THE BUNCH LENGTH MEASUREMENT OF BEPC WITH A STREAK CAMERA*

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Abstract

A dual-axis streak camera Hamamatsu model C5680-11, has been installed on Beijing Electron-Positron Collider (BEPC) to measure the bunch length and the bunch lengthening in the storage ring. The results of the measurement are more accurate and reliable than that measured with other instruments, and play important roles in the future upgrade of BEPC.

In this paper we describe the synchrotron light extracting optics setup, the operating principle, features, the basic system configuration of the streak camera. Some typical results of the measurement in recent years are presented. The measurement errors including systematic and random are also analyzed.

1 THE OPTICAL SETUP

The bending magnet and optics used to extract the synchrotron light out of the storage ring vacuum chamber is shown in figure 1.

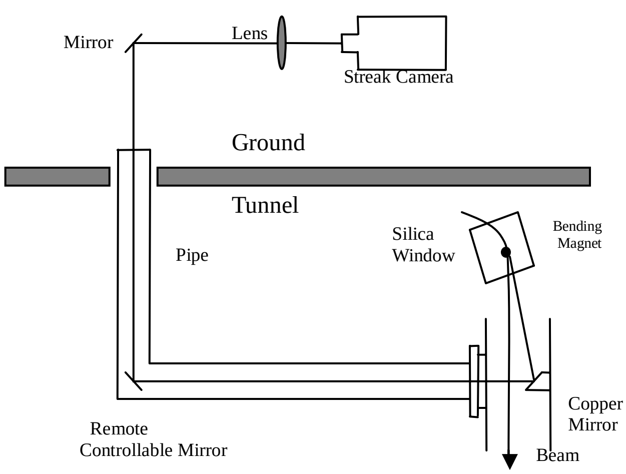

Figure 1: The synchrotron light extracting setup.

The synchrotron light is emitted from the beam traveling through a bending magnet near the straight injection region. The synchrotron light is reflected by a copper mirror which is inside the vacuum chamber. The mirror's surface is gilded with gold, and it cooled by water to dissipate the large incident synchrotron radiation power. The light is transported outside the storage ring through a silica window, and reflected by a remote controllable mirror, then go through a pipe ended at the optical bench above the beam-line where the streak camera is located. A lens is positioned just before the streak camera and used to focus the synchrotron light onto the slit in front of the streak camera.

2 THE STREAK CAMERA OPERATION PRINCIPLE

Figure 2 shows the operating principle of the streak camera.

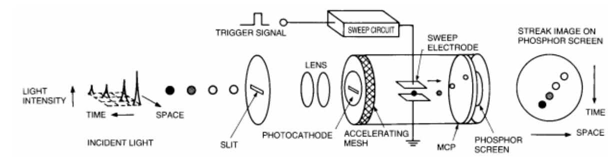

Figure 2: The operating principle of the streak camera [5].

We can imagine the light being measured as several optical pulses that slightly different in time, space and optical intensity. These pulses passing through the slit and optics form the image on the photocathode of the streak tube. The incident light on the photocathode is converted into electrons. The number of those electrons is proportional to the intensity of the light. The electrons go through a pair of accelerating electrodes to get higher speed. Then they pass between another pair of sweep electrodes where a high voltage synchronized to the incident light is applied. During the high-speed, the electrons that arrive at a slightly different time are deflected in slightly different angles in vertical direction. At last, they enter the micro-channel plate (MCP), where they are multiplied several thousands of times, and bombard against the phosphor screen, converted again into light.

3 SYSTEM DESCRIPTION

The system configuration is shown in figure 3.

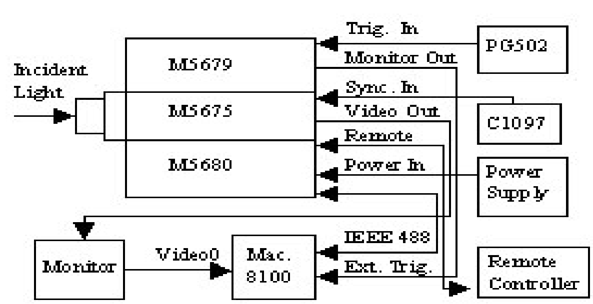

Figure 3: The system configuration.

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The whole system consists of a Hamamatau C5680-11 streak camera fitted with an M5679 dual time extender and an M5675 synchroscan unit, and some other auxiliary parts such as the delay unit C1097, the manual controller, the control computer, and the monitor. The synchrotron light pulses pass through the optics and enter the streak camera. The RF signal (99.765MHz) goes into the synchroscan unit M5675 after the delay unit C1097. At the same time the 10Hz signal from the pulse generator (PG 512) acting as the horizontal sweep repetition frequency is sent into the dual time axis expansion unit M5679. The control computer of the streak camera is the Macintosh computer 8100, with an image processing board, a GP-IB board and the streak camera control software U5565.

4 THE RESUTS OF MEASUREMENT

Some graphical results of measurement are shown in figure 4.

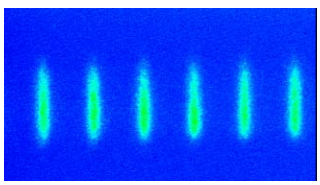

Figure 4(a): The Bunch Image of BEPC.

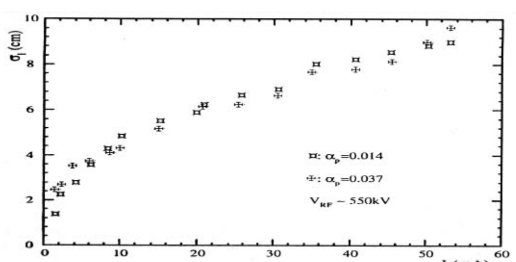

Figure 4(b): Bunch lengthening in different α_p [1].

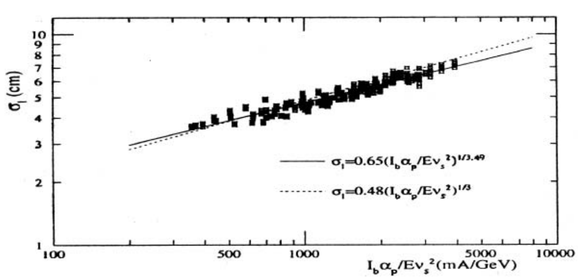

Figure 4(c): Scaling law for the bunch lengthening [1].

Figure 4(a) shows the bunch image of BEPC. The revolution period of the bunch in the storage ring in single bunch operation mode is 800ns. The horizontal sweep time of the streak camera is 5μs, so 6 consecutive turns of the same bunch can be seen on the screen at a time. Figure 4(b) shows the bunch length variation with bunch current at different momentum compaction factors when the RF voltage is kept unchanged. It shows that at very low current, the natural bunch particle population increases, the bunch lengths with different α_p merge gradually. So, above a certain current, when the RF voltage and beam energy are fixed, the bunch length is independent on α_p. Figure 4(c) shows the scaling law for the bunch lengthening of BEPC. The dashed line gives the 1/3 power law for the scale parameter $\xi = I_b \alpha_p / E_s^2$. From Figure 4(c), we can see that the BEPC bunch length scaling low dose not deviate very much from the Boussard's formula [4].

With the scaling low, we can get an empirical expression for the threshold current of the microwave instability:

$$I_{th}(mA)=4.71\times\alpha_p^{2.49}E(GeV)^{4.49}/V_s^{1.49}$$

5 ERROR ANALYSIS

Since the streak camera provides an absolute measurement of the bunch length, we use this method as the primary measurement of the bunch length in the BEPC, therefore the error of this measurement becomes very important.

5.1 Systematic error of the streak camera

The systematic error involves the static image, non-linearity in each different scale, differences among scales, and error caused by different attenuations [3].

The static image error is that induced by the light in its scanning direction when the vertical scan voltage is zero. Switching off the vertical and horizontal scan of the camera, we can measure the static image passing through different slits under the condition of natural light. Table 1 gives the measured values for static image size (rms length in Gaussian) for different slots.

Table 1: Measured rms length of the static image

Diameter (μm)	Channel (ch)	Vertical scan scale			
		I (ps)	II (ps)	III (ps)	Ⅳ (ps)
10	1.821	0.46	2.46	4.50	6.23
30	2.342	0.58	3.37	5.74	7.95
100	5.487	1.37	7.56	13.55	18.77
150	10.370	2.59	15.04	25.60	35.47

Modified by the static image, the bunch length can be found from the formula:

$$\sigma_l = \sqrt{\sigma_{means}^2 - \sigma_{static}^2}$$

For short bunches, we can find that the modifications are large, while for long bunches, they are relatively small. The non-linearity exists in each vertical scan scale, shown as Table 2. Each scale is calibrated with 480 channels.

These different measurement scales have different errors. The Ⅲ and Ⅳ scales have the error of 2-3% in measurement.

Table 2: The non- linearity of each sweep range

	Ⅰ	Ⅱ	Ⅲ	Ⅳ
Ranges (ns)	0.119	0.698	1.20	1.71
Non-linearity	0.08%	0.08%	0.47%	-0.94%

Apart from the systematic errors due to the streak camera itself, calibrations for the camera with the theoretical values of bunch length at very low beam current give an average error of -3.17% at different beam energies [2]. It follow that all the measured bunch lengths are longer than the theoretical values with a relative error of -3.17%.

5.2 Random errors

The random errors in the measurement come mainly from the turn-turn error, which means the measured bunch length varies in two consecutive turns and may come from the bunch longitudinal oscillation, and may come from the data fitting error, which is about ±2.5% on average. To reduce the turn-turn error, we take 10 snapshots for each measured value to minimize the discrepancies. Then the turn-turn error is around ±1.76%.

6 CONCLUSION

In resent years the streak camera have been used in many applications in accelerators, and provided not only precise measurements, but also instructive visualizations of beam characteristics and behavior that cannot be obtained from other beam instrumentation. In the future, we will try to realize the remote control of the streak camera, realize the turn-by-turn and bunch-by-bunch measurement of the bunch length, as well as three dimensions measurement of the bunch length with the streak camera.

7 ACKNOWLEDGEMEMTS

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8 REFERENCES

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