HIGH RESOLUTION SYNCHROTRON LIGHT ANALYSIS AT ELSA*

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Abstract

The Electron Stretcher Facility ELSA provides polarized electrons with energies up to 3.5 GeV for external hadron experiments. In order to suffice the need of stored beam intensities towards 200 mA, advanced beam instability studies need to be carried out. An external diagnostic beamline for synchrotron light analysis has been set up and provides the space for multiple diagnostic tools including a streak camera with time resolution of $\Delta t < 1$ ps. Beam profile measurements are expected to identify instabilities and reveal their thresholds. The effect of adequate countermeasures is subject to analysis. The current status of the beamline development will be presented.

INTRODUCTION

The Electron Stretcher Facility ELSA consists of several accelerator stages, the last one being a pulse stretcher ring. In order to improve the optical beam diagnostics for the stretcher ring a new beamline has been constructed (Fig. 1). It guides the synchrotron light into an external laboratory, thus offering flexibility for transverse and longitudinal beam profile measurements. A synchrotron light

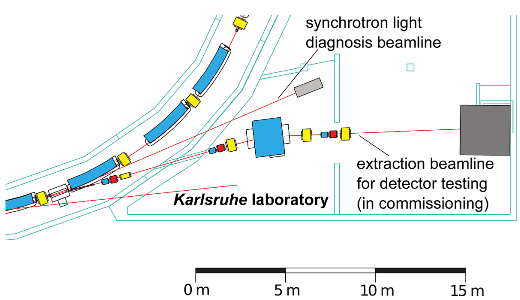

Figure 1: External diagnostic beamline for synchrotron light analysis.

monitor operating in the UV range provides high resolution transverse profile measurements. The application of a streak camera system is planned and expected to start operation in summer 2013. The streak camera displays beam profiles over a wide range of time scales with a resolution down to 1 picosecond. The longitudinal and both transverse planes can be observed separately. Measurements of single bunch lengths, charge distributions and synchronicity conditions will be subject of analysis. The diagnostic tools impose several requirements on the beamline. The system concept, its properties and the setup will be explained in detail. A first beam profile measurements is presented.

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BEAMLINE

The beamline can be subdivided into an evacuated section, a vertical chicane and an optical table where the diagnostic tools are installed.

Evacuated Beamline Section

The 12 m long beamline guides the synchrotron light from the vacuum chamber of the stretcher ring through the concrete shielding into the laboratory. An aperture defining slit system is positioned 3 m downstream from the source point. The most crucial element of the beamline regarding the beam diagnostics is the symmetric primary mirror deflecting the visible and UV components of the synchrotron light out of the accelerator plane. The mirror absorbs most of the synchrotron radiation's energy. A rear sided water cooling system suppresses the increase of the mirror temperature. Water pressure and temperature gradient lead both to a deformation of the mirror surface. Its flatness profoundly determines the beam image quality. The magnitude of deformation was studied in an FEM analysis. The final design chosen limits the estimated deformation to 170 nm (Fig. 2).

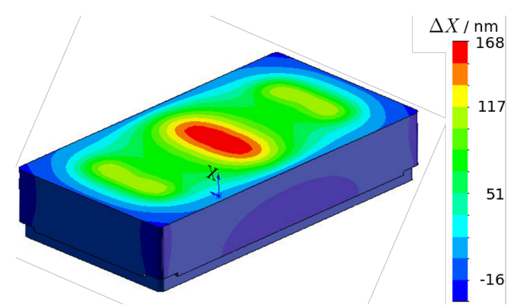

Figure 2: FEM analysis showing the deformation of the mirror surface when irradiated and water cooled [1].

The pressure of the vacuum system has to be kept below 10^{-8} mbar to avoid blackening of the mirror surface due to reactions of the synchrotron light with the residual gas molecules [2]. To minimize the desorption of the walls the vacuum chamber was heated up to 120°C in the commissioning process. Three pump stations equipped with ion getter pumps along the beamline and a non-evaporable getter pump close to the mirror ensure a sufficient suction capacity. After installation of the beamline the pressure at the mirror section was measured to be $4 \cdot 10^{-10}$ mbar on average. However, when irradiated the pressure strongly depends on the width of the aperture defining slit, hinting that the vacuum chamber is still desorbing.

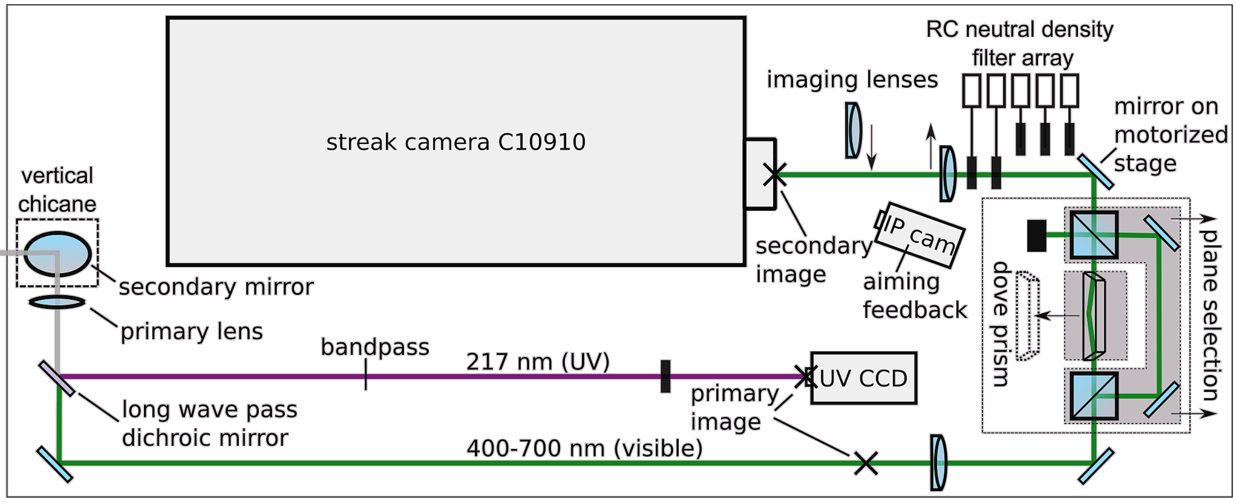

Figure 3: Optics layout roughly to scale. A dichroic mirror separates the UV from visible synchrotron light. The latter is collimated and guided into a plane selecting section. Variable imaging lenses determine the magnification ratio.

Diagnostics Section

The synchrotron light exits the vacuum system vertically through a fused silica glass window and enters an optically sealed box. The commercially available optics and instruments for the synchrotron radiation monitors are installed here on a $150 \times 60\,\text{cm}^2$ large optical table. A schematic drawing of the optics layout is shown in Fig. 3. A secondary mirror deflects the synchrotron light sidewards, thus rotating the image by 90°. The primary focusing lens ($f = 1000$ mm at $\lambda = 530$ nm) is positioned directly downstream from the secondary mirror. The broad band synchrotron light is then separated by a long wave pass dichroic mirror at an angle of incidence of 45°.

The UV components are reflected sidewards and filtered by a bandpass ($\lambda = 217 \pm 10\,\text{nm}$). Neutral density filters reduce the intensity before the image is captured by a CCD camera approximately 1080 mm downstream from the lens. The camera is mounted vertically onto a motor driven stage. The orientation accounts for the rotated image and the motorized stage for the deviating lens' focal length in the UV region. The magnification ratio is $M \approx 0.083$, allowing a large margin of beam movement during the commissioning phase.

The dichroic mirror transmits the visible light components which are used for streak camera imaging. A broad band mirror reflects it onto a path parallel to the UV light where a primary image is formed. Point-to-parallel optics then collimate the beam. The light performs a U-turn within this telescope section in which the image orientation and magnification can be modified. A Dove prism tilted by 45° rotates the image by 90°. The rotation is crucial for projecting the beam onto the narrow slit of the streak camera input optics that only allow the imaging of one transverse plane at a time. The prism can be moved out of the light path in order to select the transverse plane. An optical bypass around the Dove prism will be installed, consisting of two cubical 50 % beam splitters and two mirrors. The chicane and the resulting signal delay allow detailed investigation of linearity of the streak camera as well as simultaneous imaging of both transverse planes. The bypass branch can also be moved out of the beam path. A set of different imaging lenses (parallel-to-point) can be inserted into the path in order to focus the beam onto the streak camera input slit. Thus, total magnification ratios available are $M = 0.33, 0.26$ and 0.17. The seclusion of the laboratory requires remote controlled adjustment of several optical elements. This is granted by a set of remote controlled DC motors as well as linear and angular stages. An IP camera films the setting. Its feedback helps to aim the beam onto the streak camera slit.

DIAGNOSTICS

A CCD camera operating in the UV spectral region and a streak camera form the optical diagnostic tools of the beamline.

The UV Synchrotron Light Monitor

In order to provide high resolution transversal beam profile measurements a synchrotron light monitor is installed. The bending of the electron beam, the finite depth of field of the installed optical system and the diffraction lead to an angle dependent broadening of the image. The operating wavelength of $\lambda = 217 \pm 10$ nm is chosen to minimize broadening caused by diffraction. In Fig. 4 the broadening of the image depending on the horizontal opening angle is shown. The red curve shows the broadening of the new synchrotron light monitor. Compared to an older monitor operating at 486 nm the broadening could be reduced. The horizontal and vertical opening angles can be adjusted by the slit system.
The long focal distance of the primary lens ($f = 1000$ mm) minimizes the depth of field broadening. Neutral den-

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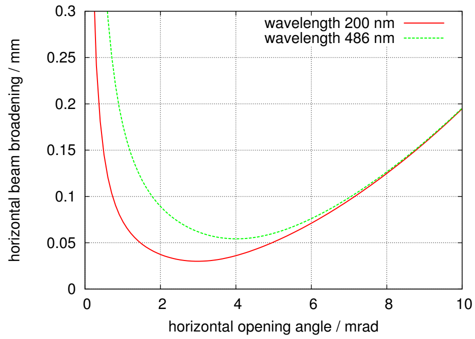

Figure 4: The broadening of the image [3].

sity filters avoid the saturation of the CCD camera. The used camera has a frame rate of 16 fps and a pixel size of 4.65 μm. The CCD chip has a sensitive response of 47 % at the used wavelength. A first measurement at 1.2 GeV is

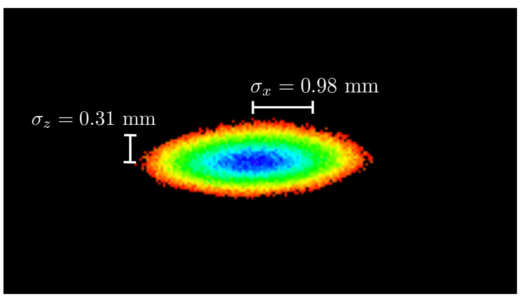

Figure 5: The beam profile in the UV range at 1.2 GeV. The measurement was performed with a non-dichroic mirror.

shown in Fig. 5. To analyze the beam profile an in-house developed software fits a Gaussian curve to the projected profiles. The emittance $\epsilon_{x/z}$ for both planes and the coupling κ are calculated using the theoretically computed beta function, the dispersion at the source point and the measured beam widths. The results for 1.2 GeV are shown in Table 1. The CCD camera also acts as beam position reference tool for the streak camera.

ϵ_x / nm rad	ϵ_z / nm rad	κ
131 ± 19.8	9.5 ± 3.2	0.072 ± 0.027

Table 1: The emittance and coupling at 1.2 GeV.

Streak Camera System

The streak camera of our choice is the *all-purpose* model C10910 by Hamamatsu. It is expected to provide a time resolution of below 1 ps FWHM [4] and offers the option of locating its control computer more than 100 m away from the camera system. The necessity of this feature is given by the seclusion of the laboratory and its status as radiologically controlled area during machine operation. The bridging occurs via fibre cables and corresponding patch panels for USB, FireWire and Ethernet signals (Fig. 6). Connection errors due to pure remote control via Ethernet are eluded this way.

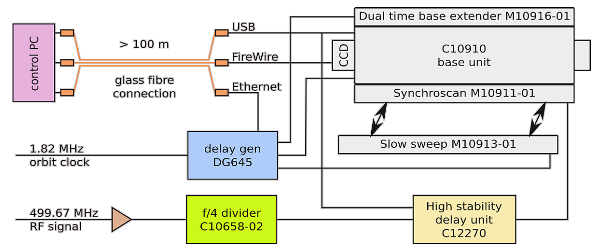

Figure 6: Streak camera block diagram.

Due to the option of image rotation the streak camera may display either a top or side view of the beam. The analysis of beam dynamics is possible for a wide range of adjustable time windows which become available due to three separate sweeping units. The synchroscan unit M10911-01 resolves single bunches in time windows from 48 ns to 100 ps and allows studies of longitudinal coherent beam dynamics as well as single bunch charge distributions. It is operated at 1/4 of the 499.67 MHz cavity RF and therefore displays either even or odd bunches depending on the set delay. The option of operating at 1/2 of the cavity RF was rejected due to a suffering of resolution. The dual time base extender unit M10916-01 performs linear sweeps along the second screen axis in order to separate the bunch sequences. Time intervals available range from 60 ns to 100 ms and allow sectional studies of the 548 ns long bunch train as well as beam behavior over multiple turns. The sweep repetition is limited to 10 Hz. Image sampling over multiple cycles therefore requires good synchronization with the RF signal and the 1.82 MHz ring orbit clock. The synchroscan unit can be switched with another linear slow sweep unit M10913-01, thus displaying the continuous bunch train on time scales from 1.2 ns to 1 ms. This allows the study of beam dynamics in both transverse planes.

SUMMARY

The UV branch of the beamline is fully operational. The vacuum system and primary deflecting mirror show satisfactory behavior. The streak camera will be installed shortly. First images are expected for summer 2013.

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