BUNCH LENGTH MEASUREMENT FOR PETRA III LIGHT SOURCE STORAGE RING

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Abstract

To fulfill the demand for a very high brilliance synchrotron light source, it is required, that the transversal beam size does not exceed certain limits in linear dimension and divergence during the storage time. To control the energy spread, which might couple in the transverse plane due to dispersion, the length of the particle bunches must be measured.

While the transversal beam size is determined in a setup using X-rays, the bunch length measurement system described in this paper is working in the visible range of the synchrotron light.

A detailed description of the dipole magnet visible synchrotron light extraction, the light transport and the analysis by means of a Streak Camera System is given. The influence of the custom designed apochromatic refractive optics transport line on the time resolution of the bunch length measurement is discussed and values are given. The final time resolution of the whole system transport optics and Streak camera is shown to be not bigger than 3 ps.

Several measurements from PETRAIII runs are presented and results of the bunch length measurements are shown. The typical bunch length measured is about 40 ps, in accordance with the expectations.

GENERAL SETUP

The measurement of the bunch length of the PETRAIII storage ring is based on the analysis of visible synchrotron radiation from a bending magnet. The main parameters, characterising the storage ring and the light source are given in Table 1.

Table 1: Storage Ring and Light Source Parameters

Parameter	Design Value
Operating energy E / GeV	6.0
Revolution Frequency f / MHz	500.0
Beam Current I / mA	100.0
Magnetic Radius ρ / m	191.7
Critical Energy E / eV	2499.2

The bunch length measurement setup (Figure **1**) is situated in the straight line after the PETRAIII NL bending section and before the damping wiggler section of the storage ring. Synchrotron light from the last bending magnet at NL 50 m is extracted using a Cu-mirror and a quartz window in the vacuum beam pipe.

Outside, an apochromatic optical beam line [1] transports the light into a laboratory beside the accelerator tunnel.

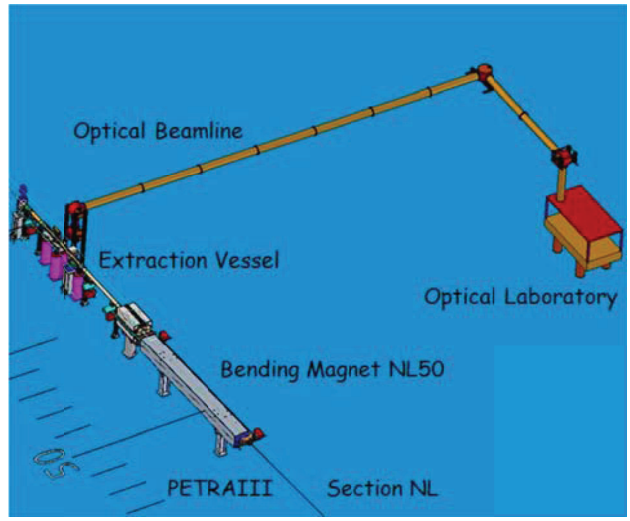

Figure 1: Bunch length measurement setup.

There it is analysed with a streak camera system, using a vendor supplied software package [2].

Plans and work for additional analysis systems, such as wave front sensors and dedicated analysis software are underway.

SYNCHROTRON LIGHT EXTRACTION

UHV Section Light Path

The Synchrotron light from the last bending magnet of the PETRA NL section at 50 m, is extracted using a specially designed extraction vessel (Figure 2). This vessel deviates from the circular shape of the PETRAIII straight section vacuum pipes in order to avoid vignetting of the tangentially emitted synchrotron light by the pipe walls.

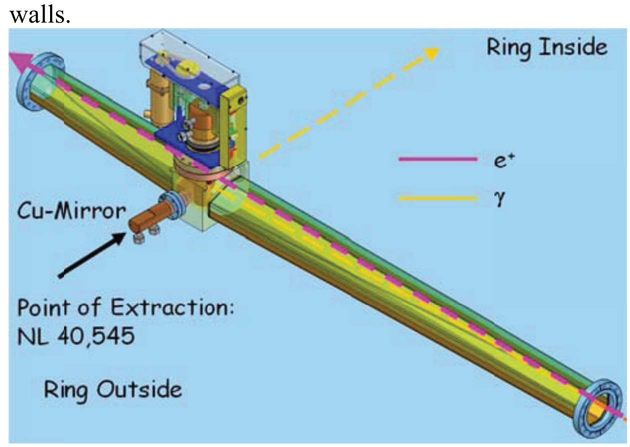

Figure 2: Light extraction vessel.

The source point for the light extraction is located 1.5m beam upstream inside the magnet and the light is reflected by a water-cooled Cu-mirror of 22 x 22 mm^2 (ϕ=2.8 mrad, ψ=2.8 mrad) projected area. The light exits the vacuum pipe through a quartz window into a separate optical beam line. This beam line is not part of the machine vacuum and is designed to be operated either under its own vacuum or, as now, at normal air pressure.

Thermal Considerations

Since the optical part of the synchrotron radiation spectrum is very small in terms of power, most of the radiation power impinging on the mirror is dissipated as heat. In order to minimize a thermal deterioration of the mirrors optical surface, advantage is taken of the spectral angular distribution of the synchrotron radiation.

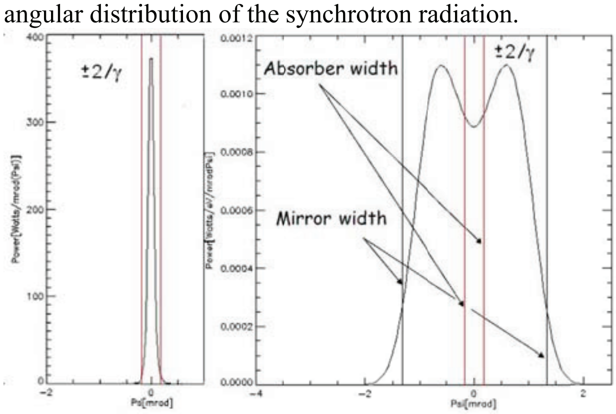

Figure 3: Left: Total radiation power over ϕ=2,8 mrad, right: same at 2 eV.

While the major part of synchrotron radiation is emitted nearly in the orbit plane with an opening angle of $1/\gamma$ (about 100 µrad for PETRAIII), the optical part with $\hbar\omega$ << $\hbar\omega_{crit}$ has a much broader distribution with a typical out-off-plane angle much larger than $1/\gamma$.

Therefore, placing an absorber with a width of $+/-2/\gamma$ in front of the mirror will obstruct the high energy fraction from the mirror [3]. The loss of visible light, also obstructed by the absorber, is about 15%.

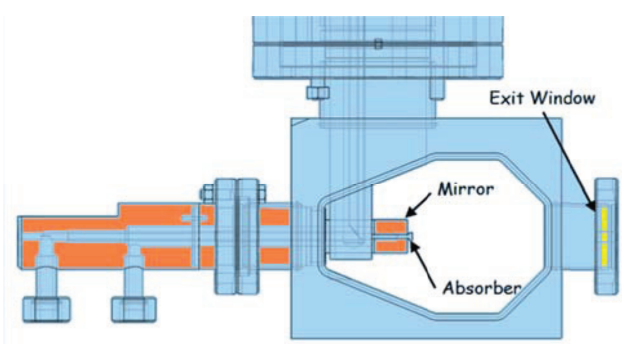

Figure 4: Copper mirror, absorber and exit window.

The final design of the extraction vessel includes a Cu-mirror and an absorber, both water-cooled (Figure **4**). The temperatures of the mirror and the absorber as well as selected vessel areas are measured using PT100 thermometers and the corresponding data are processed by the PETRAIII temperature monitoring system.

OPTICAL BEAM LINE

Light Transport

Figure 5 gives an overview of the optical beam line (OBL). It is used to transport the synchrotron light into the laboratory and consists of one imaging lens (D=100mm, f'=700 mm), five high quality flat mirrors (D=150mm, λ/20 p.t.v. at 632 nm) and two relay lenses (D=150 mm, f'=2250mm. The relay system provides full colour and full geometrical correction in order to allow for further wave front analysis based diagnostics.

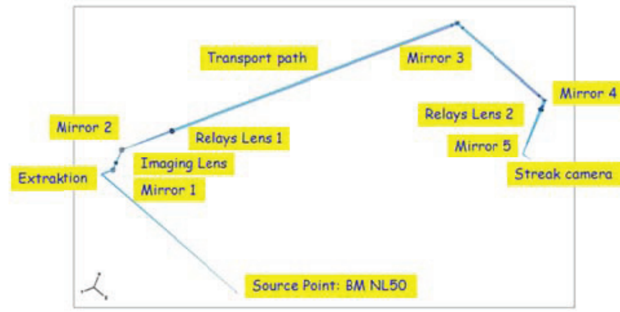

Figure 5: Optical path from magnet to Streak camera.

Time Resolution

Using apochromatic lenses [4], the dispersion in the region from 400 nm to 700 nm and thus the chromatic focal shift was minimized. Their chromatic focal shift is 0.2 mm each, corresponding to a time blur of the complete OBL of Δt_{OBL} = 0.4 / c = 1.34 ps compared to typically 2 mm or 6.67 ps of a single achromatic lens [5]. This value remains constant throughout the whole field of view (Figure 6).

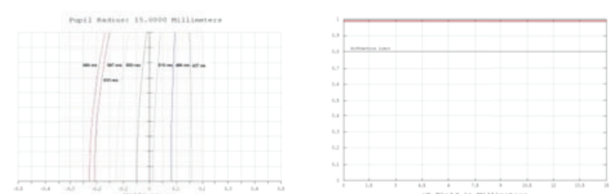

Figure 6: Left: Time resolution in terms of the longitudinal spherical aberration. Right: Light yield in terms of the Strehl ratio for 437 nm – 656 nm.

The light yield is typically two times more, than an achromatic system can deliver, if it could operate on such a broad spectral range. Thus, the loss of 15% of intensity due to the absorber in the extraction system is more than compensated using apochromatic lenses.

STREAK CAMERA

General Description

Finally, the light is fed into a Hamamatsu C5680 Streak Camera (SC) with dual time base extender, operated at 250 MHz, thus allowing the observation of single bunches in a 500 MHz bunch train in the synchroscan mode.

The input optics of the SC is matched to the apochromatic transport beam line, allowing a spectral range from 400 to 700 nm to be imaged on the photo cathode with low intensity loss and with a flat spectral intensity distribution [6]. It is connected to the PETRAIII timing and feedback system (Figure 7) using the standard timing module and a low noise RF amplifier system [7].

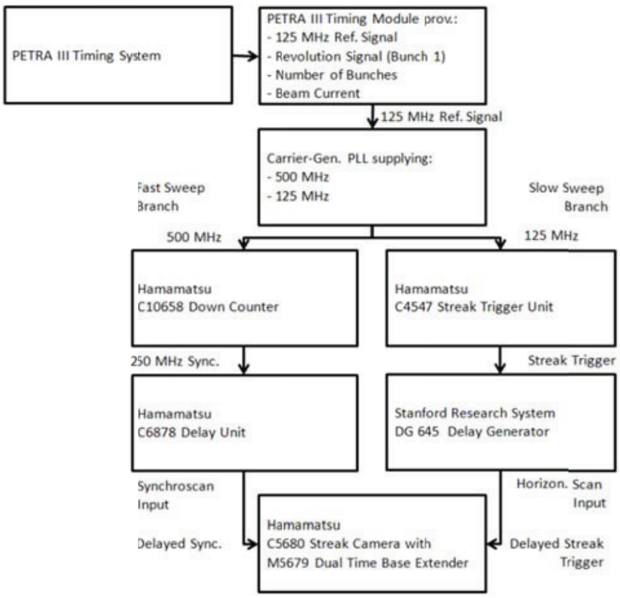

Figure 7: RF system signals for the Streak camera.

Time Resolution

The SC time resolution, including the input optics, measured with a pulsed Ti:Sa LASER, is about Δt_S=2 ps (Figure 8, [8]).

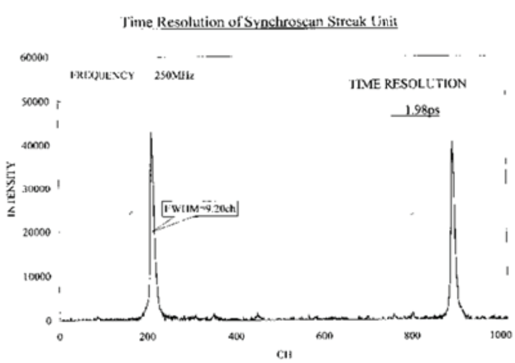

Figure 8: Time resolution of the Streak unit.

Adding the time resolutions of the SC and the OBL quadratically, a total resolution of $\Delta t_T=\sqrt{\Delta t_{SC}^2 + \Delta t_{OBL}^2}$=2.4 ps is achieved

BUNCH LENGTH MEASUREMENT

Typical measurements with the described setup include single bunch as well as bunch train measurements.

In a single bunch measurement (Figure 9), a bunch spot, the corresponding intensity profile and its half widths is given. The half widths of Γ_b = 95.8 ps corresponds to a sigma of the bunch length of $\sigma_b=\Gamma_b/2.3458$=40.8 ps, in accordance with the PETRAIII design parameters.

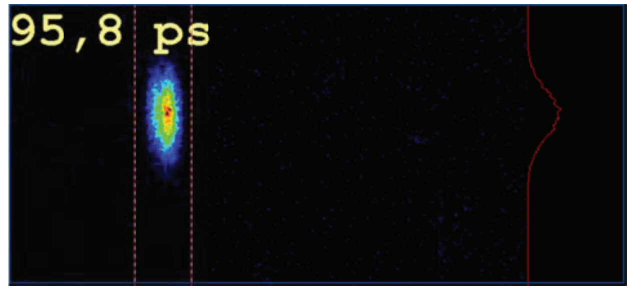

Figure 9: Single bunch measurement, run with 40 mA and 72 bunches.

Analyzing the bunch train allows the determination of several beam parameters not presented here. Work on dedicated software is currently underway [8]. In Figure 10 a 5 µs wide and 430 ps high window shows a part of the bunch train of a 50 mA, 72 bunch filling of PETRAIII.

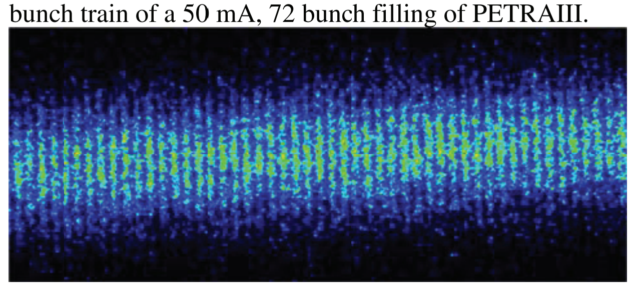

Figure 10: Part of bunch train of 50 mA with 72 bunches.

CONCLUSION

The presented PETRAIII bunch length measurement system is sufficient to measure the bunch lengths of single bunches and parameters of complete bunch trains.

The time resolution is shown to be less than 3 ps, a typical bunch length of 40 ps, in accordance to the PETRAIII design parameters, was measured.

Investigations to improve the time resolution and the measuring process are underway.

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