# BUNCH LENGTH MEASUREMENT WITH STREAK CAMERA AT SSRF STORAGE RING

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*Abstract*

A streak camera is installed to measure the bunch length of storage ring at SSRF. The principle, structure, configuration and error analysis of the measurement is introduced. Some result of the measurement are analysed to explain the physical meaning of beam status. The system is used in daily operation and machine study at SSRF.

## MEASUREMENT OF ELECTRON BEAM BUNCH LENGTH

There are two kinds of techniques to measure beam bunch length: Time-domain measurement techniques and frequency domain measurement techniques. Time-domain measurement techniques include streak camera, RF kicker cavity, energy spread measurement's, electro-optic sampling, electro-optic sampling with chirped laser pulses, and frequency domain measurement techniques include Fourier transform spectroscopy, Hilbert transform spectroscopy and so on. Time-domain measurement techniques are usually applied to single bunches and deliver on-line information of the longitudinal charge distribution. Frequency domain measurement techniques are ideally suited for shorter bunches but have the drawback of longer data acquisition times and rather indirect Fourier analysis methods. [1] At the storage ring of SSRF, the designed beam bunch length is about 13 picosecond,s and it's a suitable size to be measured with a streak camera.

## STREAK CAMERA

We adopt a C5680 Streak Camera to measure the bunch length at SSRF storage ring. The C5680 Streak Camera is developed at HAMAMATSU, and features extremely high-level time resolution. The C5680 Streak Camera can be used as a high-speed single-sweep model (with a time resolution of 2 ps or better), as a low-speed single-sweep model (with a time resolution of 50 ps or better), or as a synchroscan sweep model (with a time resolution of 2 ps or better), simply by replacing the plug-in module. The streak camera converts incident light into electrons and sends them through a high speed sweep (the electrons are swept in the direction from top to bottom) in order to determine the intensity distribution of the incident light in relation to time. The operating principle of the streak tube is shown in Fig. 1.

The light passes through a slit and forms an image on the photocathode of the streak tube. The photocathode converts the light into electrons, and these electrons are directed towards a phosphor screen by accelerating electrodes. A high-speed and high voltage is applied to the sweep electrodes, so that the electrons are swept in the direction from top to bottom. The swept electrons are directed towards an MCP (micro-channel plate) where they are amplified, and then directed to the phosphor screen where they are converted back into light. The optical image produced on the phosphor screen is called the "streak image", and this serves the intensity distribution in the vertical axis direction as time passes. In this way, the temporal intensity distribution is substituted for a spatial intensity distribution on the photocathode.

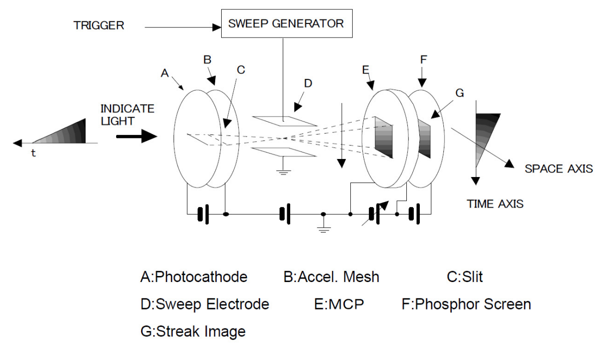


Figure 1: The Operating Principle of Streak Tube.[2]

In addition, if the light is passed through a spectroscope or other equipment and directed to the photocathode, the spatial information is output to the horizontal axis direction, thus the time resolution of the light spectrum is measured using a single streak image. Furthermore, Applying a high-speed and high voltage to the horizontal sweep electrodes enables analysis in both axis, which is applicable to applications such as Synchrotron and Linac electron bunching measurement.[2]

## OPTICAL LAYOUT

The source point of SRM is bending magnet near injecting point. The synchrotron light is extracted by a water-cooled beryllium mirror. Then three mirrors guide the light to the dark room. The setup of all diagnostic

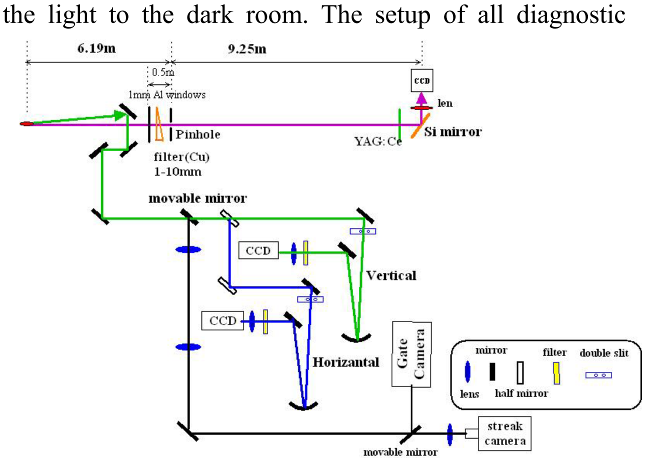


Figure 2: Layout of the Optical Diagnostic Beamline. [3]



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beam line, it is include interferometer, x-ray pinhole camera and streak camera as shown in Fig. 2.[3]

In front of the streak tube, an optical relay system is employed to form an image of the entrance slit onto the photocathode of the streak tube. Conventional streak cameras use lens systems with refractive optics, which induce certain dispersive effects (e.g., optical path differences (OPD)) in the bunch length measurement. On the other hand, reflective optics is free from dispersive effects because the light does not pass through the inside of glass material. The Offner's relay system, comprising two nearly concentric spherical mirrors, yields images with one-to-one magnification at a high resolution and low distortion. [4]

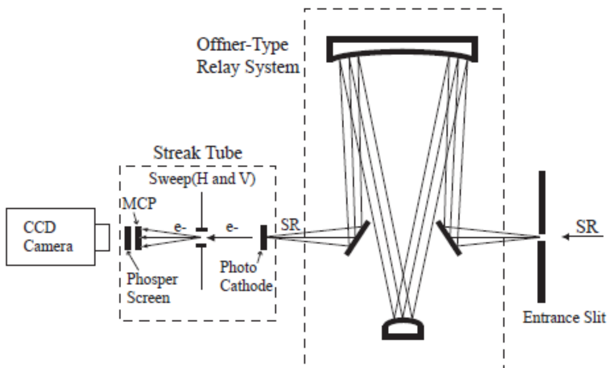


Figure 3: Schematic drawing of the Offner relay system installed in the streak camera. [4]

## CONFIGRATION OF THE MEASUREMENT

The streak camera (HAMAMATSU C5680) uses a scan streaking of 125 MHz (1/4 RF) and also dual time streaking is available. The attainable phase stability is good: less than 2 ps, and a bunch separation of 2 ns, while the revolution frequency is 694 kHz. The synchroscan unit operates at 125 MHz allowing the bunch train to be analysed bunch-by-bunch, even bunches on one sweep and odd bunches on the return sweep. The temporal resolution of the synchroscan unit is less than 2 ps which will allow an individual bunches to be resolved clearly and analysed.

As shown in Fig. 4(a), the trigger signal is from timing system, 1/4 of the RF frequency. The trigger section controls the timing of the streak trigger. This section has to be adjusted so that a sweep is initiated when the light being measurement arrives at the streak camera. The delay unit C6878 is used to control how long the trigger signal which initiates the streak sweep is delayed, and a frequency divider, which divides the frequency of the external trigger signal by 1/4. In the other way, A signal of 1.44 μs(Rep rate) was sent in as the sweep trigger. Fig. 4(b) illustrates the time relationship between the trigger and sweep signals, and Fig. 4(c) shows the corresponding streak image.

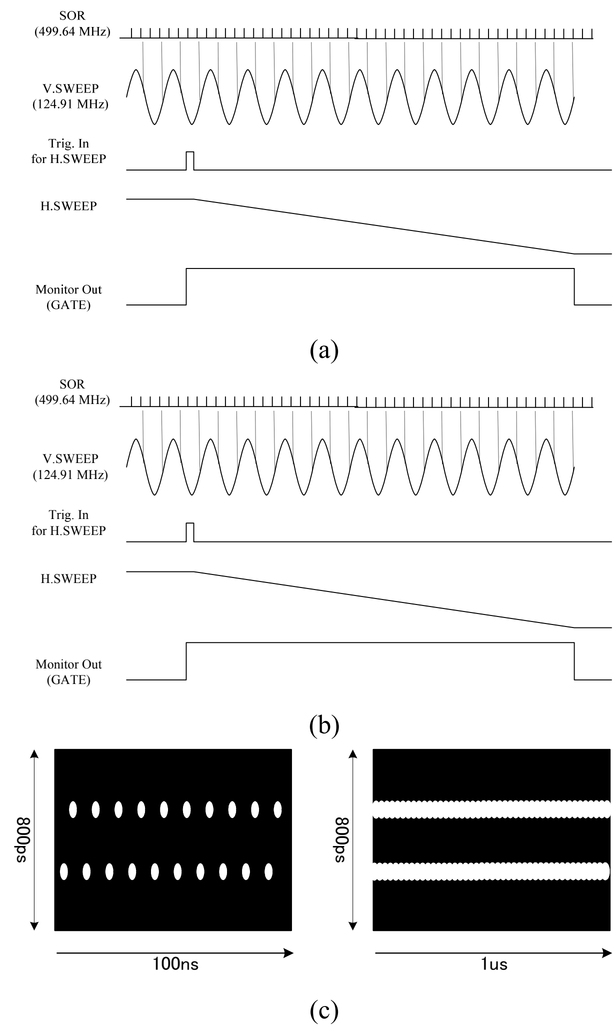


Figure 4: (a) System Layout, (b) Timing Chart, (c) Streak Image. [2]

## RESULT OF THE MEASUREMENT

### *Time Structure of Beam Bunch*

The synchroscan unit was used to measure the time structure of the beam, the pictures in Fig. 5 shows the structure within two different time range. In synchroscan mode, the horizontal direction illustrates time scale, the scale of the streak in vertical direction shows the bunch length. In Fig. 5(a), the time range in horizontal direction is 100 ns, every spot indicates one bunch, and about 20 bunches were contained in the picture. The photon is too few to generate clear image, the picture in Fig. 5(a) was integrated by 50 shots. In Fig. 5(b), the time range in horizontal direction is 20 μs, every spot indicates multi bunches in one circle of the storage ring. The horizontal gap between the spots demonstrates the filling pattern of the injection: about 500 of 720 time slots in the heading were filled, and the rest were spared. The RMS bunch length can be calculated by Gaussian fit to the profile in vertical direction, but the static image should be deducted.



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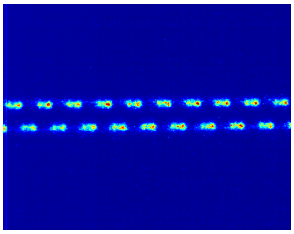
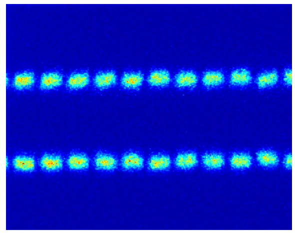


(a)Time range: 100ns(H),1700ps(V)



(b) Time range: 20us(H), 700ps(V)

Figure 5: Time Structure of Beam Bunch.

### *Longitudinal Instability Measurement*

A MATLAB script was written to analysis the longitudinal instability in frequency domain, as shown in Fig. 6. The raw image is the same as the picture in Fig. 5(b), the pixel number of the image is 512*512, every pixel in horizontal direction represent 39ns (20us/512), and every pixel in vertical direction represent 1.37 ps (700 ps/512). All the columns were connected one by one, and the interval slots were filled by zero, so it became a sampling sequence with 1.46E7 points (20 us/1.37 ps), every column with data in 700 ps were placed in one horizontal pixel (39 ns), the rest samples were set to zero, as shown in the second picture in Fig. 6.

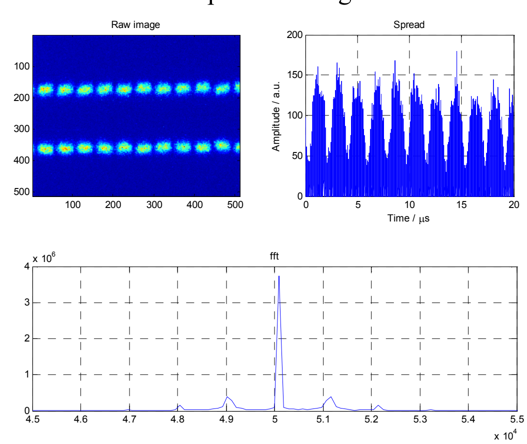



Figure 6: Longitudinal Instability Measurement.

The algorithm of FFT was executed to the sampling sequence, and the result is shown in Fig. 6. The main peak off the Y axis is at the frequency of 50 kHz, and this is the frequency of longitudinal oscillation. The second peak is separated the main peak by 1.2 kHz, and the result is correspond with a noise study of BPM system, the source of the noise is suspected to a set of low level RF equipment.

## CONCLUSION

The streak camera of C5680 was plant at the storage ring of SSRF to measure the bunch length and observe the longitudinal structure of the beam. The longitudinal instability can be analysed by FFT of the transformation of the streak image. There are more applications of streak camera to be carried on, and the frequency domain analysis can be penetrated deeply.

## REFERENCES

[1] M. Geitz, "Bunch Length Measurements", DIPAC 1999 – Chester, UK

[2] Hamamatsu Photonics K.K, "Streak Camera C5680Instruction Manual"

[3] J. Chen, Z.C. Chen, et al, "The Synchrotron Radiation Diagnostic Line At SSRF", MOPB70 Proc. IBIC2012, Tsukuba, Japan, p. 236 (2012); http://jacow.org/

[4] T. Obina and T. Mitsuhashi, WEPB12, Proc. DIPAC 2007, Venice, Italy, p. 256, (2007); http://jacow.org/



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