DUAL STREAK CAMERA AT THE ESRF

K.Scheidt, Machine Division, ESRF,France

ABSTRACT

The Hamamatsu dual sweep Streak Camera C5680-31 has been in operation since June 1994. It measures both the bunch length and longitudinal instabilities. The camera is fed with 0.85T dipole light with a photon flux sufficient to perform single shot measurements at Storage Ring intensities below 100µA. The Streak tube has a 200-800nm spectral sensitivity and uses an internal MCP intensifier with a gain range of 10^3 that is gateable down to 70ns. The fast sweep is continuous at 88.05MHz (i.e. 1/4 RF ESRF) with full time ranges between 150ps and 1.5ns which offers a temporal resolution down to 2ps.

Using, in addition, a dual time base module (with ranges between 100ns and 100ms) means that several individual bunches in the Storage Ring can be measured on a turn-by-turn basis over many consecutive turns.

The Streak Camera is fully integrated in the ESRF's computer system. Protection against over-exposure, remote control of all aspects and a powerful image treatment system guarantuee reliable and user-friendly remote operation from the ESRF's control room for operation purposes.

Used extensively in 1995 for various special studies on the Storage Ring, a wealth of results illustrating its performance and versatility are presented.

1 THE LIGHT SOURCE, ITS FLUX, DURATION AND TIME STRUCTURE

The light source is shared with a number of other UV and visible light diagnostics [1]. Extracted from a 0.85T bending magnet it provides a total photon flux of $\approx 4\cdot 10^{16}$ per second in the spectral band of 200-700nm for a nominal ESRF Machine current of 200mA. About 5% of this flux ($\approx 2\cdot 10^{15}$ per sec.) is used for the Streak Camera. Depending on the Machine current and filling pattern the maximum available light flux for the Streak Camera is $\approx 3\cdot 10^8$ per bunch. The Streak Camera's lower limit for pure single bunch measurements is $\approx 10^6$ thus permitting such measurements at less than 100µA.

The ESRF's acceleration frequency (RF) is at 352.2MHz with an orbit frequency at 355Khz (RF/992). A variety of filling patterns are possible: 300 grouped bunches (1/3 fill, 200mA), one Single Bunch (10mA), a combination of both (Hybrid fill), and the 16 Single Bunches (equally distributed over the circumference, 90mA). The consequent light input frequency is either 352.2MHz, 5.68Mhz or 355KHz (T=2.8ns, 176ns or 2.8µs respectively.).

The total range of bunch lengths possible with all routine and special Machine tunings is 30-200ps (fwhm).

2 THE STREAK CAMERA

2.1 General Characteristics

The Hamamatsu C5680-31 Streak Camera can be characterised as follows :

Input optics & streak tube :

- spectral sensitivity : 200 to 800nm
- photocathode quantum efficiency : ≈10% (@≈500nm)
- input light aperture : slit (5µm graduation) or pinhole (10, 30 and 100µm selectable)
- input lens : f=35mm, F5, 1:1 magnification
- internal MCP intensifier (gateable, Gain : 10 to 10^4)

fast deflection axis (Streak) :

- Synchroscan Unit @88.05Mhz (i.e. 1/4 RF ESRF)
- temporal resolution : better than 2ps
- streak time scale : 150ps, 500ps, 1ns and 1.5ns
- jitter <2ps

dual time base :

- repetition frequency 10Hz max.
- dual time scale : 100ns to 100ms

internal electrical gating :

- MCP : ≈70ns min. width @2Mhz frequency (burst of 100, $\approx 10^3$ extinction ratio.)
- Photocathode : 10Khz max. ($>10^3$ extinction ratio)

read-out system :

- CCD camera fiber-coupled to streak-tube's phosphor screen, 739 X 575 pixels, 11µm square
- standard CCIR video output, 1V pk-pk 75 Ohm

full IEEE control

2.2 Input Optics and Protection

The extracted dipole light is focused by an external achromat (f=300mm) through the pinhole of the streak camera. An internal relay lens focusses this light onto the photocathode. The dimensions of the pinhole determine the spatial resolution which, together with the streak speed used, determines the temporal resolution, e.g. a 30µm pinhole gives a spot size of 7pixels fwhm which results in a time resolution of 7ps with a 500ps streak time scale (≈1ps/pixel). For special Machine Physics other pinholes or the slit aperture were used together with telescope optics that preserve the transverse dimensions of the electron beam.

The C5680 streak tube features an internal MCP intensifier which avoids the degradation of spatial resolution compared to external MCPs. As this MCP can be permanently damaged by over-exposure, a protection consisting of an external shutter driven by a saturation detector on the CCD's video output signal was added. Reliable and in-expensive, it reacts within 40ms.

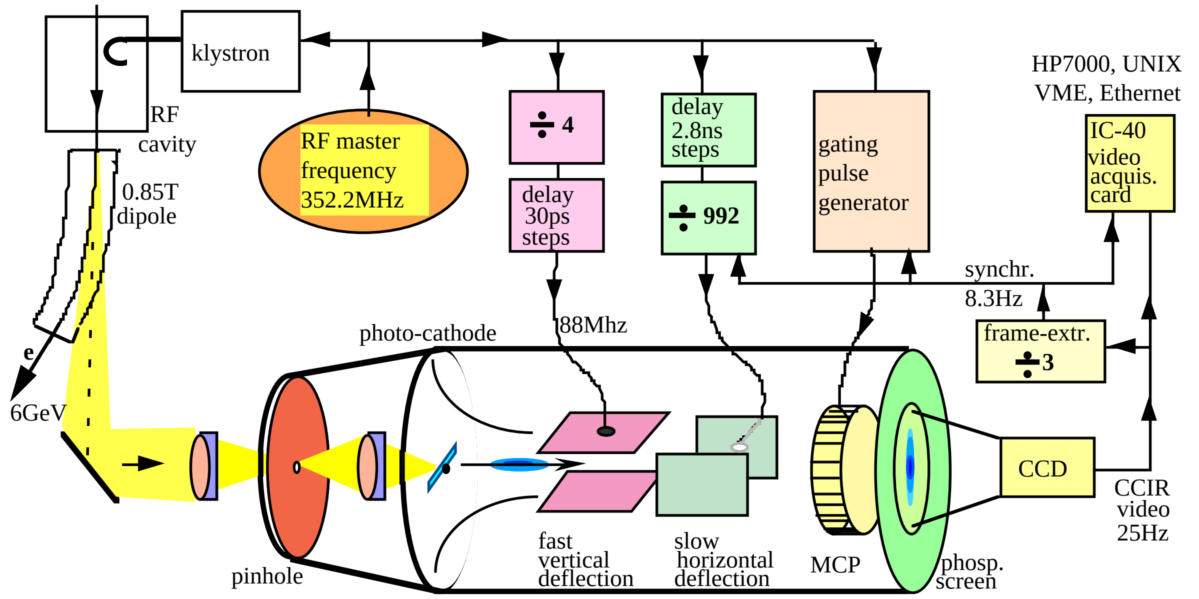

Figure: 1 Synchronisation of the Streak Camera system

2.3 Synchronisation Aspects

The vertical, fast (streak), deflection uses a so-called synchroscan module that provides a permanent sinusoidal deflection at 1/4 of the RF frequency. It permits a far higher repetition frequency with better jitter than is possible with ordinary ramp generators. Synchro-scanning at 1/4 RF with an RF light input frequency causes 2 out of 4 light impulses to be deflected out of image range (say bunch 1 & 3), and the other bunches to be scanned in the opposite direction (say, bunch 2 up- and bunch 4 down-wards). This aspect has no negative consequences for the Streak Camera's application or the interpretation of results.

The horizontal (slow, dual time base) deflection is synchronised with both the orbit frequency and the CCD read-out camera. This is done at $8^1/_3$Hz and ensures a very stable 'life' generation of streak images through a video acquisition card synchronised to it.

The gating (light obturation) on the MCP intensifier is externally accessible offering a great deal of flexibility. The burst-envelop of gating pulses for this MCP is synchronised in a similar way to the horizontal deflection, with the individual gating pulses inside this burst synchronised to the RF frequency. The exact number of gating pulses, their timing, duration and frequency is fully programmable which allows the full exploitation of the light gating possibilities of this Streak Camera. This makes it possible to detect and visualise phenomena of the electron beam in the longitudinal dimension which would otherwise remain unknown.

The gating on the photocathode is always internally synchronised with the horizontal deflection in order to avoid parasitic light images during the fly-back of this horizontal sweep.

3 REMOTE CONTROL AND IMAGE TREATMENT SYSTEM

3.1 Remote Control

The C5680 is the heart of the Streak Camera system and it is has a full IEEE interface. The ESRF Computer network uses a LAN/HP-GPIB module and associated software to control the C5680 from a Unix environment. A 30ps step programmable delay uses the same interface.

Other components and sub-systems (gating pulse generator, delay units, video card, optical filter-changer, image intensity measurement, external shutter) are controlled through VME modules.

The transverse displacement of the 300mm focussing achromat is done with analog signals and allows to adjust for (closed orbit) movements of the light source point.

3.2 Image Treatment

The acquisition of the Streak Camera's video signal is done with an IC-40 card at the $8^1/_3$Hz repetition frequency. The card drives an RGB monitor in the ESRF control room to display this 'life' image with high contrasted colours and a number of limited options.

The same image matrix (640 X 480 pixels) is transmitted over the Ethernet to the UNIX environment where an application program offers a large number of specially adapted options and manipulations to extract rapidly and automatically all the significant characteristics and measurement results. First a correction of the non-uniformity (≈20% over the entire read-out matrix) of the system is carried out. Then a large number of 'streaks' inside an image are localised and analysed with their numerical results displayed, after which individual or grouped bunch profiles images can be generated. This chain of operations takes ≈4seconds.

3.3 *Application for Control Room Operator*

The Streak Camera system's objective was to provide a powerful yet user-friendly instrument to the control room operator covering all possible applications, yielding reliable data and being protected against possible ill-use by non-experts. The remote control and image treatment have been integrated into one single application program that also guides the user by the availability of pre-configured files, an indication of image intensity (in % of saturation level) and a number of measurement modes.

In 'continuous' mode the user has direct access to all parameters in the system so to adjust these to the beam conditions and the type of information to be extracted. Once this adjustment finished the program puts the system in 'stop' mode (shutters closed, MCP at 0) where it remains until a measurement sequence is initiated.

This may be done manually by clicking a single button or automatically at pre-programmed time intervals. A measurement sequence takes a few seconds, it first puts the right MCP gain, then opens the shutters, reads and transmits the image file, performs all the pre-selected image treatment operations and (optionally) stores the results in a data file. A 'refresh' mode permits a safe, un-attended use over a long period (e.g. a beam decay of 12 hours) with limited usage of the streak tube (≈3 secs per measurement) and automatic generation of reliable data.

4 MEASUREMENTS & RESULTS

4.1 *Measurement methods*

The Streak Camera using the synchroscan and dual time base generates multiple pure single shot 'streaks' in one image. The Image Treatment system can treat these streaks individually, yielding a bunch length value for each and a statistical average. However, the input light flux per bunch should be kept limited to avoid the photo-electron space-charge effects in the streak-tube which increases the result values. The exact flux level where these effects are non-negligible depend on the bunch length and the used streak-speed. However, a too low input light flux results in rather noisy single shot streaks with a consequent false interpretation of their length.

A solution to this is to simply verify visually that the series of streaks in one image do not manifest a jitter between them and then to apply an image treatment averaging operation on the streaks before one single result value is yielded. This method gives reliable and reproducible data, is easy to verify, and has been used for most bunch length measurements.

4.2 *Results*

Routine User Service Mode :

The bunch length in all Machine filling modes and at all beam currents is measured. The strong dependence of bunch length on beam current is precisely assessed. [2, 3]

Also longitudinal phenomena in certain filling modes are systematically demonstrated and characterised.

Special Machine Physics Studies :

Over the last 2 years the Streak Camera played a central role in a number of profound studies carried out on the Storage Ring Machine's longitudinal characteristics for different Machine tunings. Quasi-Isochronous Machines with low α (+ & -) were extensively tested. The bunch lengths mostly confirmed the theoretical predictions, i.e. bunch length independence of α in the high current regime. Similar measurements were undertaken at 1 and 2GeV Machine energy. [4]

The injected beam energy could be optimised by measuring the behaviour directly at the time of injection. Also Head-Tail bunch instabilities could be demonstrated.

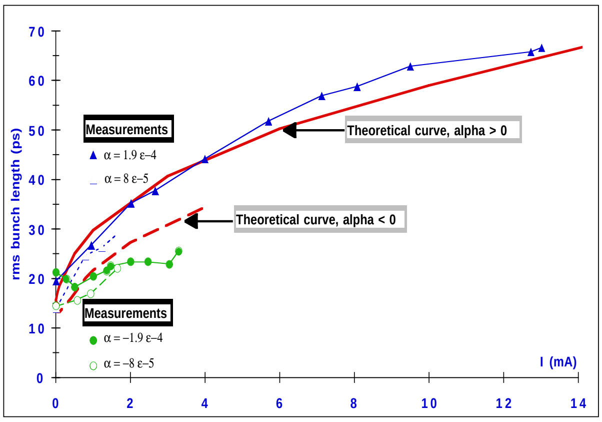

Figure: 2 Bunch Length versus Bunch Current

5 ACKNOWLEDGEMENTS

Thanks are extended to : P.Verdier who developped the image treatment system and fully integrated the Streak Camera into the ESRF's Computer System through a reliable and user-friendly application program, I.Fladmark for the software controlling the IEEE interface, P.Pinel for the support in Digital Hardware and development of the gating pulse generation, and C.Limborg for the preparation and analysis of the measurement results.

REFERENCES

[1] K.Scheidt, "UV and Visible Light Diagnostics for the ESRF Storage Ring", these proceedings.

[2] C.Limborg et al, "ESRF Machine Dedicated Time Reports on Bunch Length and Longitudinal Studies".

[3] J.M.Lefebvre "Higher Brilliance at the ESRF", these proceedings.

[4] A.Ropert "Probing Issues of 4th Generation Light Source at the ESRF", these proceedings.