

# Development of image processing software for online measurements at streak camera system in Indus-1 synchrotron radiation source

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## ABSTRACT

Indus-1 is a 450 MeV, synchrotron radiation source in India. Visible light from wide synchrotron radiation spectrum is focused by visible diagnostic beamline for the study of electron beam parameters. The longitudinal profile of electrons is captured (images) and measured by the indigenously developed streak camera system. Image processing software is developed for measurement of bunch length and bunch centroid position of electron beam (visible part). In this paper the algorithm for development of image processing software is discussed and results obtained after measurement under different light condition and with changing background during the natural decay of beam current are discussed.

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## Introduction

Indus-1 is a synchrotron radiation source (SRS) in RRCAT, Indore. The circulating electrons are emitting the synchrotron radiation from mid-IR to soft x-ray in the dipole magnets. Its RF frequency and harmonic number are 31.6 MHz and 2 respectively. There are five operational beamlines at Indus-1 SRS. Visible diagnostic beamline (V-DBL, BL-5) is used for study of beam parameters of electron beam at dipole magnet DP-3 in Indus-1. For measuring the bunch length and bunch centroid position of order of few picoseconds, it requires very high temporal resolution devices to analyze the beam in the time domain. Several methods are used for these measurements by using electronic and optical instruments.

The bunch length represents the length of longitudinal distribution of the electrons inside the bunch, and bunch centroid position is the position of bunch in image. The bunch length and bunch centroid position is important for the study of the beam behavior at different light condition. Precise measurements of these longitudinal parameters are helpful in understanding longitudinal dynamics of electron beam in Indus-1 SRS. Streak camera is used to measure the duration of ultra fast optical phenomena, by measuring the variation of light intensity in a pulse with time [1]. Its temporal resolution is in few picoseconds. An indigenously developed streak camera system is installed at V-DBL for measurement of bunch length and bunch centroid position of electron beam in Indus-1.

In a streak camera, final image (streak) is captured on a charge coupled-device (CCD) camera to measure the temporal profile of the light pulse. The streak camera system and image capturing at CCD camera need to be properly synchronized to capture the required pulse. Fig 1 shows the block diagram of optics and synchronization setup of streak camera system in Indus-1 SRS.

The image captured at CCD camera is processed to get the required temporal information of electron beam. Image processing software is developed for precise measurement of bunch length and bunch centroid position of electron beam. Various image processing techniques are applied to enhance the image quality for getting precise information under changing conditions of signal and background. Various steps for the development of the image processing software and measured results under different light conditions with changing background during the natural decay of beam current are discussed.

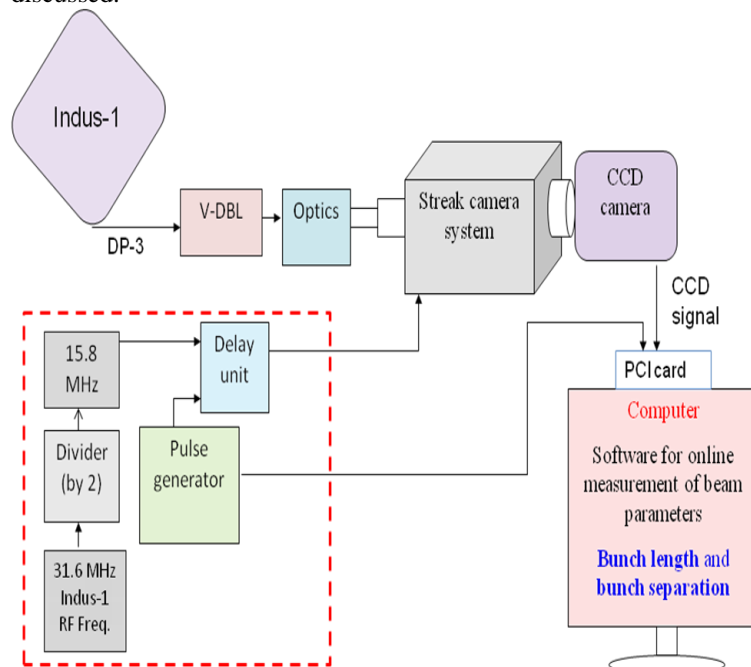


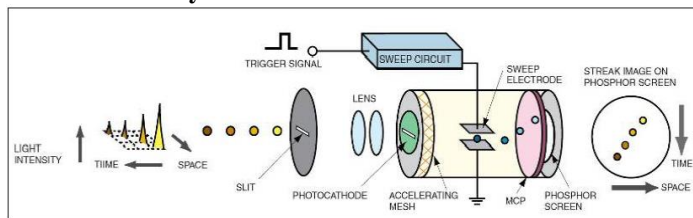
Figure 1. Block diagram of optics and synchronization setup of streak camera system in Indus-1 SRS

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## Streak camera system



**Figure 2 Operating principle of streak camera system [1]**

Fig 2 shows the operating principle of streak camera system. The light pulse which is to be measured is passed through slit and focused through optics; an image is formed on the photocathode. In the photocathode, the light pulse is converted into number of electrons proportional to the intensity of the incident light. These electrons are accelerated by accelerating electrodes and a high sweep voltage synchronized with incident light is applied in between such that the electrons which arrive at different time are deflected in different angles. After that electrons are passes through micro channel plate (MCP) where electrons are multiplied thousand numbers of times and bombarded on the phosphor screen. In this way, streak camera system converts the temporal profile of a light pulse into a spatial profile.

Fig 3 shows the indigenously developed optical streak camera system at V-DBL Indus-1 SRS. The temporal resolution and spatial resolution of developed streak camera is 4ps and 150  $\mu\text{m}$ .



**Figure 3 Experimental setup of indigenously developed streak camera installed at visible diagnostic beamline in Indus-1 SRS [2]**

## Development of software

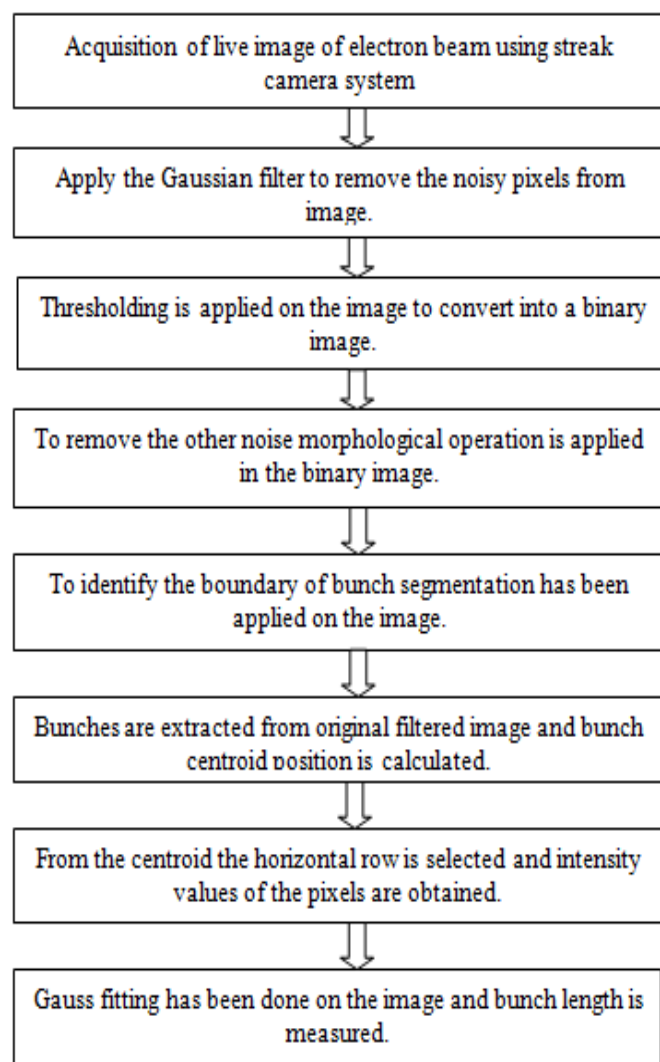
A menu based image processing software is developed in LabVIEW in such a way that it should be able to capture the live image, apply necessary image processing techniques to detect bunches and measure the bunch length and bunch centroid position precisely. Major challenge on developing the software is the drastic change of background due to system non linearity and decay of beam current and some other factors.

The software works in following steps:

1. Acquisition of online image of electron beam (visible part) using CCD (charged coupled device) camera from streak camera system.
2. Enhance the quality of images through image processing techniques like filtering, thresholding, morphology and segmentation.
3. Measurement of bunch length and bunch separation of electron beam at different light condition.

Fig 4 shows the flow chart of algorithm of software development. Firstly, the acquisition of the live image of electron beam is captured through PC0 Pixelfly camera (CCD). Software displays the live image of the electron light pulse. During acquisition and transmission or due to other factors the

noise gets attached to the image. In order to remove the noise, optimal filter is applied on the image. Since the noise of the light pulse is found to be normally distributed in nature so  $3 \times 3$  Gaussian filter is applied to the image. Histogram is calculated from the captured image to obtain optimal threshold value for the thresholding. After applying obtained threshold value to the filtered image, binary image is obtained. For removing the other types of noise present in the binary image morphological operation are applied. Now, the object is detected from the background through segmentation. And the boundary of bunches is identified. Bunches are extracted from the filtered image through boundary coordinates and centroid is calculated. A horizontal row is selected from a centroid and the pixel intensity is measured. The intensity values obtained are in bell shape in nature so Gauss fitting is done on the measured values. Bunch length is measured from the standard deviation value of Gauss fitting and bunch separation is measured from the difference between the centroid of the consecutive bunches.



**Figure 4 Flow chart of algorithm of image processing software**

A suitable region of interest (ROI) is selected by user such that bunches are covered in the selected ROI as shown in Fig 5. The threshold image created from the ROI extracted image as shown in Fig 6. Further processing is done on the threshold image as shown in Fig 7 and boundary of bunches are identified as shown in Fig 8 through segmentation. Gaussian fitting is done on the obtained values and bunch length is measured.

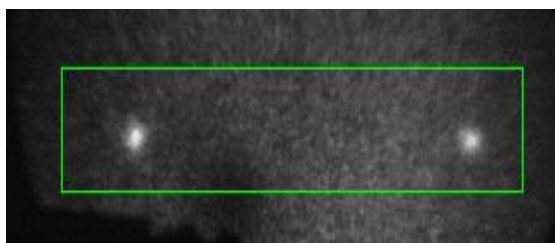


Figure 5. Typical image of electron beam taken from streak camera at beam current of 48 mA.

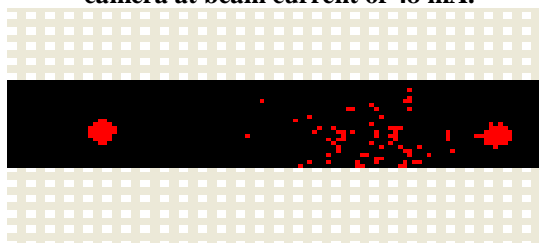


Figure 6. Binary image after thresholding.

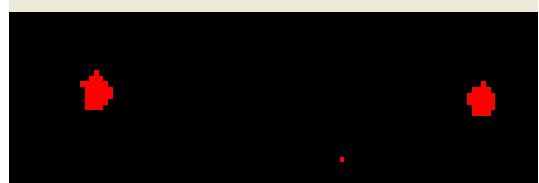
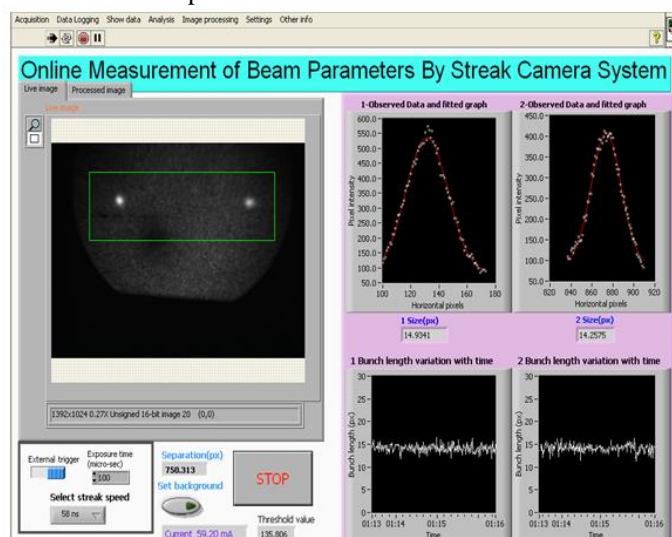


Figure 7. Image after morphological operation.



Figure 8. Bunches extracted through segmenting operation. GUI of software

Fig 9 Shows the GUI of menu based software, the left part shows the live image captured from CCD camera, and in the right side (upper) shows the Gauss fitting is done on the measured data obtained by the software to calculate the bunch length. Two graphs shown below displays the bunch length variation with respect to time.



### Measured results

During the natural decay of beam current, the bunch length of the both bunches is measured at 1 Hz. Typical plots showing the variation of bunch length of 1<sup>st</sup> and 2<sup>nd</sup> bunch during the natural decay of beam current from 120 mA to 20 mA are shown in Fig 9 and Fig 10.

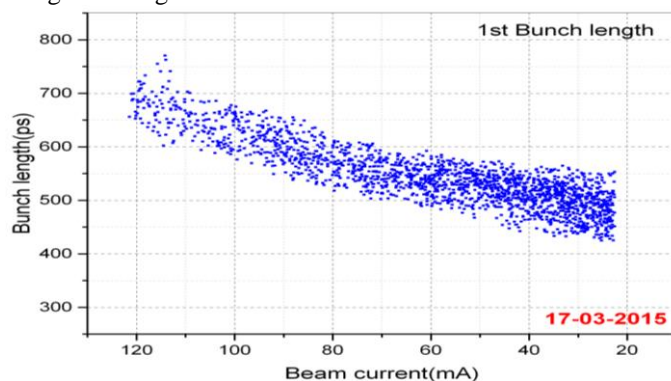


Figure 9. Measured bunch length of 1<sup>st</sup> bunch at Indus-1 during natural decay of beam current.

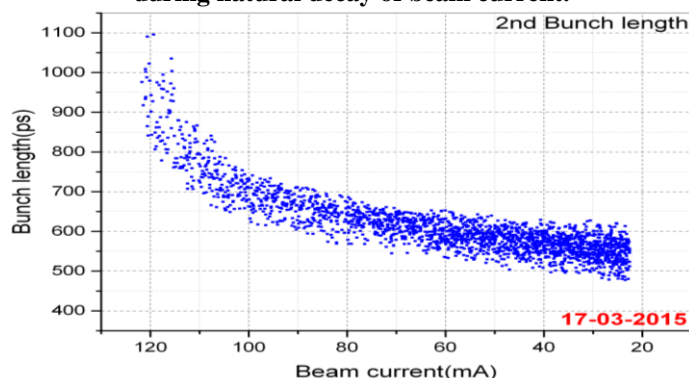


Figure 10 Measured bunch length of 2<sup>nd</sup> bunch at Indus-1 during natural decay of beam current.

It was observed that during the natural decay of beam current from 120 mA to 20 mA in Indus-1 SRS, the measured bunch length (RMS) of 1<sup>st</sup> bunch is decreasing from  $700 \pm 50$  ps to  $500 \pm 50$  ps and 2<sup>nd</sup> bunch is decreasing from  $1000 \pm 50$  ps to  $600 \pm 50$  ps. In all these measurements, it was observed that the 2<sup>nd</sup> bunch has remained on higher side as compared to 1<sup>st</sup> bunch. Typical plot of bunch length comparison for 1<sup>st</sup> and 2<sup>nd</sup> bunch is shown in the Fig 11. From these measurements, it was also observed that 2<sup>nd</sup> bunch has shown sharp reduction of bunch length at higher beam currents (110-120 mA). Both bunches are showing similar trend of bunch length reduction below 110 mA.

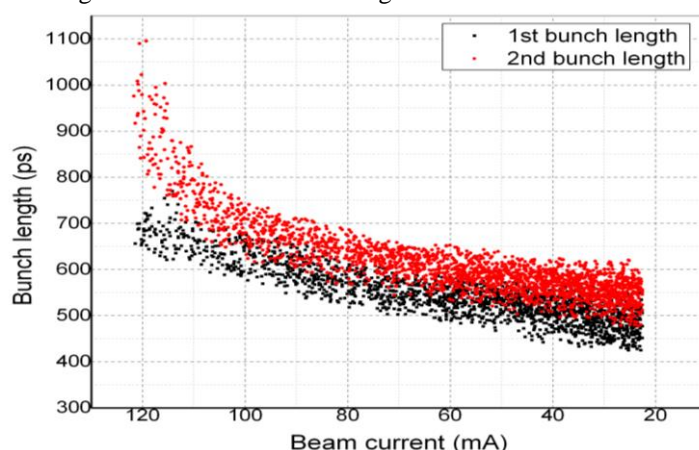
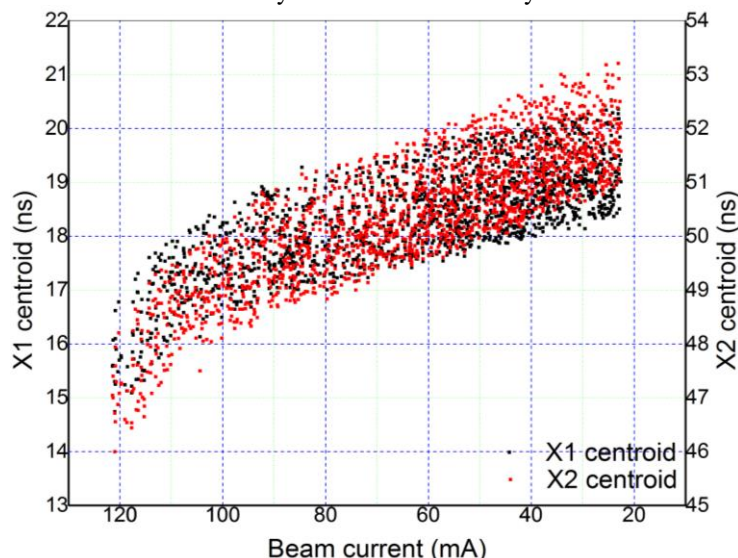


Figure 11 Measured bunch length of both bunches at Indus-1 during natural decay of beam current



We measured the bunch centroid of both bunches with image processing. Typical graph with the variation of bunch centroid (X) for the natural decay of beam current from 120 mA to 20 mA are shown in Fig 11. It was observed that during the natural decay of beam current, the measured bunch centroid of 1<sup>st</sup> and 2<sup>nd</sup> bunch are repeatable within  $\pm 1$  ns. In all these measurements, it was observed that the centroid position of 2<sup>nd</sup> bunch shifts by  $\sim 1$  ns higher as compared to 1<sup>st</sup> bunch. It may be because of nonlinearity of the measurement system.



**Figure 4.3.1 Measured bunch centroid of bunches at Indus-1 during natural decay of beam**

### Conclusion and future scope

The image processing software for the measurement of longitudinal beam parameters of electron beam has been developed and installed at streak camera system in Indus-1 SRS. Different longitudinal beam parameters of electron beam such as bunch length, bunch separation, amplitude, centroid, position etc are measured. It has been observed that during the natural decay of beam current bunch length (in RMS) has reduced by 200 ps with current from 120 mA to 20 mA. And the bunch centroid position of 2<sup>nd</sup> bunch shifts by  $\sim 1$  ns higher as compared to 1<sup>st</sup> bunch. Further, to improve the quality of image fitting more image processing functions can be tried on the image.

### References

- [1] Hamamatsu, "Guide to Streak Camera"
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