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SYNCHROTRON RADIATION DIAGNOSTICS PERFORMANCE AT ELSA*

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Abstract

The pulse stretcher ring ELSA delivers polarized and non-polarized electrons with an adjustable beam energy of 0.5–3.5 GeV to external experimental stations. To meet the growing demands of the user community regarding beam intensity and quality, the upgrade of vital accelerator components is an ongoing process. This includes the improvement of the beam diagnostics in order to resolve and monitor intensity and quality limiting effects. ELSA has recently been equipped with a diagnostic synchrotron radiation beamline housing a streak camera as main beam imaging device. It extends the diagnostics capabilities into the picosecond temporal resolution regime and captures fast longitudinal and transverse beam dynamics. The obtained measurements provide crucial feedback for further machine optimization. The overall performance of the streak camera system and machine relevant measurements are presented.

INTRODUCTION

The ELSA facility [1] is specialized for double polarization photoproduction experiments. The general beam properties of the pulse stretcher ring are listed in Table 1. The current funding period supports studies for the increase of stored and extracted beam currents, beam quality and degree of polarization. Beam instabilities occurring above the standard operation current of 25 mA are to be investigated with adequate instrumentation. In order to gain information of fast beam dynamics with temporal resolution, a synchrotron radiation diagnostic beamline has been constructed [2] and recently started operation [3]. Specifications are the ability to display longitudinal, horizontal and vertical beam dynamics on a wide range of time scales through non-averaged single shot measurements. Hence the challenge lies in the sufficient detection of the low amount of photons emitted within picosecond time intervals and in overcoming the aperture restrictions of the vertically narrow slit aperture of the streak camera. This $0.15 \times 4.41\,\mathrm{mm}^2$ large photo cathode usually restricts the imaging of beam dynamics to only one transverse plane. The following sections describe the current capability of simultaneous transverse imaging and single shot bunch length measurements. Resolution affecting restrictions are pointed out.

THE BEAMLINE

The diagnostic beamline has been designed to meet the specific requirements at ELSA. Of importance is the protection of the primary downwards reflecting mirror from

Table 1: ELSA Pulse Stretcher Ring Parameters

Parameter	Value
Beam energy E	0.5–3.5 GeV
Revolution period T_{rev}	548 ns
Cavity RF frequency f_{RF}	499.67 MHz
Momentum compaction α_c	6.3 %
Bending radius R	10.88 m
Natural emittance ϵ_x (1.2 GeV)	105 nm rad
Bunch length σ_s (1.2 GeV)	34 ps
Synchrotron frequency f_s	88 kHz
Tune Q_x, Q_z	4.61, 4.43

blackening reactions with residual gas molecules, as it accepts the full load of the emitted synchrotron radiation. The result is a 12 m long beam pipe allowing for sufficient differential vacuum pumping, but is also responsible for a large beam diameter at the vacuum window. Currently a commercially available 2" secondary mirror reflects the beam from the vertical chicane into the optical plane of the diagnostics table, hence defining the restricting beamline aperture. A larger mirror is soon to be installed. A primary focusing lens creates a real image with magnification $M = 0.088$. This image acts as source point for a relay line (Fig. 1) whose lens pair defines the final image magnification. Inbetween the

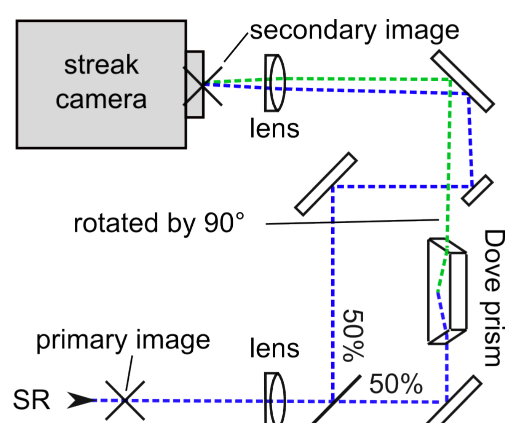

Figure 1: Optical setup providing simultaneous beam imaging of horizontal and transverse planes, as one part of the optical beam is rotated by 90° after exiting the Dove prism.

beam is split by a 50% beam splitter of which one branch is transversally rotated by 90°. Both beams rejoin with slight displacement and angular deviation. By proper optics adjustment a vertically orientated beam ellipse is projected next to a horizontally orientated ellipse onto the streak camera's

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input slit. Large transverse beam displacements in either plane remain detectable. The beamsplitter and Dove prism are situated on precision stages which can be removed if maximum, undivided intensity is needed.

THE STREAK CAMERA SYSTEM

The available sweeping modules for the dual-axis streak camera Hamamatsu C10910 are two slow sweep units (M10913-01: vertical & M10916-01S: horizontal) and a synchroscan unit (M10911-01: vertical) [4]. The slow sweep units are triggered by either the 0.91 MHz half orbit clock signal or by an experimental trigger which can be fired manually. It may synchronize the effect of a beam actuator (e.g. a kicker) with the recording trigger of a diagnostic tool. Two trigger delay generators allow the timing adjustment for both slow sweep units. The synchroscan unit runs at 1/4 of the RF frequency and provides picosecond signal resolution. However, the quality of the imaging depends on the available light intensity which is a limiting factor for single shot operation. Integration over multiple beam revolutions is possible but as the beam changes position at the source point, the image is naturally broadened due to picture overlap. The wiring and the available time ranges are shown in Fig. 2.

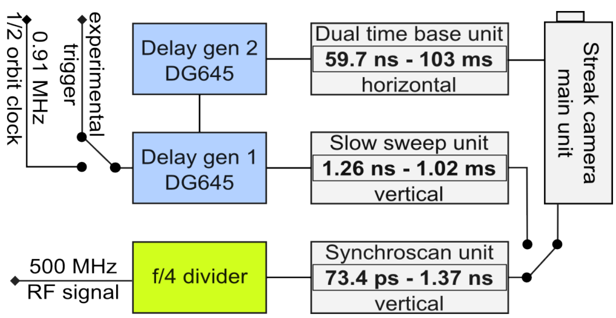

Figure 2: Trigger signal wiring and available time ranges of the streak camera system.

Transverse Measurements

The performance of the dual transverse beam imaging setup is illustrated in Fig. 3. With the streak units at rest (a), both elliptical beam images are visible within the narrow vertical slit aperture. Note that e.g. horizontal beam movement would cause the left image to move vertically and therefore to exceed the aperture's acceptance. The vertical slow sweep unit is used to measure the charge distribution of the first injected 232 ns long booster bunch train (b). Its horizontal deformation is likely to be caused by a slight timing mismatch of the injection kickers. The lower charge distribution of the tail suggests that a partial collision of the beam with an aperture, e.g. the septum edge, has been taken place. Fine-tuning of the injection process based on these measurements will follow shortly. Note that the horizontal betatron phase advance from the location of the injection septum (maximum displacement) to the source point of the diagnostic beamline is $\psi(s) \approx 80^\circ$ as in

$$x(s) = \sqrt{\beta_x(s)\epsilon_x}\cos(\psi(s)),$$

where $x(s)$ is the horizontal single particle displacement, $\beta(s)$ the betatron function and ϵ_x the horizontal emittance. Therefore the measured displacement in turn one will be close to the design orbit. Image (c) shows multiple subsequent revolutions of the injected bunch train within the ELSA pulse stretcher ring. The displacements at the source point correspond to the horizontal tune of $Q_x = 4.61$. The large horizontal oscillation amplitude causes a suppression of the vertical image at the second visible turn. This suggests an upper dual transverse resolution limit of approximately 100 pixel which corresponds to 21 mm at the source point – or one beam width at 1.2 GeV injection energy. As the amplitude approaches this resolution limit, the loss of signal is proportional to beam displacement. Reducing the image magnification would increase the dynamic resolution. However, the trade-off is a decrease of pixel resolution.

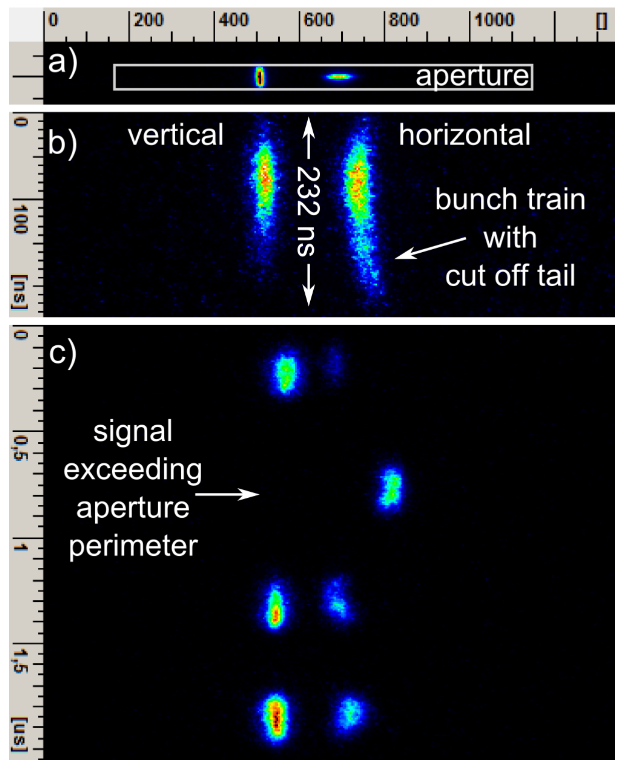

Figure 3: Simultaneous imaging of the vertical and horizontal plane in focus mode (a) and slow sweep operation: The injected bunch train at its first revolution (b) and its oscillations over four revolutions in the stretcher ring (c).

Longitudinal Measurements

The synchroscan unit is used for bunch length and phase deviation measurements (Fig. 4). Its single shot performance limit is given by the shortest exposure time as the dual timebase extender unit stretches the bunch signals horizontally apart. Its minimum time range of 60 ns allows the separate

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visualization of every fourth bunch, adding up to seven and a half bunches in one row. In measurement (a) the beam was captured at an instability which lead to a homogeneously broadening of the charge distribution within the bucket. As common button- or cavity-based diagnostics only detect the displacement of the distribution centroid, the streak camera image was able to reveal the broadened structure of the bunches. Note that the declining slope of each streak results from the velocity difference between the vertical and horizontal sweeping unit ($v_{\text{ver}}/v_{\text{hor}} \approx 60$). The varying signal strength of the individual bunches indicate that the instability has been acting with different effect upon the subsequent bunches, leading to partial particle loss. The investigation for occurrence and countermeasure of this instability is yet ongoing. A well damped beam at standard beam current is shown in image (b) for comparison. Here the non-integrated single shot image yields a sufficient signal-to-noise ratio.

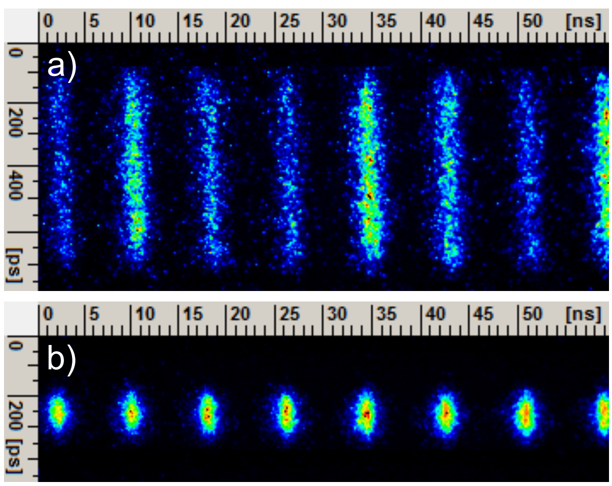

Figure 4: Comparison of synchroscan measurements: Single shot image of strong incoherent longitudinal particle oscillations around the reference phase at 1.2 GeV and 145 mA beam current (a) and damped bunches at standard beam current (b).

As the horizontal time window is increased during synchroscan operation, the single bunch images overlap and longitudinal effects become visible only by statistical evaluation of the intensity profile. Fig. 5 shows a grow-damp measurement where the bunch-by-bunch feedback system [5] was turned off at approximately 26 ms for 5 ms. The beam starts to oscillate coherently with rapidly rising amplitude. As the feedback system is switched on again, it damps the coherent oscillation within 30 ms as indicated by the solid blue line returning to the center of the vertical distribution. As the coherent oscillation decreases, the beam envelope yet widens at ≈ 42 ms as the population of incoherently oscillating electrons rises. This is due to the finite width of the synchrotron frequency Δf_s. The fitted exponential decay suggests a damping constant of $\tau_s = (34.4 \pm 2)$ ms taking into account systematic errors given by the analysis of the bitmap image. The damping constant lies in the vicinity of the theoretical value

$$\tau_s = \frac{2ET_{\text{rev}}}{\Delta E_{\text{SR}} \cdot (2 + \frac{\alpha_c L}{2\pi R})} \approx 36.7\,\text{ms},$$

where E is the beam energy, ΔE_{SR} the energy loss per turn due to synchrotron radiation, α_c the momentum compaction, L the length of the accelerator and R the dipole bending radius.

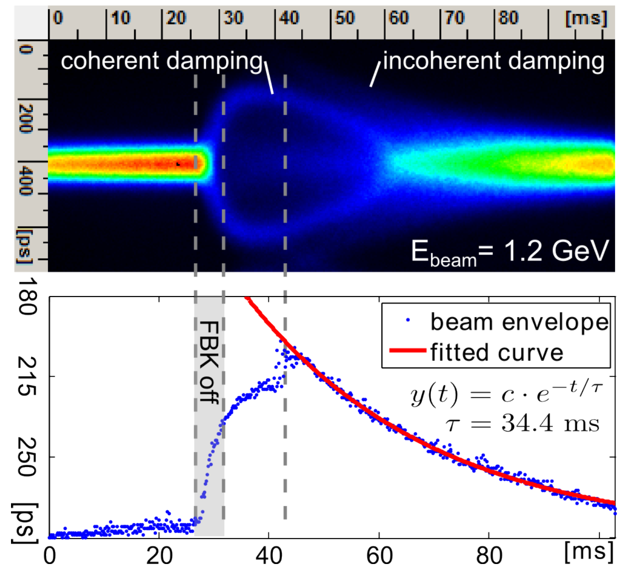

Figure 5: Coherent and incoherent damping observed when the bunch-by-bunch feedback was switched off for 5 ms.

CONCLUSION

The streak camera system meets its specifications as it successfully measures vertical and horizontal beam dynamics simultaneously as well as resolves individual bunch dynamics with single shot measurements. The beam splitting beamline section provides satisfactory results, yet the resolution limit is naturally given by the slit aperture of the streak camera and the beamline aperture. The installation of a larger secondary mirror and magnification reducing optics are expected to provide a clearer signal-to-noise ratio for single shot, short-time exposed measurements as needed for resolving head-tail instabilities.

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