UPGRADE OF THE BESSY FEMTOSLICING SOURCE *

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Abstract

As the first undulator-based source, the BESSY femtoslicing source has succesfully demonstrated its capabilities of providing 100 fs x-ray pulses in an energy range from 400 to 1400 eV with linear and circular polarisation. Even with a better signal-to-noise ration compared to the slicing sources utilizing radiation from a bending magnet the number of detected photons at the user frontend is still limited to $\approx 10^3$/s. To increase the photon flux the laser system was upgraded to a higher repetition rate. A new beamline utilizing a reflective zone-plate was installed. Finally a new vacuum guided laser beam path will be implemented for better stability.

INTRODUCTION

After being first suggested by Zholents and Zolotorev in 1996 [1] the ”slicing” technique for generation of sub-ps x-ray pulses in a strorage ring now has been implemented at three facilities: the ALS (Advanced Light Source), at BESSY (Berliner Elektronenspeicherring) and the SLS (Swiss Light Source).

The first undulator-based source, the BESSY femtoslicing facility, has well proven its concept of angular separation with an excellent signal-to-background ratio [2]. With its helical undulator it produces x-ray pulses of variable polarization (linear an circular) with a pulse length of ≈100 fs FWHM (full width at half maximum). With circular polarization the BESSY femtoslicing source is an unique tool to study magnetic phenomena at sub-ps time scale by XMCD (x-ray magnetic circular dicroism), providing element specific sensitivity, and being able to distinguish between orbital and spin momentum [3]. Albeit the good signal to noise ratio the experimental data acquisition was limited by the the low number of photons on the sample that is in the order of 1 to 10 per sliced pulse. Different improvements aiming at an increased photon flux on the sample and better stability are discussed below.

UPGRADE OF THE LASER

In order to improve the flux of femtosecond x-ray photons at the experiment the laser system was upgraded from 1 kHz to 3 kHz. The amplifier of the Ti:Sapphire laser system utilizes a single-stage multipath setup with a cryo-cooled crystal [4]. With the progress in laser technology, diode-driven pump lasers are nowadays available for high pulse energies (≈25 mJ) with a repetition rate of up to 3 kHz [5]. Since thermal lens effects are negligible, when the amplifier crystal is cryo-cooled the upgrade could simply be realised by exchanging the pump laser and installing a cryo chiller with a higher cooling capacity. With the new pump laser the system can deliver 2.5 mJ with a repetition rate of up to 3 kHz which corresponds to a maximum average power of 7.5 W. With the lack of thermal lensing this 7.5 W could - within certain limits - also be differrently distributed. For example with a higher pulse energy and a lower repetition rate. Increasing the repetition rate has the strongest impact on the number of sliced x-ray photon flux with a linear dependence. Alternatively increasing the pulse energy would only increase the number of sliced photons with roughly the square root of the pulse energy.[6]. However the maximum possible repetition rate is also limited as will be described below.

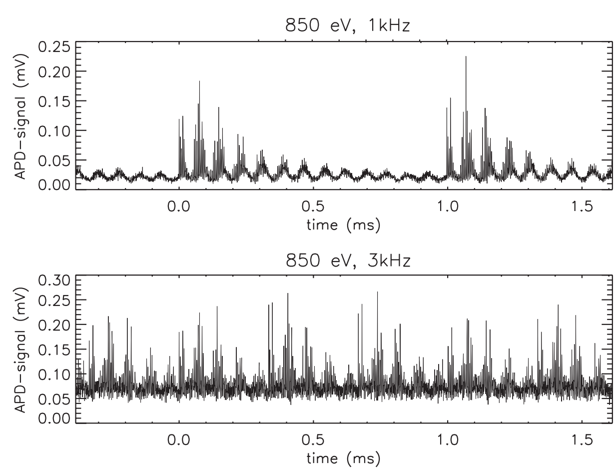

Figure 1: Temporal evolution of the x-ray intensity at 850 eV (detected on the maximum of the undulator harmonic shown in Fig. 2) over a temporal range of 2 ms for the case of 1 kHz laser repetition rate (upper) and for 3 kHz (lower), respectively. The peak intensity of the APD signal averaged over 1000 laser shots was extracted from a data set acquired with a 2 GHz sampling rate.

The BESSY storage ring is normally operated in the so-called hybrid mode. This is a multibunch fill pattern with one larger (single) bunch in the gap which is used for femtoslicing. The laser induced modulation of the electron energy is transferred into an angular deviation at the slicing chicane dipole. When tracked through the magnetic lattice of the storage ring this transversal displacement alternates

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with an energy modulation. According to this effect the intensity of the x-ray pulses, seen in the beamline, also oscillates. As the dispersion of the ring optic elongates the energy-modulated region, the recurring x-ray pulses contribute to a picosecond background.

The temporal evolution of the x-ray pulses over 2 ms with a laser repetition rate of 1 kHz and 3 kHz respectively is shown in Fig. 1. As described in [2], the signal exhibits a 200 kHz modulation due to betatron oscillations decaying over 0.1 ms and a 14 kHz modulation by synchrotron oscillation. When the next laser shot occurs, a modulation is still present from the previous one, since the time between two succesive laser shots is small compared to the longitudinal damping time of 5 ms. Increasing the laser repetition rate, the background, which corresponds to ps-pulses [7] increases, because since the betatron oscillations with a decay time of 0.1 ms are not yet fully damped after 0.33 ms. Because the laser repetition rate is variable, the next laser-shot can be placed at a minimum of the synchrotron oscillation mudulation to further increasing signal-to-background. At 3 kHz the increased background can be still handled by placing apertures in the beamline accepting only the on axis radiation from the undulator. Radaiation from the remaining modulation will be mostly radiatin off-axis. At a higher repetition rate, laser interaction with more than one bunch, which requires a different fill pattern, becomes necessary.

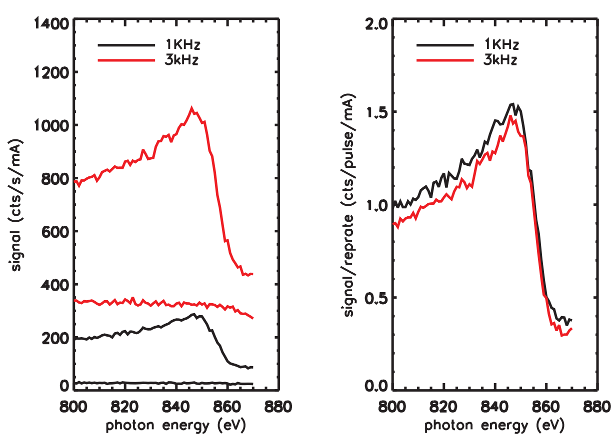

Figure 2: Left: Comparison of the undulator spectra at 1 kHz (black line) and 3 kHz (red line). The measurement was taken at the regular slicing beamline with the plane-grating monochromator tuned to 850 nm at a spectral bandwidth of 0.1% (vertical polarisation). The spectra were taken by scanning the undulator over the 3rd harmonic at 850 eV. The corresponding ps-background intensities of the sliced photons arriving 1 turn prior to the short pulse are also shown. Right: The fs x-ray spectra after subtraction of the ps-background and normalized to the repetition rate. This proving indeed the expected linear increase of the photon flux by a factor of 3.

The spectra in Fig. 2 show the photon rates detected with a 1 mm diameter Si-APD for a usual slicing setup at the beamline accepting a solid angle of 0.2x0.1 mrad^2 at 0.65 mrad off the central cone radiation of the UE56, an elliptical undulator with 56 mm period length. The sliced photons show a pronounced intensity peak when scanning the undulator over the photon energy which is preset at the beamline. This is because the sliced photons appear on-axis with respect to the beamline whereas the background photons (remaining after 300 μs) are observed only off-axis and do not show any structure. After correcting for the ps-background 15 short-pulse photons are detected per pulse at 10 mA bunch current (5 nC). Note that these photons are emitted only from the slice (and only electrons with dE/E<0) containing $< 2.5\text{x}10^7$ electrons out of $5\text{x}10^{10}$ electrons in the whole bunch.

ZONE-PLATE BEAMLINE

Another step to increase the photon flux at the experiment is the installation of a new high-transmission beamline using a reflective (Bragg-Fresnel) zone-plate instead of a conventional grating monochromator. The zone-plate beamline with only one reflection has an overall optical transmittance of approx. 6.5% compared to 0.5% of the standard slicing beamline. The zone-plate is fabricated from a gold-covered Si substrate by using a special technology including e-beam lithography, photo lithography and ion etching. The lens has three design wavelength, working at 715, 785 and 861 eV. The off-axis reflection zone-plate exhibits an energy dispersion in the focal plane of 35 eV/mm, the spot size is 300 μm (hor.) x 25 μm (ver.). With a temporal resolution of $\approx$30 fs this beamline is well suited for transmitting the fs x-ray pulses of $\approx$100 fs. Details of the zone-plate beamline will be published elsewhere.

Performance of the Zone-Plate Beamline

To demonstrate the improvements in flux from the new zone-plate beamline a two-dimensional angle scan of the photon distribution from the slice was performed. For this purpose a pinhole of 0.2 x 0.2 mm at 11 m behind the radiating undulator (UE56) was scanned over the radiation cone (Fig. 3). The distribution was measured for linear and elliptical polarisation. The remaining background from the previous slice was simultaneously determined by gating on the signal one round trip (800 ns) prior to the next slice. The data were taken in the slicing at 850 eV photon energy at a bandwidth of 4 % and 2.5 mA bunch current. Integrating the projected data (right plots in Fig. 3) indicates that $\approx 10^6$ photons arrive at the experiment within that bandwidth accepting a solid angle of 0.09 mrad^2. Further measurements show that the photon flux of the sliced photons is a factor of 15 higher than on the high-resolution PGM (plane grating monochromator) beamline, if both are operated at the same bandwidth, as expected by the fact that only 1 optical element is involved at the zone-plate beamline. The beamline now addresses experiments that require a high flux but not a good energy resolution.

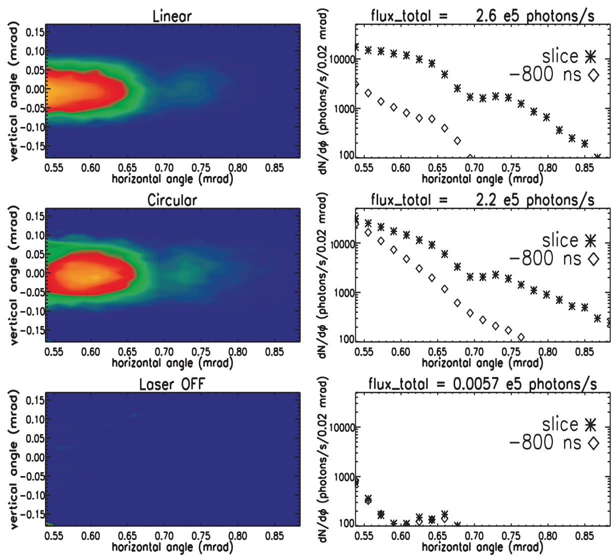

Figure 3: The left column shows the two-dimensional angular distributions of fs x-ray photons at 850 eV detected behind the zone-plate monochromator for vertical linear (top) and elliptical (center) polarization. For comparison the measurement at elliptical polarization was also made without the slicing laser (bottom). The curves shown in the right column are derived by projecting the data onto the horizontal axis (filled symbols). The picosecond background signal emitted from electrons one turn (800 ns) prior to the next sliced pulse is also shown (open symbols).

NEW LASER BEAMLINE

While operating the femtoslicing source for the last years a problem was encountered concerning the in-vacuum laser mirrors that are located in the storage ring tunnel. A decrease of reflectivity was observed, accompanied with a dark shade at the position of the laser spot. The laser power density on the mirrors were at least a factor of 3 below the nominal damage threshold. The damage was different to the one that appears under ambient conditions on the laser table. For that reason we assume this to be a combined effect of the laser beam and the vacuum. Though the effect is not understood so far, the laser beamline was newly designed for two reasons. Firstly, we wanted to have the last mirror before the modulator placed at a larger distance. With a given beam waist in the modulator the beam spot on this mirror will have a larger diameter. Prolonging the distance to the maximum possible extend will roughly double the distance therefore reducing the power density by a factor of four. Secondly since the damage mechanism is not understood, changing the mirrors should be facilitated and doeable within a few hours. Currently the mirror change requires a longer machine shutdown. The new laser beamline takes a longer path of approx. 21 m instead of 11 m previously. With the experience from the current setup we see a dramatic effect from the air turbulences along the beam path. In order to make the slicing source more stable the new laser beamline will be evacuated. The new beamline, being installed in September 2007, comprises five mirrors and two lenses all being motorized. With a camera system the beam spots on the mirror surfaces will be monitored also enabling the installation of an automated feedback system.

SUMMARY AND OUTLOOK

The upgrade of the laser repetition rate from 1 to 3 kHz triples the photon flux but slightly decreases the signal-to-background. However, when going to a higher laser repetition rate, a sophisticated fill pattern of the storage ring will become inevitable where not only one bunch will be used for slicing. With the new zone-plate beamline the number of photons per second is increased by a factor of 15 compared to the high resolution (PGM) beamline. The zone-plate beamline will be addressed for high flux and low resolution experiments. The implementation of the new laser beamline in a vacuum pipe will give higher stability of the laser electron interaction. With its mirrors being fully motorized it allows for an automated aligning and feedback control.

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