IBIC2023

12th INTERNATIONAL BEAM INSTRUMENTATION CONFERENCE
SASKATOON, CANADA
September 10-14, 2023
Canadian Light Source | Centre canadien de rayonnement synchrotron

Bunch length measurement at a bunch-by-bunch rate based on time-frequency domain joint analysis techniques and its application

Hongshuang Wang[12], Xing Yang[12], Yongbin Leng[14], Yimei Zhou[3], and Jigang Wang[4]

1. Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China;
2. University of Chinese Academy of Sciences, Beijing 100049, China;
3. Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai 201204, China;
4. National Synchrotron Radiation Laboratory, University of Science and Technology of China, Hefei 230026, China

Introduction

- Streak cameras cannot simultaneously achieve high time resolution and large dynamic range in beam length measurement[1].
- Traditional dual-frequency systems have narrow measurement bandwidths and can only provide average bunch length measurements for multiple bunches over multiple turns.

$$\sigma_{\Delta S} = \frac{c\eta_C}{\Omega}\frac{\sigma_p}{p_0} = \sqrt{\frac{c^3}{2\pi q}\frac{p_0\beta_0\eta_C}{h f_0^2 \hat{V}\cos(\phi_S)}}\frac{\sigma_p}{p_0}$$

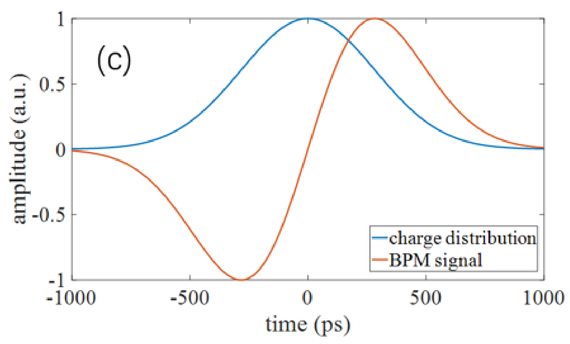
- Bunch by bunch
- Bunch length
- Time-frequency domain
- Transfer impedance

Algorithm

$$I(t) = \frac{Q}{\sqrt{2\pi}\sigma} exp\left[-\frac{(t-t_0)^2}{2\sigma^2}\right]$$

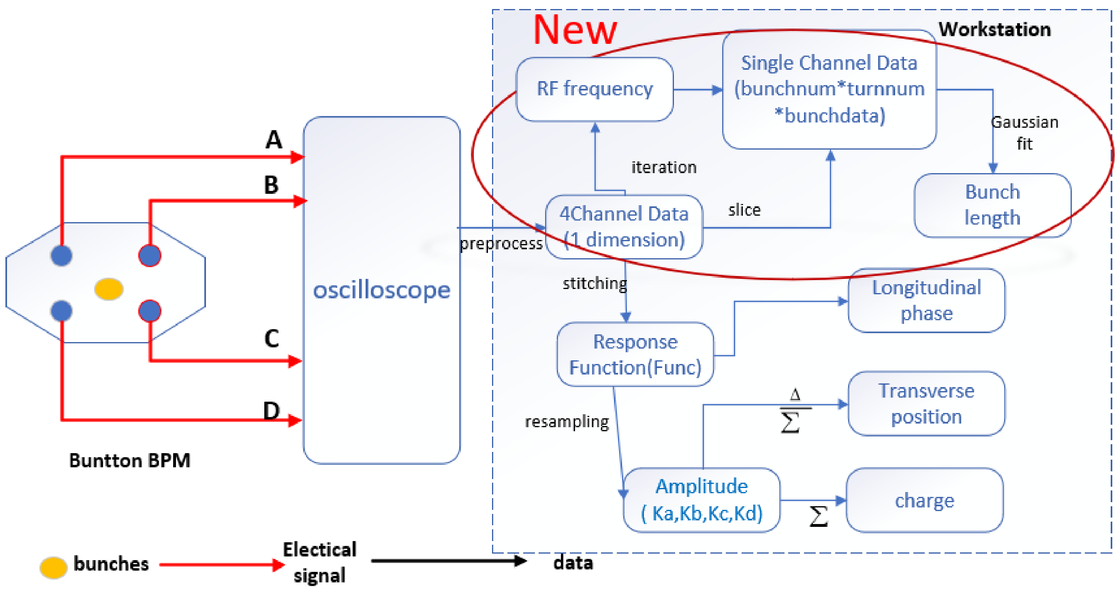
$$V_b(t) = I(t) * H_{Button}$$

$$V(f) = I(f) \cdot R_{Button}(f)$$



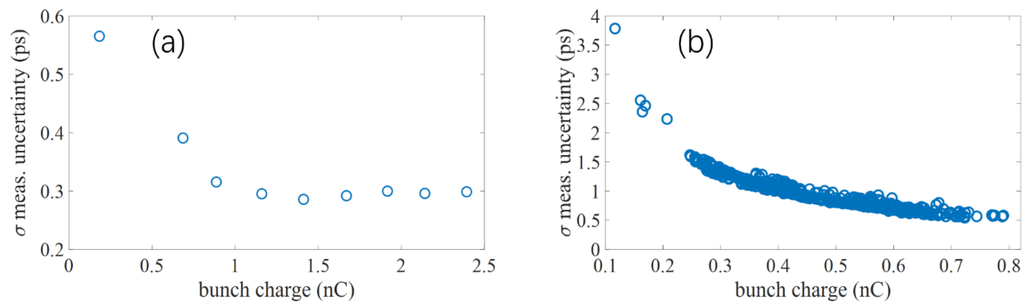
- V(f) is the frequency-domain distribution of the detected signal.
- I(f) is the frequency-domain distribution of the beam signal (Gaussian distribution).
- R_Button (f) is the frequency-domain transfer impedance to be calibrated
- By measuring V(f), I(f) can be obtained, and then the bunch length can be obtained

Experimental system



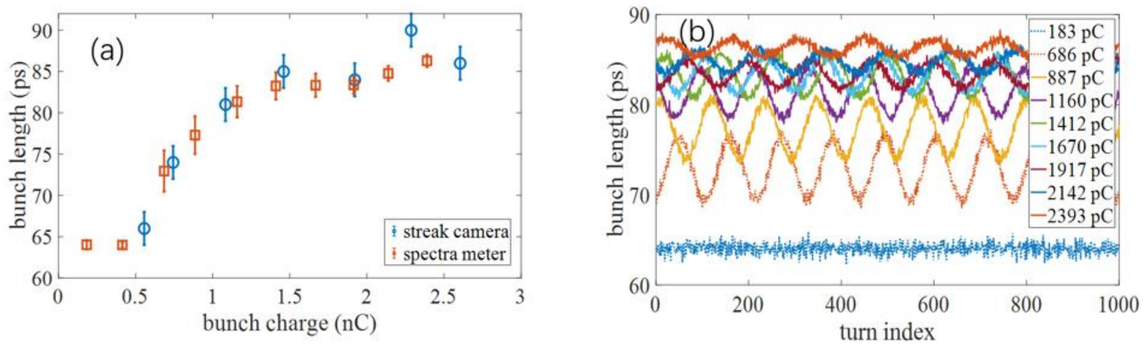
- The four-electrode signals from the BPM probes are acquired using a high-sampling-rate and high-bandwidth digital oscilloscope. These signals are then imported into Python scripts for further analysis.
- Adding a new bunch length calculation module to the existing HOTCAP bunch-by-bunch measurement system

Uncertainty Evaluation



- (a) Uncertainty assessment of the beam length measurements for different charge values in the single-bunch mode at the HLS.
- (b) In the multi-bunch operation mode at the SSRF, with different charges for each bunch, the total charge for all bunches are calculated, and the beam length uncertainty is assessed for each individual bunch.
- In both experiments, it is observed that the bunch length measurement uncertainty is approximately inversely proportional to the bunch charges.

Experimental results



(a) In the single-bunch experiment at the HLS, in conjunction with a streak camera, the distribution of the bunch length with respect to the beam charge was measured. The results obtained through the time-frequency joint analysis method showed excellent agreement with the streak camera results.
(b) Under different charges, the beam length exhibits noticeable oscillations when the charge exceeds a certain threshold.

Conclusion

- The existing parameters of wideband, high-speed oscilloscope technology have met the requirements for bunch-by-bunch and turn-by-turn bunch length measurements.
- The phase measurement uncertainty is more than 0.2 ps, the bunch length measurement uncertainty is more than 1 ps, and the dynamic range exceeds 10 ms.
- This technique can be integrated as an additional module in the existing 3D bunch position measurement system, HOTCAP[2], thereby forming a comprehensive multi-parameter bunch-by-bunch measurement system that includes the position, bunch length, and charge.

References
[1] Iriso U, and Fernández F. Streak Camera Measurements at ALBA: Bunch Length and Energy Matching, IBIC2012, Tsukuba, TUPA46 (2012): 458.
[2] Xu X Y, Leng Y B, Gao B, et al. HOTCAP: a new software package for high-speed oscilloscope-based three-dimensional bunch charge and position measurement[J]. Nuclear Science and Techniques, 2021, 32: 1-11.

Contact Email: lengyb@ustc.edu.cn