Longitudinal impedance measurements with streak camera at BEPC II electron storage ring

Dechong Zhu †, Wan Zhang, Yanfeng Sui, Junhui Yue, Jianshe Cao, Jiuqing Wang

Institute of High Energy Physics ,Chinese Academy of Sciences

Abstract:

We measure the bunch length of electrons at BEPC II using a dual sweep streak camera at visible light diagnostic beamline. The impedances estimated by a series *R*+*L* impedance model. Resistive impedance of R=446±21Ω is obtained by measuring loss factor from measured synchronous phase advancing with streak camera. An inductance impedance of L=23.3±1.8nH has been estimated by measuring single bunch lengthening with beam current.

Both loss factor and inductance are close to the impedance budget. Besides, the streak camera is also used to measure synchronous phase at low current as RF voltage changing from 0.85MV to 1.65MV.

Longitudinal Impedance

The longitudinal broadband coupling impedance of the storage ring can be divided into real and imaginary parts. The real part is a resistance, can be characterized by the loss factor as an energy loss of the bunch. The imaginary part does not cause energy loss, but it leads to energy transfer inside the bunch, and results in bunch lengthening and energy spread growth. We measure the impedance with streak camera, the real part resistance from synchronous phase shift measurement , and the imaginary part from bunch lengthening measurement.

1. Synchronous phase shift

Streak camera is OptoScope SC-10 from Optronis. For synchronous phase shift measurement, it works at synchroscan sweep mode with 249.9MHz (1/2 RF frequency). Ten reference bunches are injected in adjacent even buckets with 0.1mA per bunch. Reference bunches have long beam lifetime with fixed low intensity. The main bunch is injected in an odd bucket with current changes from 0.5mA to 10mA. Phase jitter of main bunch is reduced by subtract the reference bunches phase. The measured loss factor is 2.04 ± 0.10 V/pc, resistance is 445.6 ±21.0 Ω.

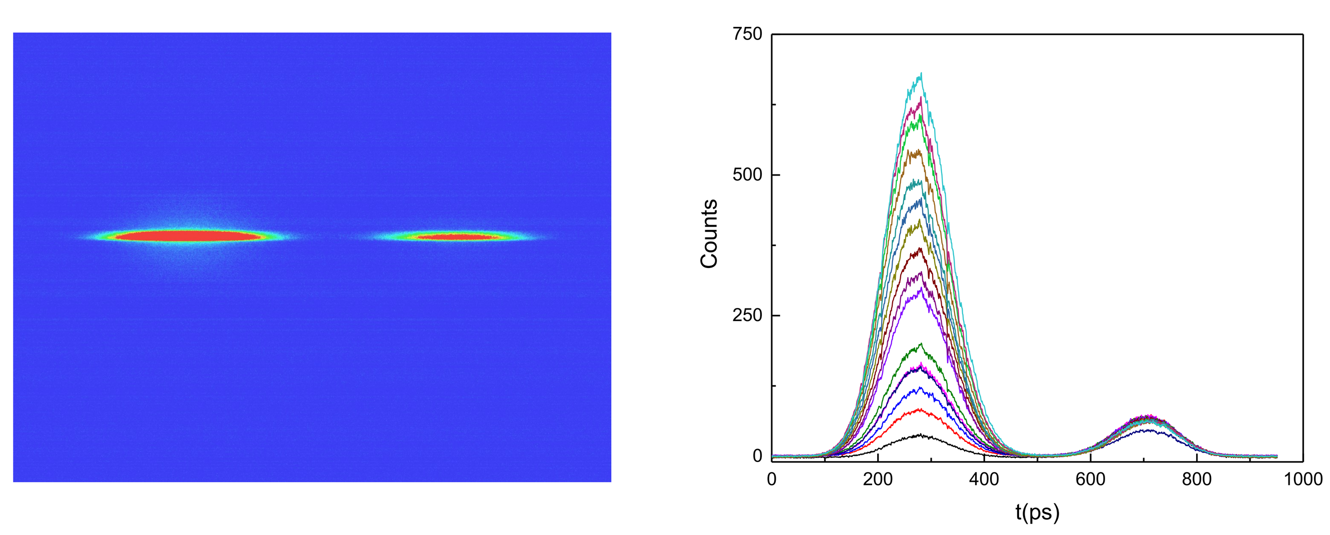
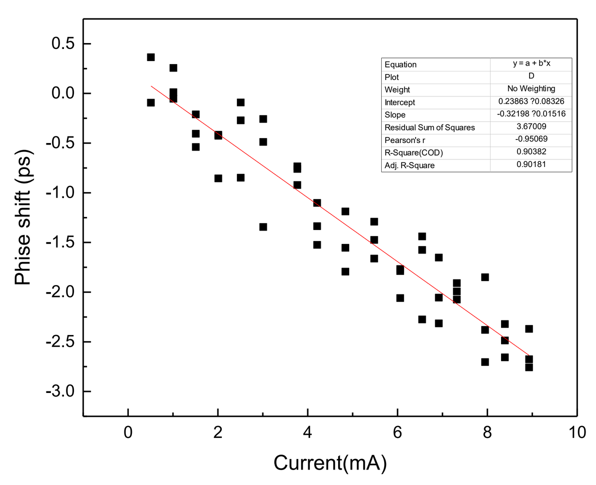


Figure1. Left: Bunch profile image captured by streak camera.
Right: Bunch profile with main bunch current from 0.5mA to 10mA



V_0: RF voltage
φ_s: Synchronous phase
$\Delta\varphi_s$: Phase shift with current
k_{loss}: loss factor
I_b: Main bunch current
f_0: Revolution frequency
R: Real part of longitudinal impedance
σ: Bunch length

Figure 2. Phase shift with different bunch current.

$$V_0\cos(\varphi_s)\Delta\varphi_s = k_{loss}\frac{I_b}{f_0} \qquad k_{loss}=R/2\sqrt{\pi}\,\sigma_z$$

φ_s:165.24 deg f_0: 1.2421 MHz σ_z:1.85cm (61.7ps)

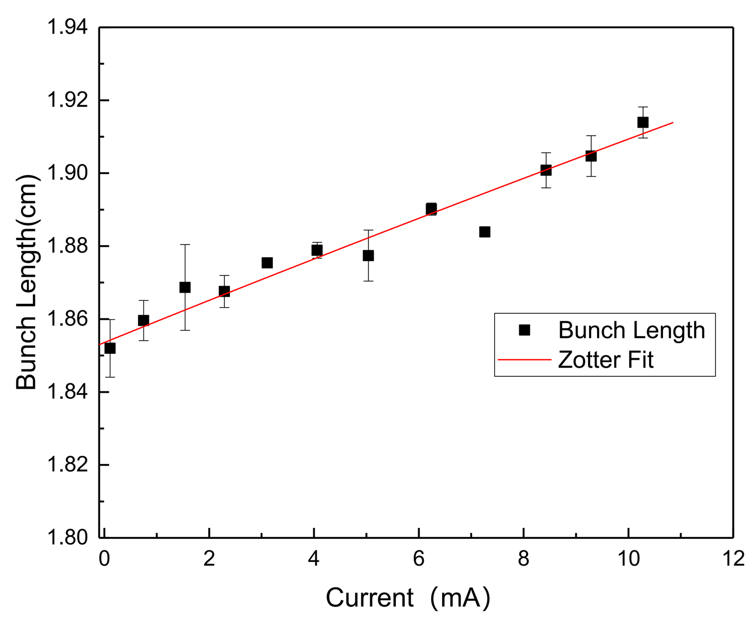
$$\Delta\tau = 0.32 \pm 0.02 \text{ ps/mA}$$
$$k_{loss} = 2.04 \pm 0.10 \text{ V/pc}$$
$$R = k_{loss} \times 2\sqrt{\pi} \times \sigma_Z = 445.6 \pm 21.0\ \Omega$$

2. Bunch lengthening

Potential-well distortion (PWD) and microwave instability are two major factors result in bunch lengthening. Since the single beam current in BEPC II design is 910mA with the single bunch current of 9.8mA, a strict impedance budget with $(Z/n)_0$=0.23Ω was designed in order to control the bunch lengthening. The microwave instability threshold would be more than 30mA with single bunch.

Streak camera works at synchroscan sweep mode in order to detect the low current beam. Bunch length is measured with single bunch current changing from 0.1mA to 11mA, which is below the microwave instability threshold, so that bunch lengthening is caused by PWD. All IDs are moved out. Zotter's formula is applied to calculate longitudinal coupling impedance. The measured $(Z/n)_0$ is 0.185Ω, inductance is 23.3±1.8 nH.

$$\left(\frac{\sigma_l}{\sigma_{l0}}\right)^3 - \left(\frac{\sigma_l}{\sigma_{l0}}\right) + I_b\frac{e\alpha_p \mathrm{Im}\left[\left(\frac{Z_\parallel}{n}\right)_{eff}\right]}{\sqrt{2\pi}\nu_{s0}^2 E}\left(\frac{R}{\sigma_{l0}}\right)^3 = 0$$



E = 2.474GeV
α_p = 0.0189
ν_{s0} = 0.02767
R = 38.26m

Figure3. Bunch lengthening with current from 0.1 to 11mA

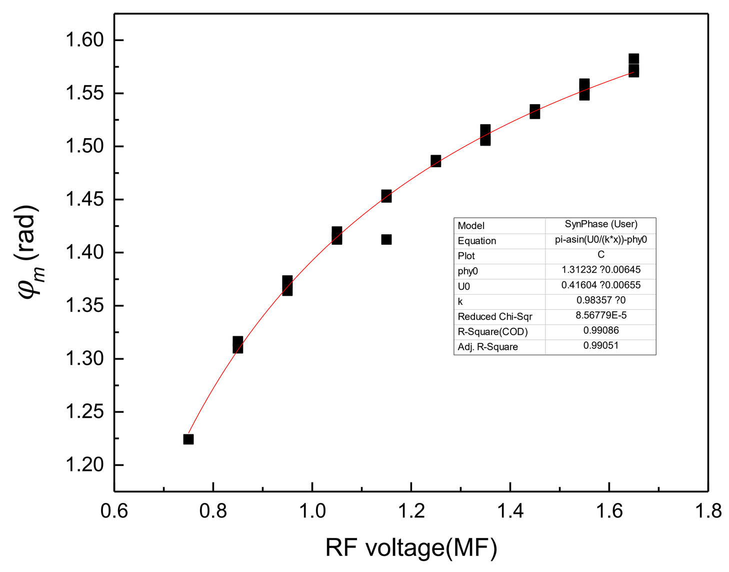
Synchronous phase measurement

At low bunch current, phase shift due to parasitic energy loss can be neglected. The synchronous phase φ_s is determined by RF voltage V_{rf} and synchrotron radiation energy loss per turn U_0 as the followed formula.

$$\varphi_s = \varphi_m + \varphi_0 = \pi\text{-}\arcsin\left(U_0/eV_{rf}\right)$$

Where φ_m is the measured phase, and φ_0 is the relative phase which is a constant.

Streak camera is applied to measure beam profile at low current (<0.1mA), the mass center phase can be obtained after fitting the beam profile with Gaussian. As the RF voltage changes from 0.85MV to 1.65MV, different mass center phases are obtained. By fitting the data with the formula, φ_0=75.2° can be measured, φ_s at different RF voltage can be calculated .



V_{RF}(MV)	φ_s
0.75	144.8°
0.85	150.0°
0.95	153.2°
1.05	155.8°
1.15	157.2°
1.25	159.9°
1.35	161.2°
1.45	162.5°
1.55	163.8°
1.65	164.9°

Figure4. Phase shift with RF voltage