop and expand the applications of the streak camera and optimize the optical measurement system, all of which are desired to be applied to the broad fields of terahertz radiation and FELs.

CONCLUSION

In this article, we have summarized some current longitudinal beam dynamics studies on the HLS-II storage ring based on the streak camera measurement system. It mainly contains bunch lengthening, potential-wall distortion, and longitudinal beam oscillations, RF modulation, and beam instability. These experimental investigations have certain physical significance for the operation and debugging of the HLS-II.

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