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LONGITUDINAL IMPEDANCE MEASUREMENTS WITH STREAK CAMERA AT BEPC II ELECTRON STORAGE RING*

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Abstract

We measure the bunch length at BEPC II electron storage ring 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±21 Ω is obtained by measuring loss factor from measured synchronous phase advancing with streak camera. An inductance impedance of L=23.3±1.8 nH 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 0.85 MV to 1.65 MV.

INTRODUCTION

BEPC II is a double-ring e+e- collider that operates in the τ and charm region. The energy reached to 2.474 GeV, the highest collision energy by far in Feb. 2021. Beam-based experiments are made to determine the longitudinal impedance. Some parameters are shown in Table 1.

Table 1: Main Parameters of BEPCII

Parameters	Value	unit
Energy	2.474	GeV
Revolution frequency	1.2421	MHz
RF frequency	499.8	MHz
RF voltage	1.65	MV
Momentum compaction factor	0.0189	--
Synchrotron tune	0.02767	--
Energy spread	6.9*10^{-4}	--

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.

Synchronous Phase Shift

The parasitic energy loss induced by real part resistance is dependent on charge in the bunch as $\Delta E = -k_l q^2$. In terms of voltage it becomes $\Delta V = -k_l q$ or $\Delta V = -k_l \frac{I_b}{f_0}$,where I_b is the bunch current and f_0 is the revolution frequency. For the reason of energy balance of the bunch, the current-dependence synchronous phase shift $\Delta\varphi_s$ can be derived from the equation as follows:

$$V_0 cos(\varphi_s)\Delta\varphi_s = k_l \frac{I_b}{f_0} \quad (1)$$

where V_0 is the RF voltage, φ_s is the synchronous phase at zero current. The time shift is:

$$\Delta\tau = \frac{k_l I_b}{\omega_{RF} V_0 cos(\varphi_s) f_0} \quad (2)$$

Streak camera at BEPC II is OptoScope SC-10 from Optronis. For synchronous phase shift measurement, it works at synchroscan sweep mode with the frequency of 249.9 MHz (1/2 RF frequency). Ten reference bunches are injected in adjacent even buckets with 0.1 mA per bunch and a total current of 1mA. The reference bunches have fixed low intensity so that have long beam lifetime. The main bunch is injected in an odd bucket, its current changes from 0.5 mA to 10 mA with a step of 0.5 mA. Since just synchroscan sweep plate is applied, the image has two profiles in the central part, the left profile is main bunch while the right profile is reference bunch, as in Fig. 1.

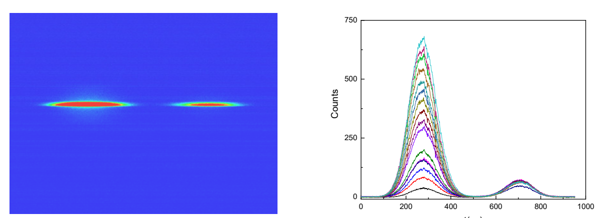

Figure 1. Left: Bunch image captured by streak camera. Right: Bunch profile with main bunch current from 0.5 mA to 10 mA.

The profile data are fitted with asymmetric Gaussian distribution [1, 2]:

$$I(z) = I_0 + I_1 exp\left\{-\frac{1}{2}\left(\frac{(z-\bar{z})}{[1+sgn(z-\bar{z})A]\sigma_Z}\right)^2\right\} \quad (3)$$

I_0 is the initial pedestal, $I_1$is the maximum value of the distribution, σ_Z the longitudinal rms size, $\bar{z}$ the center of the distribution, and *A* the asymmetric coefficient.

Time jitter of main bunch profile can be reduced by subtracting the reference bunch profile's center time. By linear fitting the corrected profile center time data with current, the time shift $\Delta\tau = 0.32 \pm 0.02$ ps/mA is obtained, as in Fig. 2. The loss factor is calculated with Eq. (2) as $k_l =$

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2.04 ± 0.10 V/pc, while the k_l budget is 1.76 V/pc. Resistance is $R = k_l \times 2\sqrt{\pi} \times \sigma_Z = 445.6 \pm 21.0\ \Omega$.

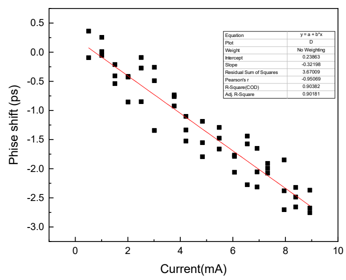

Figure 2. Phase shift with different bunch current.

Bunch Lengthening

Potential-well distortion (PWD) and microwave instability are two major factors result in bunch lengthening. Since the beam current in BEPC II design is 910 mA with the single bunch current of 9.8 mA, a strict impedance budget [3] with $(Z/n)_0$=0.23 Ω was designed in order to control the bunch lengthening. The microwave instability threshold would be more than 30 mA of single bunch.

Streak camera is applied to measure bunch length. It works at synchroscan sweep mode in order to detect the low current beam. Bunch length is measured with single bunch current changing from 0.1 mA to 11 mA, which is below the microwave instability threshold, so that bunch lengthening is caused by PWD. All IDs are moved out. Zotter's formula [4] for PWD is applied to calculate longitudinal coupling impedance as follows:

$$\left(\frac{\sigma_l}{\sigma_{l0}}\right)^3 - \left(\frac{\sigma_l}{\sigma_{l0}}\right) + I_b \frac{e\alpha_p \mathrm{Im}\left[\left(\frac{Z_\parallel}{n}\right)_{eff}\right]}{\sqrt{2\pi}\nu_{S0}^2 E}\left(\frac{R}{\sigma_{l0}}\right)^3 = 0 \quad (4)$$

where σ_l is the rms bunch length, σ_{l0} the natural rms bunch length, I_b the average beam current, e the electron charge, α_p the momentum compaction factor, E the beam energy, ν_{s0} the synchrotron tune.

Figure 3 shows the bunch lengthening data and fitting results. The measured $Im\left[\left(\frac{Z_\parallel}{n}\right)_{eff}\right]$ is 0.185 Ω, the inductance L is 23.3±1.8 nH. While the budget of $Im\left[\left(\frac{Z_\parallel}{n}\right)_{eff}\right]$ is 0.23 Ω.

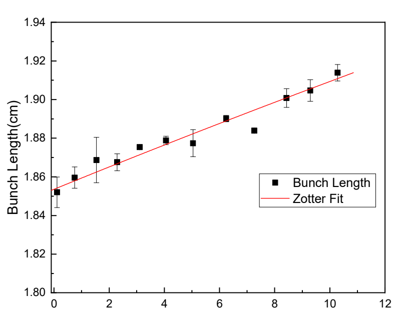

Figure 3. Measured bunch length as function with beam current.

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:

$$\varphi_s = \varphi_m + \varphi_0 = \pi\text{-}\ arcsin\left(U_0/eV_{rf}\right) \quad (5)$$

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 (<0.1 mA), the mass center phase can be obtained after fitting the beam profile with Gaussian. As the RF voltage changes from 0.85 MV to 1.65 MV, different mass center phases are obtained. By fitting the data with the formula, φ_0=75.2° can be measured, as in Fig. 4. φ_s at different RF voltage can be calculated and shown in Table 2.

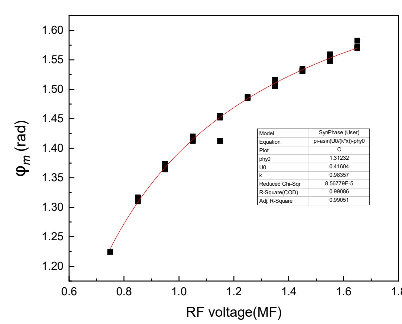

Figure 4. Bunch phase as function with RF voltage.

Table 2: Synchronous Phase at Different RF Voltage

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°

CONCLUSION

BEPC II operated at its highest collision energy of 2.474 GeV. Some beam-based experiences are applied to determine the longitudinal impedance and synchronous phase with streak camera. Resistive impedance of R=446±21 Ω is obtained by measuring loss factor from measured synchronous phase advancing. An inductance impedance of L=23.3±1.8 nH has been estimated by measuring single bunch lengthening with beam current. Both loss factor and inductance are close to the impedance

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budget. Synchronous phases at different RF voltage are measured at low current with streak camera.

REFERENCES

[1] Q. Qin *et al.,* "Studies of bunch lengthening at the BEPC",*Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* vol. 463, pp. 77-85, 2001.

[2] Garg, A. D. *et al.*, "Studies of longitudinal profile of electron bunches and impedance measurements at Indus-2 synchrotron radiation source", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 814, pp. 66-72, 2016.

[3] J. Q. Wang, Z. Y. Guo, Q. Qin, and J. Xing, "Collective Effects Study for BEPCII", in *Proc. 8th European Particle Accelerator Conf. (EPAC'02)*, Paris, France, Jun. 2002, paper WEPRI017.

[4] B. Zotter, "Potential-Well Bunch Lengthening", Rep. CERN-SPS/81-14 (DI), Geneva, Switzerland, 1981.