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DEVELOPMENT OF THE ELECTRON-BEAM DIAGNOSTICS FOR THE FUTURE BESSY-VSR STORAGE RING*

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Abstract

This contribution focusses on the different types of new or improved electron-beam monitors at BESSY II for bunch resolved measurements under future BESSY-VSR conditions. A new diagnostics platform, involving three different dipole beam lines will be built for different dipole-related optical and THz methods. Our main concepts for robust future monitors for bunch length, beam size and position are presented in the following.

MOTIVATION

The BESSY II electron-storage ring at the Helmholtz-Zentrum Berlin (HZB) is operated at the electron energy of 1.7 GeV at a maximum current of 300 mA. The cavity RF of the ring is about 500 MHz. Different optics modes are available and various bunch-filling patterns are distributed within 400 buckets separated by approximately 2 ns.

The upgrade of the BESSY II light source towards the **V**ariable pulse-length **S**torage-**R**ing BESSY VSR [1,2] will lead to even more complex filling patterns with co-existing electron bunches that differ significantly regarding their bunch length, bunch charge as well as transverse profile and charge density. Thus, bunch resolved diagnostics of lateral size, position and bunch length with high sensitivity, good signal-to-noise ratio and time resolution is demanded. This requires improved properties of the future beam-diagnostics hardware.

BEAM-POSITION MONITORS

Status at BESSY II:

A typical Beam-Position Monitor (**BPM**) at BESSY II is based on a set of four pick-up electrodes. A recently improved treatment of RF-signals delivered by these electrodes enables bunch resolved position determinations at a few µm uncertainties [3]. This improvement includes signal transfer (kHz switching and conditioning of analog BPM signals) and pulse analysis (using 14-Bit ADCs at an analog bandwidth exceeding 500 MHz). This scheme has proven to be very successful and robust, specifically concerning thermal drift and aging of electronic parts.

Developments for BESSY VSR:

The BPMs in use involve some internal multi-GHz pulse-reflections that lead to oscillations producing a crosstalk between neighboring pulses. A low pass filter at about 750 MHz is applied to minimize this crosstalk. For BESSY II, the crosstalk between two sequential filled buckets is limited to a few percent, which is acceptable.

However, at BESSY VSR the intensity of the subsequent bunches within each turn cycle may vary significantly. Thus, the BPM system needs to be improved further for quantitative position analysis of the future (more complex) filling pattern, specifically for the weak signals. Currently different types of low-pass filters are under investigation, in order to reduce unwanted RF oscillations produced inside some LC-type filters. The main emphasis, however, is on signal conditioning in the time domain. [4] Analog signal mixing with reflected pulses might lead to significantly improved pulse shapes and strong reduction of crosstalk effects. Preliminary tests with such a scheme (see Fig. 1) are very promising.

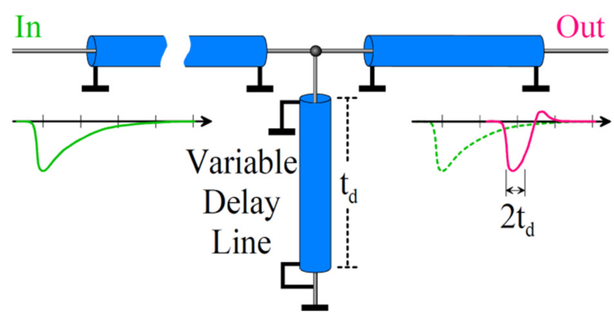

Figure 1: Passive signal-conditioning scheme in the time domain with input (green) and modified output (red) pulses. After twice the delay time t_d, the outgoing signal is influenced by pulse reflection via the delay line and finally reacts to the short-circuit [4].

BEAM-SIZE MONITORS

Status at BESSY II:

The BESSY II electron ring is equipped with two hard-X-ray pinhole cameras for determination of beam size and angular distribution (emittance)[5,6]. They are located in different segments of the storage ring (30 m apart) and consist both of arrays of 11x21 pinholes of 20 µm diameter at 6.1 m from the dipole source. Mo absorption filters (100 µm thickness) restrict the detected photons to energies around 16 keV, in order to minimize diffraction effects. The diffraction limited image resolution of the pinholes is 11 µm rms [5] and corresponds to 33 µm rms beam-size resolution (when the system demagnification of 3:1 is accounted for). A (slow) phosphorescent screen in front of a CCD camera is used for X-ray conversion into visible light.

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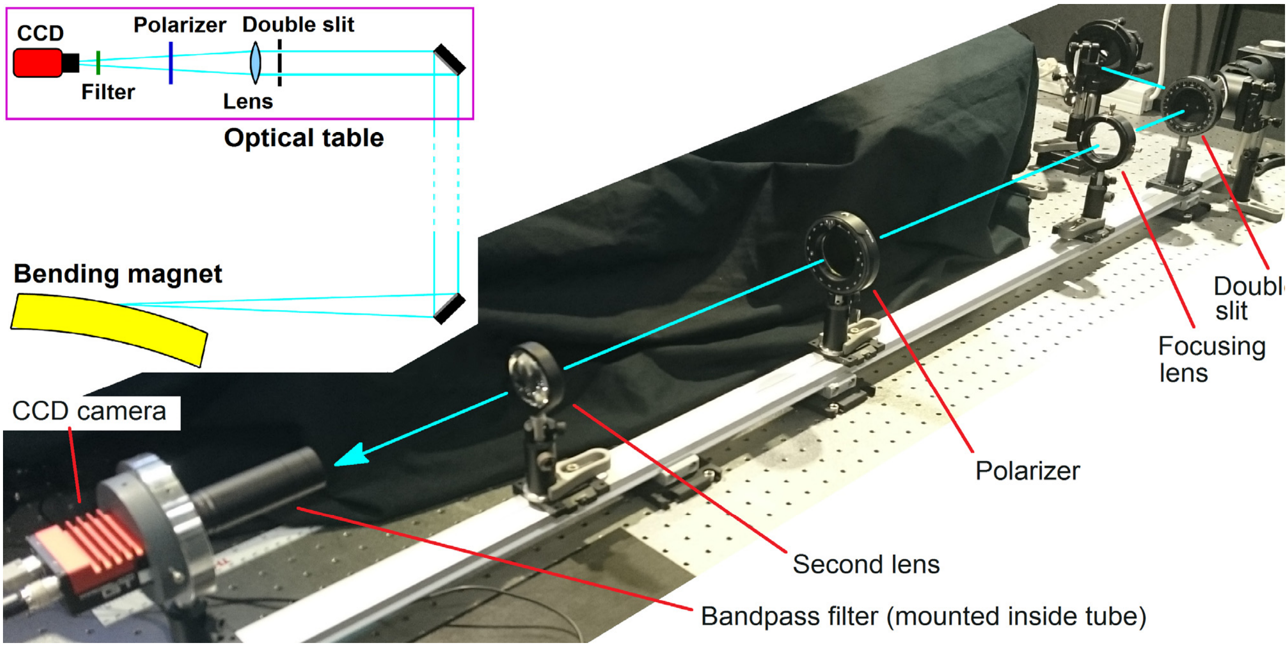

Figure 2: Scheme and photo of the optical Interferometric Beam-Size Monitor (IBSM).

Organic (crystal, plastic, liquid) as well as inorganic scintillator materials (typically crystalline) convert primary excitations into visible and UV light within 1.4 ns to 15 µs [7]. Crystalline BaF_2 involves the fastest decay component of any scintillator (~0.7 ns fall time at 220 nm) which, however, constitutes only <20% of the converted light signal. Some specific fluorescence processes (e.g., for the fluorophore CY3) are slightly faster, but not applicable to X-ray conversion. Thus, we might try to restrict the sensitivity to the fast component of BaF_2, for achieving bunch selectivity. However, a signal background of about 7% from the previous bunch cannot be avoided. Thus, this method is not applicable to the future BESSY-VSR filling conditions.

Developments for BESSY VSR:

Current avalanche-photodiode arrays are intrinsically too slow for distinction of neighboring bunches (separated by 2 ns) and they also require a scintillator for X-ray conversion. Alternatively, on may use an image intensifier with direct illumination of a microchannel plate for X-ray-to-electron conversion and amplification. A position-sensitive detector coupled to the output would allow for an acceptable time resolution, but only at very low event rates. In principle, one may also use a gated image intensifier for achieving a sub-ns time resolution, in combination with a phosphorescent screen and a CCD camera. This method sounds feasible, but it requires optical in-vacuum installations that are not easily serviced.

Thus, we have focused on another development for beam-size diagnostics that relies on interferometry instead of geometrical optics. The optical Interferometric Beam-Size Monitor (**IBSM**) has been worked out by T. Mitsuhashi [8]. We have successfully developed and tested such a system also at BESSY II [9,10]. As shown in Fig. 2, it consists of a double-slit for diffraction at a distance of about 15 m to the source point in the dipole. Visible light is guided by plane mirrors to this point. The emerging interference pattern is focused on a CCD camera, after a band-pass and a polarization filter. In this way, a point like photon source in the dipole yields a pronounced interference pattern in the camera. Any extension of the source distribution will give rise to a blurring of the measured interference pattern. Quantitative analyses of such patterns yield the source sizes σ_x and σ_y, in good agreement with our two pinhole cameras. Without any optimization for low σ, the current experimental IBSM resolution is about 25 µm rms [10], slightly better than the pinhole cameras.

Further improvements of the new IBSM will be necessary before it will be fully integrated into the standard hardware suite for BESSY II and prepared for BESSY VSR. Wave-front errors will be reduced by using a hard X-ray blocker in a new dipole beam line. Furthermore, the system will be mounted in a new hutch for dust protection and also vibrations due to ground motion will be reduced. Finally, an intensified CCD camera with high-speed gating will be installed for bunch resolved beam-size measurements.

BUNCH-LENGTH MONITORS

Status at BESSY II:

Properties and challenges of the production and use of different BESSY-II timing patterns and bunch lengths have recently been presented [11]. Bunch length, phase and intensity are currently measured with a Hamamatsu C5860 streak camera at an rms time resolution of ~2 ps. Laser-trigger scans at the fs-slicing facility enable bunch-profile determinations (using either the induced THz signal or a material with a fast pump/probe reaction) at precisions ~300 fs [12-13]. This provides a valuable option for checking time-structure determinations.

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Developments for BESSY VSR:

A new Fast Streak Camera (**FSC** type C10910-05 by Hamamatsu) with a synchro-scan repetition rate of up to 1 kHz was delivered for BESSY VSR. This FSC has recently been tested with pump-laser pulses at the BESSY slicing facility. Fig. 3 shows the sum over about 4000 laser shots (after removing slow drifts related to the laser frequency-stabilization system). The projected red curve shows a sharp peak in the vertical streaking direction, corresponding to a width of 7.4 pixels FWHM. Accounting for the remaining jitter due to laser and trigger-timing effects, we derive an FSC resolution of (0.88±0.18) ps FWHM (σ ~0.37 ps rms), consistent with the factory specification.

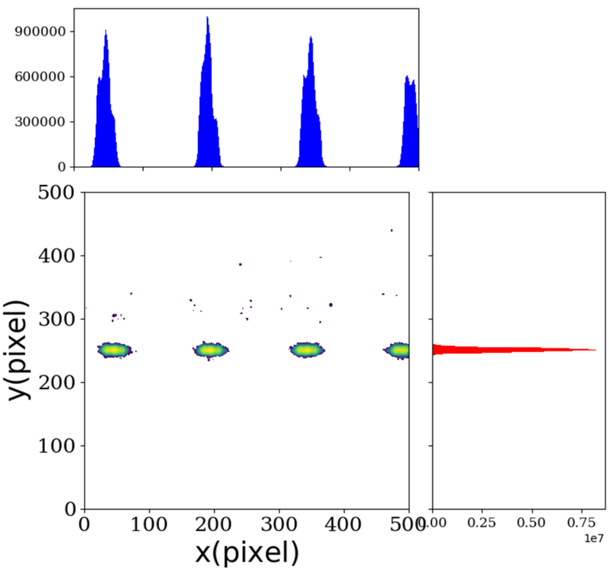

Figure 3: Streak-camera measurement series displayed in a scatter plot and the corresponding two projections. Drift-corrected sum over 1000 single scans with 4 visible laser shots each, at a separation of 24 ns in the x direction. The fast streaking appears in the vertical (y) direction.

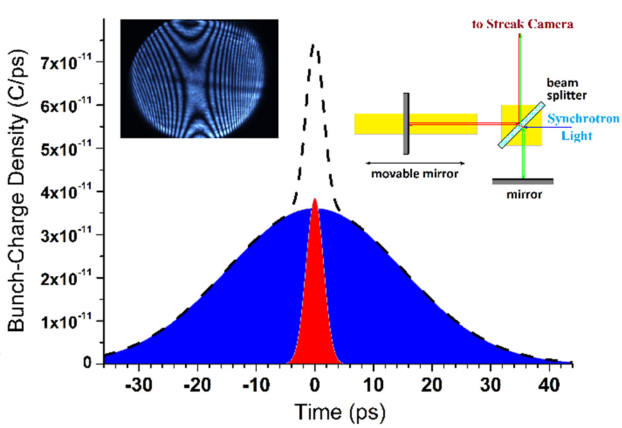

Figure 4: Projected FSC distribution (bottom) estimated for BESSY-VSR conditions using a delay stage (upper right corner). The upper left corner shows the linear interference pattern measured behind the delay stage for time-zero overlap of both light paths.

The FSC involves a vertical scanning frequency of 125 MHz synchronized to the 500-MHz ring RF (divided by 4). This means, however, only every second bunch can by visualized (either odd or even bunch positions of the filling pattern). Fig. 4 indicates a way to circumvent this condition, by using a delay stage for achieving an overlap in time between odd and even bunches. As can be seen, it is possible to distinguish the long high-charge multi-bunches from the neighboring weak ones (accounting for the bunch characteristics and FSC time resolution) even at maximum pulse overlap. Time zero is determined from a CCD-camera picture behind the Michelson delay stage. A very small coherence length can be chosen (~10 μm rms in Fig. 4) corresponding to fs accuracy. This principle has already been tested with the slower streak camera at BESSY II and it works perfectly.

Currently, we are investigating additional methods for the bunch-lengths determination that are appropriate for the quantitative investigation of short bunches. [14] The current filling-pattern monitor should also be working for BESSY VSR. Nevertheless, a possible application of fast photo diodes for a more rapid data acquisition of the pattern is also on the agenda.

CONCLUSION

Many current activities are running in parallel for improving the electron-beam diagnostics at BESSY II in order to reach robust bunch-selective monitoring of beam-position, beam size and timing for the BESSY-VSR project. Already now we have solutions for bunch-length and beam-size determination that have passed many tests successfully. Other methods are still in the evaluation phase.

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