PSEUDO SINGLE BUNCH QUALITIES ADDED TO SHORT PULSE OPERATION OF BESSY II*

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Abstract

BESSY II features sophisticated filling patterns as well as manipulation and separation techniques of custom bunches to serve both timing and photon hungry experiments at the same time [1]. Recently, the low-α operation mode [2], providing bunch lengths as short as 2 ps, was extended by pseudo single bunch options. A robust technique to excite one bunch with constant displacement and enlargement was implemented for pulse picking by resonant excitation (PPRE) [3] users. In addition, reliable scraping of an isolated bunch to provide zero current bunch length is opening new timing opportunities. The simultaneous usage of different photon characteristics: high intensity THz coherent synchrotron radiation (CSR), non-bursting CSR, short duration as well as operation mode specific X-rays impose new challenges. Sensitive tune measurements and feedback mechanisms had to be developed for all three dimensions. Negative alpha is in consideration to overcome the TopUp efficiency constraints.

OVERVIEW

Capabilities of synchrotron radiation light sources for timing experiments are limited by available pulse duration and repetition rates. Fixed properties of the storage ring, like RF frequency and accelerator circumference, can only be combined with operational parameters, like tweaking optics details, filling pattern and longitudinal focusing.

BESSY II like most SR facilities attempts to combine the quasi continuous high brilliance photon flux of even MB fillings with the timing options of the bunched beam into a hybrid mode. In recent years sophisticated filling patterns as well as custom manipulation of isolated bunches have been developed at BESSY [1]. These tailored configurations allow for photon pulse separation techniques enabling a new class of time resolved experiments along with the underlying MB majority user mode.

The tuning of the BESSY II optics to the nearly isochronous case at very low momentum compaction (low-α mode) has been originally invented to turn the facility into a stable, low current, non-bursting coherent synchrotron radiation (CSR) THz source [2] at the expense of only parasitic usability for X-ray experiments. In the mean time understanding of the characteristics of this optics w.r.t. a broad range of bunch charges has matured enabling a growing user group to take advantage of the low-α mode at intermediate currents. In addition new bunch manipulation techniques have become applicable in this mode too. Today the BESSY II low-α mode is unique and attractive for both high intensity THz users and short pulse X-ray timing experiments.

TIME TUNING RANGES

At the light source BESSY II pulse durations in standard user mode range from 35 ps (13 mA SB), 15 ps (300 mA MB) to the zero current limit of 10 ps, RMS. Within the limits of bunch charges the effective bunch length can be tweaked by the longitudinal focusing, adjustable via 4 HOM damped 500 MHz fundamental cavities and 4 passive 3^{rd} harmonic copper cavities. Changing the optic to low-α mode features 5 ps to 3 ps pulses (100 mA to 5 mA) and a zero current limit of 2 ps, RMS.

Within the BESSY VSR project [4] novel 20 MV/m SRF cavities will be added to the SR that promise a 100 fold increased longitudinal focusing allowing to vary the bunch length by factors. Then a proper combination of focusing, standard and low-α optics, as well as optimized fill patterns will allow for pulse durations spanning more than an order of magnitude.

BUNCH SEPARATION, PULSE PICKING

Available temporal separations of BESSY II light pulses are limited to 2 ns (500 MHz RF bucket separation, MB fill), 800 ns (full 240 m circumference, SB fill) and possible fractions and multiples. The twin orbit mode [5] presently developed at BESSY might add new options.

Deviating timing requirements of many pump-probe experiments can be additionally fulfilled by isolated bunches within custom, purity controlled dark gaps. Usually the "camshaft" bunch in the middle of the common ion clearing gap (5 ns to 120 ns) is adequate. Isolation of these pulses is either done by electronic gating, mechanical chopping or X-ray deflection.

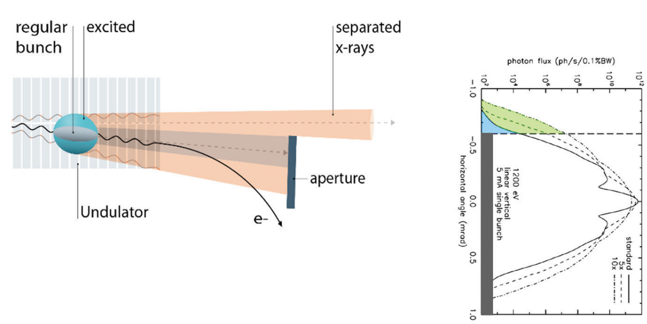

Figure 1: Separation of the MB core from the extended PPRE bunch in the horizontal wings of the undulator cone [3].

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BESSY II features two methods allowing transversal pulse separation too: (A) the energetically modified fraction of bunches copropagating with a strong laser pulse in a modulator undulator is horizontally separated in the following dipole (slicing [6]). (B) bunches are horizontally blow up by excitation close to the tune resonance. Undulator radiation from these enlarged bunches bypasses the core beam (pulse picking by resonant excitation, PPRE [3]).

Pseudo SB generated with the PPRE technique can be simultaneously used in three BESSY II undulator straights, sliced bunches at one of them. Though based on different principles transversal pulse picking is accessible in the horizontal wings of the undulator cones. Proper bump and slit settings allow for the horizontal photon separation (for the principle see Fig. 1) within the aperture of the beamline. To minimize mutual perturbation the PPRE bunch (3 mA, 1.25 MHz repetition rate) is positioned near the end of the dark gap, opposite to the 3 slicing bunches (4 mA, 6 kHz reception rate, 400 ns apart).

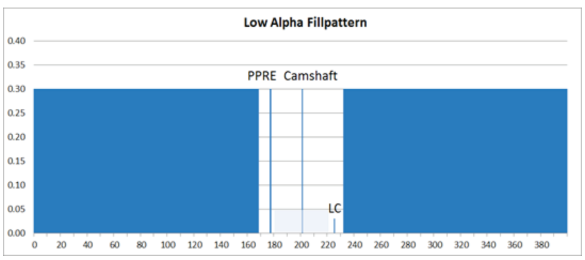

Figure 2: Low-α fill pattern: the short, low current bunch (LC) is positioned at the end of the dark gap to allow pulse separation.

LOW ALPHA SPECIFICS

The low-α mode implies some operational restrictions. The THz user community requires a very even fill pattern to prevent irregular bursting. This is provided by a specific scraping procedure. The α-buckets [7] are shrinked by quadrupole changes such that excess charges are specifically lost. For the X-ray users the resulting overall beam stability is an asset. On the other hand slicing and PPRE cannot benefit from higher bunch charges available in standard mode.

Positive experiences at the metrology light source (MLS) in negative low-α mode w.r.t. THz stability are inspiring and the request of TopUp capability advise to develop and establish this mode at BESSY II too. Unfortunately the less flexible equipped lattice of BESSY II and demands from the established THz users require careful preparations.

As a more serious left over from the initial emphasis on THz radiation the ID compensation scheme active in low-α mode deviates from the standard optics approach. The figure of merit in standard user optics are feed forward tables minimizing gap and shift dependent kick and focusing. Commissioning activities in low-α mode have been aiming for small orbit perturbation and fixed synchrotron tune to guarantee constant non-bursting THz spectra at a few permille level. Today stability of the PPRE pulses is required too. This is very sensitive on a fixed horizontal tune not addressed so far.

In low-α weeks three 8 h operational blocks offer both high current mode, decaying from initial 100 mA, and for the remaining time, non-bursting, steady CSR THz blocks on demand. For the latter mode beam is scraped to <15 mA.

The shortest possible bunch in low-α mode, close to the zero current limit is provided as low current (LC) bunch all day. For technical reasons the PPRE excited and the LC bunch are positioned close to the edges of the dark gap (see Fig. 2).

Exact bunch charge of the LC bunch is generated by the BBFB driving the bunch to amplitudes close to the aperture limits (see next chapter). Precise charge control is enabled by increased sensitivity/integration time of monitoring stripline and photon counting diode.

DIAGNOSTICS & FEEDBACK

The digital bunch-by-bunch feedback (BBFB) system, in operation at BESSY II since 2013 [8], plays an important role in the diagnostics and the manipulation of beam properties of individual bunches.

PPRE Characterisations

The basic concept of PPRE relies on the nearly resonant excitation of a single electron bunch with a fast strip-line kicker and a frequency close to the synchrotron side band of the horizontal tune. Amplitude and frequency are optimised to provide best performance w.r.t. separation of MB and pseudo SB at the experiment. The coherent excitation resulting dipole motion can be observed using the BBFB system, but is only partially usable. The incoherent excitation leading to the desired increased bunch size is not directly observable during user operation. The incoherent excitation is sensitive to non-linear effects like chromaticity and amplitude dependent tune shift. Therefore response and usability at the experiment is frequently mapped by frequency scans, an example is given in Fig. 3.

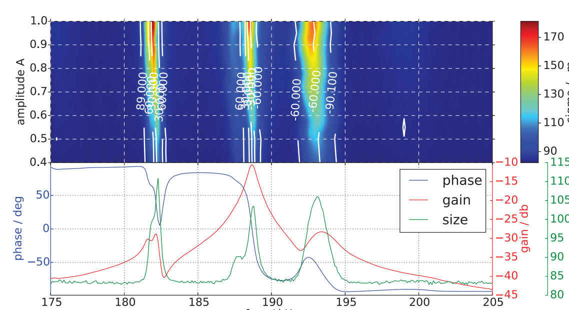

Figure 3: Frequency scan of the PPRE parameters w.r.t. optimised incoherent excitation for best MB suppression at the experiment.

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Robust Excitation

In standard operation it is usually sufficient to keep the horizontal tune constant in order to provide a robust PPRE signal. This is achieved by a combination of tune feed-forward based on the ID gap and shift settings, and a tune drift control program compensating residual tune shifts. In addition a chromaticity measurement and its readjustment are routinely performed during preparation of the machine for the next user block.

A reliable operation of PPRE in low-α mode is more intricate, since the synchrotron side bands are then very close to the main tune resonance. On the other hand due to the small momentum compaction factor the small energy shift induced by the excitation results in a visible displacement of the PPRE bunch relative to the main orbit. This can be easily resolved by the bunch-resolved orbit measurement system and can amount to as much as 400 µm [9]. This displacement together with the observed dipole motion is used in a feedback loop to control the excitation amplitude. The excitation frequency is tracked by observing the phase of the dipole motion. The combination of both loops results in stable PPRE operation with respect to most ID movements.

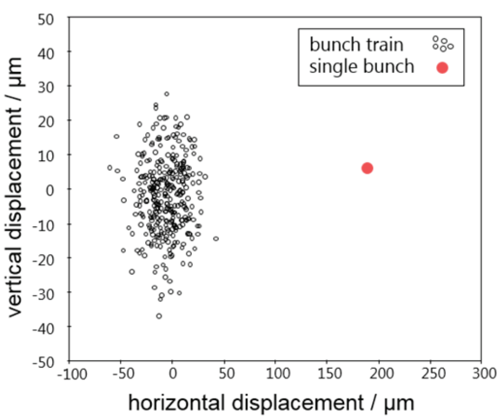

Figure 4: Measured orbit separation of the PPRE excited bunch in low-α mode [9].

The PPRE orbit separation (see Fig. 4) is expected to be sufficient to make the PPRE pseudo SB available at dipole beamlines equipped with an imaging system focusing through a tiny slit, even without a separating orbit manipulation. Preliminary attempts have not been successful yet. Proper control of the lifetime of the PPRE bunch is the remaining challenge, especially since a lost bunch can only be refilled every 8 hours.

Bunch Charge Manipulation

Bunch charge of the low current (LC) bunch, providing the shortes possible X-ray pulses, is adjusted by exploiting the bunch-cleaning capabilities of the BBFB system. After the initial population of the LC bunch with 100 µA to 150 µA the current is reduced to a current <10 µA in an automated scraping procedure (see Fig. 5) that reliably stops within a few % of the charge dialed in.

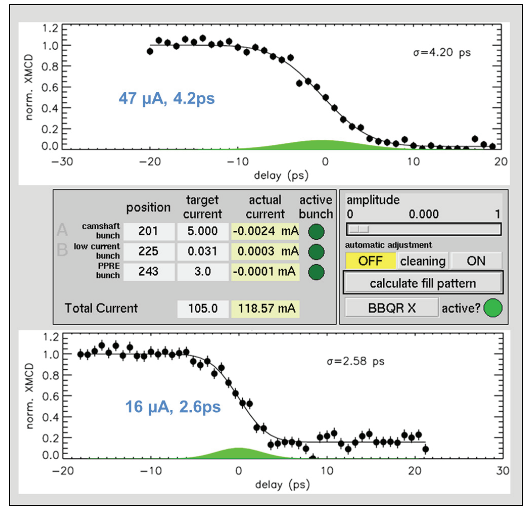

Figure 5: Dialing in bunchlength of 4.2 ps and 2.6 ps by filling the LC bunch with 47 µA and 16 µA resp. The bunch length has been verified with XMCD pump probe measurements, X-ray slicing at the L-edge of a FeGd sample at σ=65 fs precision [10].

Tune Measurements

The phase locking technique can also be exploited to provide a reliable measurement of the synchrotron tune. Therefore a very small longitudinal excitation on a selected bunch of the MB train is introduced. The phase tracking algorithm is already implemented in the digital bunch-by-bunch feedback system [8]. This measurement shows very stable results, and is independent of the beam current.

An extension to a similar tune measurement in all 3 dimension is under investigation.

SUMMARY

Key to the enhanced usability of BESSY II low-α mode for timing experiments with special requirements is a combination of stable, smooth and high intensity THz radiation, where the dark gap can serve as the trigger for the experimental data aquisition and short X-ray pulses in the range of few ps covering the full set of wavelength and polarisation properties available at the facility. The pulse shaping becoming feasible by the BESSY VSR project [4] promise to open another new branch of synchrotron based timing experiments.

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