THE STUDY OF THE BUNCH LENGTHING IN ELECTRON STORAGE RING

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Abstract

The measurements of bench length and its lengthening, and the low frequency impedance implied thereby, play an important part in accelerator field for understanding better the beam physics and improving machine performance. The bunch length was measured by the streak camera during the synchrotron radiation (SR) mode and collision mode on BEPCII and the setting of the streak camera was confirmed with a series of repeat measurements. The low frequency impedance of the storage ring obtained from the bunch lengthening due to the potential well is according with the impedance budget.

INTRODUCTION

The Beijing Electron-Positron Collider II (BEPCII) can be operated not only as collider at beam energy of 1.89GeV, but also as a dedicated synchrotron radiation (SR) facility at the energy of 2.5GeV in routine operation. Table 1 and Table 2 list some main parameters of the current BEPCII storage ring in routine operation on Collision mode and SR mode, respectively.

Table 1: Main Parameters of the BEPCII (Collision Mode)

Parameters	Collision mode
Beam energy (GeV)	1.89
Circumference(m)	237.53
Revolution frequency(MHz)	1.2612
Momentum compaction	0.23/0.0169
Natural energy spread	6.09×10^{-4}
RF frequency(MHz)	499.8
Harmonic number	396

Table 2: Main Parameters of the BEPCII (SR Mode)

Parameters	SR mode
Beam energy(GeV)	2.5
Momentum compaction	0.024
Natural energy spread	6.89×10^{-4}
Max. beam current (mA)	250

The collision luminosity has been enhanced to $7.08\times10^{32}cm^{-2}s^{-1}$ in this year, however our design object is up to $1.0\times10^{33}cm^{-2}s^{-1}$ that need many hardware upgrades and more machine studies. Bunch measurement was benefit to study the bunch lengthening rule and realize the impedance of the storage ring and improve the luminosity finally. Based on the pervious bunch results which weren't repeat or bigger than we expected [1], a series of measurements have done to examine the streak camera in background, gain of MCP and others. Finally, the bunch results can repeat well. We also give the results of bunch measurements both in collision mode and synchrotron mode; the low frequency impedance of the storage ring is discussed in below section as well.

STREAK CAMERA EXPERIMENT

The parameters of bunch can be obtained from the synchrotron light when the beams whirling in storage ring and the bunch length is often measured by the streak camera. The streak camera has great resolving power and quick response and low impact on measurement itself. We use a Hamamatsu c5680-11[1] streak associated with a set of optical lenses put on a platform at the end of the synchrotron light extraction line, to measure the bunch length and its lengthening. The synchrotron light pulse enters the streak camera directly through a small hole with diameter of 100um.

There is a Microchannel Plates (MCP) for electron multiplication with the factor form 0 to 60 in electronic parts of the streak camera. Firstly we measured bunch lengthening from 2mA to 15mA with gain of 25 and 30, respectively. Fig1 shows obviously that the bunch results of gain 35 are much bigger than the gain 25. So the gain of MCP has great impact on the finally result.

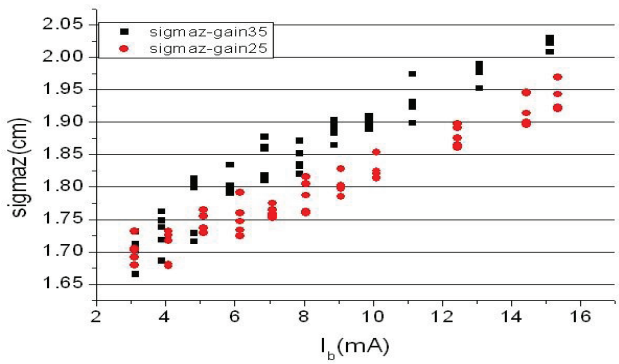

Figure 1: Bunch length results with gain of 25 and 35.

Secondly, we measured bunch length with different gains at same beam current in order to find the linear area of the streak camera. Fig2 shows the bunch results with gain of MCP from 15 to 37 while the single beam current always keeping at 8mA. We can see the results are spread when the gain is small than 20 and increasing when the gain is bigger than 30. So we can confirm that gain of below 28 is linear area and the result is believable. Other aspects like the settle of the frame number and the background are also studied. Here we directly give the conclusion that frame number has almost no impact on the result and background must be deducted before experiment.

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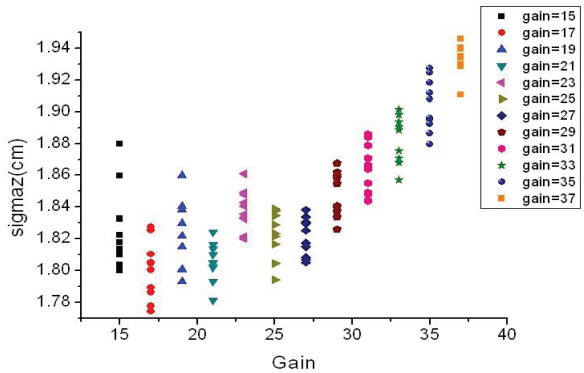

Figure 2: Bunch length results with different gains.

When the setting of the streak camera was assured, we have done some repeat experiments with different days and got repeat results finally. Fig.3 was three times experiment at different time, the bunch length almost close to each other at same beam current.

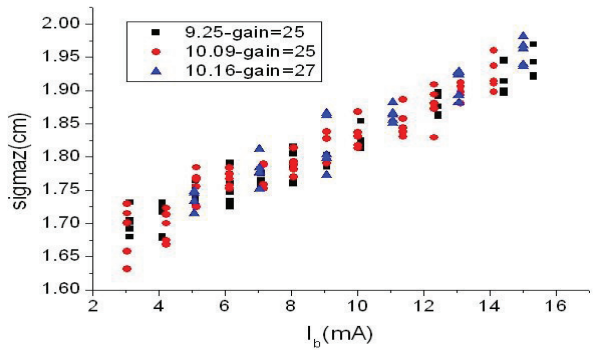

Figure 3: Bunch length variation as a function of beam current.

Based on the previous steps of measurements, the operation criterion with the streak camera was made as follows: adjusting the optical lenses to make the light spot with the greatest intensity onto the center of screen; choosing the maximal hole diameter; setting the image frame to one; making the gain of MCP at 25 nearly or using much higher gain at lower beam current; keeping the intensity counts between 2000 and 2500.

BUNCH MEASUREMENT RESULTS

All the experimental results are fitted by unsymmetrical Gauss distribution that can be expressed as:

$$\rho\ (\mathrm{z}) = \rho_0 + \rho_1 \exp[-\frac{1}{2}\frac{(z-\bar{z})^2}{(1+\mathrm{sgn}(z-\bar{z})A)^2\sigma_z^2}] \quad (1)$$

Where ρ_0 is the initial pedestal, ρ_1 is the maximal value of the distribution, $\bar{z}$ is the middle of the longitudinal distribution, A is the unsymmetrical coefficient and σ_z is the longitudinal rms size close to bunch length with low beam current. Fig4 is one of the fitting results. We can see bunch shape is close to Gauss distribution and the A is quite small with the order of 10^{-3}, which stands for the impedance of whole storage ring in BEPCII is inductive [2].

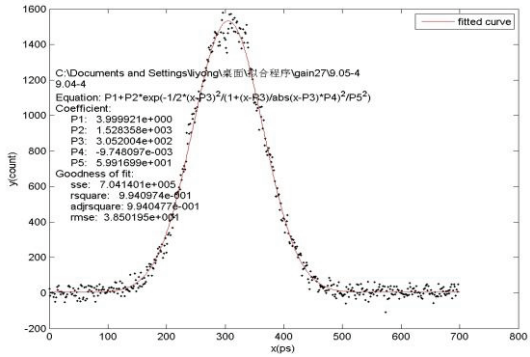

Figure 4: The fitted result of bunch length.

We choose the measurement result of the day on 10.16 for bunch lengthening analysis. First we calculated the nature bunch by expressions as follows:

$$\sigma_{l0} = \frac{\alpha_p R}{\nu_s}\sigma_e \quad (2)$$

Where σ_{l0} is the nature bunch length, α_p is the momentum compaction factor used as theoretical value, R is the average radius of the machine, ν_s is the synchrotron tunes that can be measured by frequency spectrograph, σ_e is the nature energy spread. The nature bunch length is evaluated about 1.58cm from Eqs. (2). Based on the previous experience that the bunch lengthening in our machine is caused by the potential well [4], so we fitted the bunch lengthening by the classical formula, expressed as[5]

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

Where $(Z^{//}/n)_{eff}$ is the effective impedance of the storage ring obtained from the fitting coefficient and E is the beam energy of 2.5GeV in SR mode.

Fig 5 is the fitting results of bunch lengthening with beam current from 5mA to15mA. The fitted result is quite well that proved again bunch lengthening in our machine is caused by potential well. The effective impedance of the outer ring is calculated of 0.79Ω and the corresponding inductance is about 100nH. The threshold current of microwave instability is about 22mA that acquired from expressions as follows [5]:

$$I_b(A) = \frac{\sqrt{2\pi}\alpha_p \frac{E}{e}\sigma_{p0}^2\sigma_{l0}}{R\left|\frac{Z}{\mathrm{n}}\right|_{eff}} \quad (4)$$

We have reported that the impedance budget of whole ring in collision mode is about 69nH [6]. However in SR mode, there are two additional injection Kickers which can contribute 22nH and the big 4W2 vacuum chamber that maybe contribute 10nH nearly. So the whole outer ring inductance is evacuated of 100nH nearly that is

according with the result from the experimental fitted result.

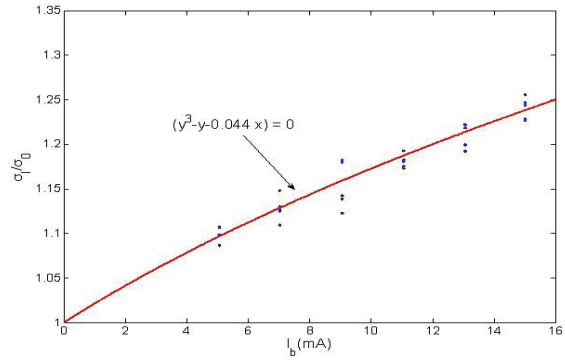

Figure 5: The fitted result of bunch lengthening.

We also measured the bunch length in collision mode; fig 6 is typical single positron and electron bunch length at the current of about 6.5mA. Positron bunch length is much longer than electron bunch and can be decreased by increasing the voltage of RF cavity. On the other side, we happily find that the bunch length is much shorter than the design value, so we can improve the luminosity by designing small α_p. We achieved the luminosity of 7.08 $\times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ with the α_p is about 0.16 that is smaller than 0.23 used in previous time.

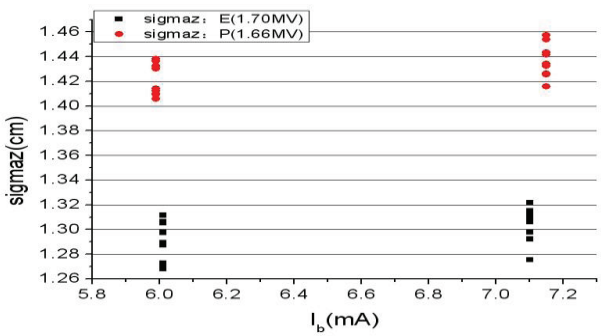

Figure 6: The positron and electron bunch length.

CONCLUSION

The operation criterion of the streak camera was proposed in this paper. The results of bunch length followed as this criterion can repeat well. The bunch length and lengthening were measured in synchrotron and collider mode, respectively. The bunch lengthening is proved caused by potential well and the impedance speculated from the lengthening is according with the impedance budget result. During the collision mode, we successfully used small α_p to improve our luminosity to the greatest grade.

ACKNOWLEGEMENTS

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