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INJECTION AND BUNCH LENGTH STUDIES AT THE BESSY II STORAGE RING

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Abstract

To improve the injection process into the BESSY II storage ring and allow for high injection efficiencies in all operational modes, one needs to know the development of the bunch length during acceleration in the booster synchrotron up to the extraction point. It will become even more important for the future BESSY VSR upgrade, when high efficiency injection into much shorter RF buckets needs to be guaranteed.

Measurements of bunch phase and energy during injection in the storage ring are presented. Studies of the bunch length evolution during the energy ramp of the booster synchrotron are described. Results are compared with numerical simulations and discussed.

INTRODUCTION

To provide new possibilities for time resolved experiments at the synchrotron light source BESSY II an innovative upgrade scheme to store both long and short bunches simultaneously in the storage ring is under realisation: the Variable pulse length Storage Ring BESSY VSR [1].

The most prominent aspect with respect to the injector is the evidence, that the bunch length on injection into the storage ring needs to be reduced from its present value, by at least a factor two in order to keep the by radiation protection required high injection efficiencies of above 90 % on an 4 h average. The problem arises from the large difference in the bunch lengths on injection and the reduced longitudinal bucket length (phase acceptance) due to the proposed VSR [2] technique as depicted in Figure 1.

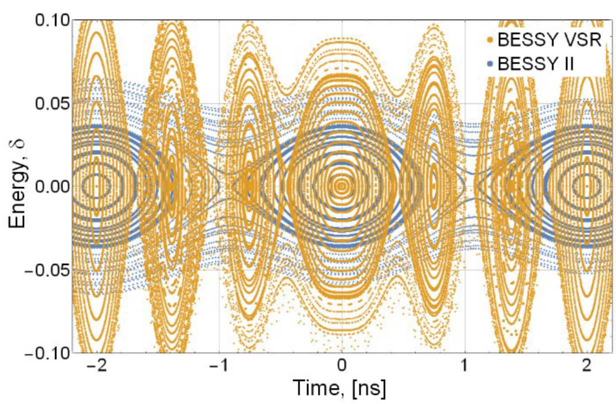

Figure 1: Longitudinal phase space comparison between BESSY II (blue) and the alternating bucket length scheme of BESSY VSR (yellow).

Presently the bunch length of the injected beam on injection into the storage ring is approximately 60 ps FWHM. Such bunch lengths will unfortunately not allow the required high efficient injection into the short BESSY VSR buckets. An upgrade of the injection systems to produce shorter bunches is foreseen.

Today there is no diagnostics at the BESSY II booster synchrotron to directly measure the bunch length during the energy ramp. One possible solution is to extract the beam during the ramp of the booster and to measure the bunch length just after injection into the storage ring. This can be achieved by reducing the energy of the storage ring, as well as the transfer line, and extracting the bunch earlier or later from the booster (with respect to a nominal energy). Then, a synchrotron light from a storage ring dipole magnet is used to get a bunch length with a dual-sweep synchroscan streak camera.

BUNCH LENGTH EVOLUTION

Figure 2 shows the evolution of the bunch length, the bunch energy and cavity voltage from elegant [3] simulations during the acceleration stage of the 10 Hz booster cycle.

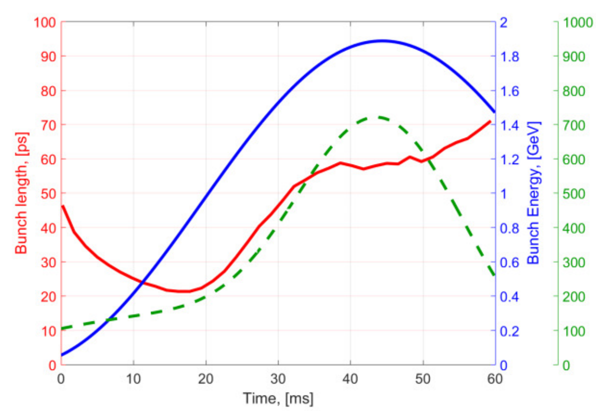

Figure 2: Simulation of the bunch length as a function of time over the 10 Hz booster cycle, the red curve, and the bunch energy, the blue curve and the cavity voltage the green dashed curve.

The beam energy is increased from 50 MeV on injection to 1.7 GeV at 35 ms on extraction. The simulation starts with parameters of the injected beam as measured during the site acceptance tests of the injector LINAC. The peak voltage in the cavity is set to 720 kV, the nominal values for booster operation. The voltage pedestal is none zero, so that the phase and with it the synchrotron frequency are also time dependent to match recent measurements in the booster.

The variation of the bunch length over the booster ramp is due to its inherent energy dependent parameters. The dy-

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namic nature of the energy spread is an equilibrium between longitudinal damping and quantum excitation which dominate at low and high energies respectively [4].

For VSR the two most common ways to produce a shorter bunch are under investigation. Like the proposal for the storage ring, an upgrade of the RF gradient in the cavity or new optic to reduce the momentum compaction could be also implemented in the booster. The present optic in the booster is based on a simple FODO lattice with a 16-fold symmetry. The momentum compaction and hence optic to produce shorter bunch lengths is heavily restricted. Installing independent quadrupole power supplies and breaking the symmetry allows more tunable optic towards low alpha [5]. Similar simulations, as shown in Fig. 2, which include low-alpha optic, have shown good promise and will be a valid option for BESSY VSR [1].

MEASUREMENT PROCEDURE

All the measurements were conducted by using a dual-sweep synchroscan streak camera which uses the synchrotron light from a BESSY II storage ring dipole magnet. The streak camera was synchronised in such a way that acquisition starts a bit earlier than the bunch injection in the main ring and the data are recorded for about 500 µs, (~625 bunch turns in the storage ring).

The typical image from the streak camera is shown in Fig. 3 (a). The vertical axis is the fast sweep of the streak camera (the shown vertical range is about 400 ps) and the horizontal one is the slow sweep (the shown horizontal range is about 400 µs). To further analyse the data, the image was cut into horizontal slices and for each slice the mean vertical position and the vertical RMS size were calculated. Fig. 3 (b) and (c) show the calculated bunch mean position and the bunch length as a function of the turn number. The blue curves show the calculated values and the red curves are the sinusoidal fit (for the bunch length data the squared bunch length was fitted by a sinus).

Ramping the Energy of the Storage Ring

To measure bunch properties of the BESSY II booster at different energies, the bunch needs to be injected into the main storage ring. For such measurements all the magnetic elements of the ring and the transfer line must be ramped down proportionally. This includes the following steps:

- turn off all nonlinear magnetic elements,
- ramp down linearly the current of the linear magnetic elements proportionally to the desired energy (dipoles, quadrupoles, sextupoles, steerers, extraction and injection kickers),
- fine adjustment based on the tune measurements (not needed for the bunch characterization but for possible BESSY II operation at lower energy).

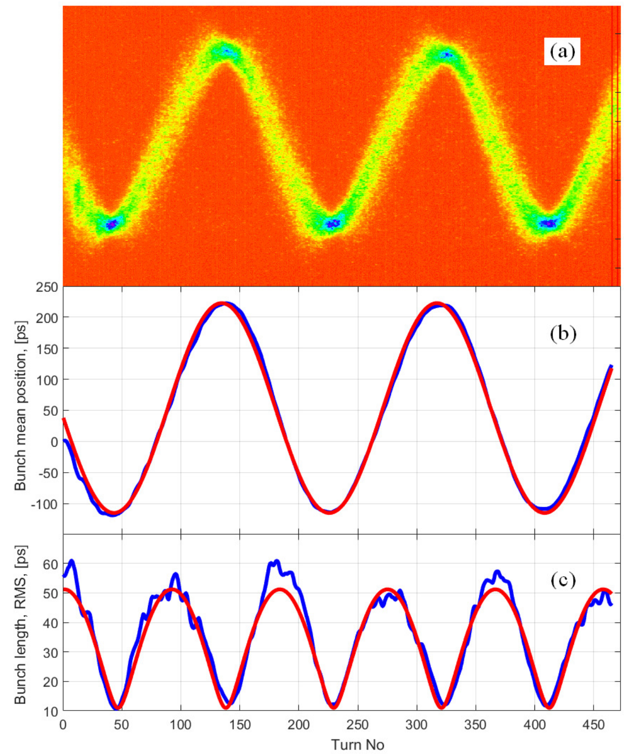

Figure 3: Result of 1700 MeV measurement: (a) is the streak camera image, (b) is the bunch mean position and (c) is the bunch RMS length. The blue curves are calculated values and the red curves are sinusoidal fits to the data.

MEASUREMENT RESULTS

The measurement results for the 1700 MeV beam energy are shown in Fig. 3. Extracting the phase and amplitude information from the fitted curve to the Fig. 3(b) the energy offset can be estimated using the equation of small synchrotron oscillation amplitudes [6]:

$$\delta = \frac{\Delta E}{E} = \frac{2\pi f_s}{\alpha} \cdot \Delta t, \tag{1}$$

where E is the reference particle energy, f_s is the synchrotron frequency, α is the momentum compaction factor and t is the time amplitude of oscillation. For the measured time amplitude of 170 ps, Fig. 3(b), for E = 1700 MeV, for f_s = 6.8 kHz and for $\alpha = 7.3\cdot10^{-4}$ the amplitude of the energy oscillation will be ΔE = 17 MeV.

Increasing the energy of the injected bunch to 1717 MeV will compensate the energy offset and decrease the synchrotron oscillation amplitude, which can be seen in the measurement results in Fig. 4. The time amplitude of oscillations is only 16 ps, Fig. 4 (b), which corresponds to an energy oscillation of 1.6 MeV, Eq. (1). This oscillations can be further decreased by adjusting the injection phase delay (delay between the booster and the storage ring) by 16 ps.

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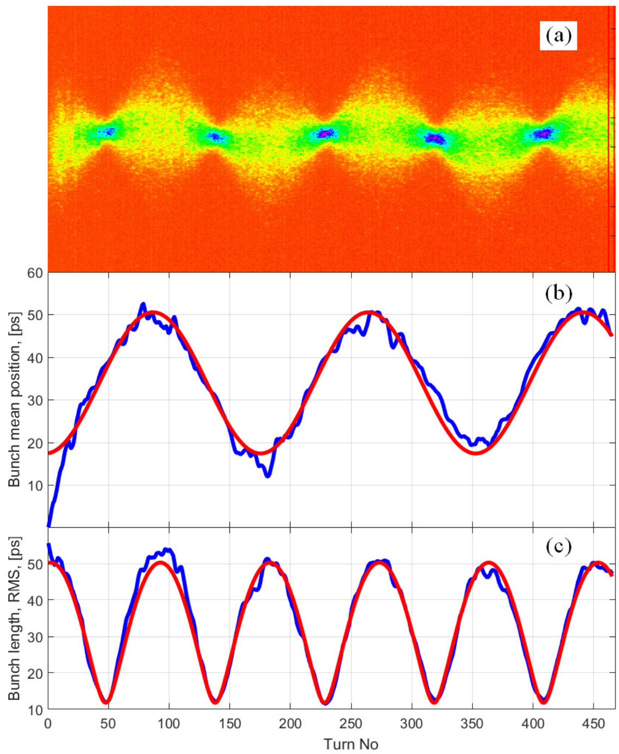

Figure 4: Result of 1717 MeV measurement: (a) is the streak camera image, (b) is the bunch mean position and (c) is the bunch RMS length. The blue curves are calculated values and the red curves are sinusoidal fits to the data.

The energy spread of the bunch injected in the main ring can be calculated as well using Eq.1 and the minimum measured bunch length during the synchrotron oscillations, Fig. 3 (c) or Fig. 4 (c). For 10 ps bunch length one can estimate the energy spread of the bunch as 1 MeV ($\delta = 6 \cdot 10^{-4}$).

The results of bunch length measurements as a function of the bunch energy in the booster are shown in Fig. 5 with blue dots. The expected bunch length from the numerical simulation with elegant is shown with red curve.

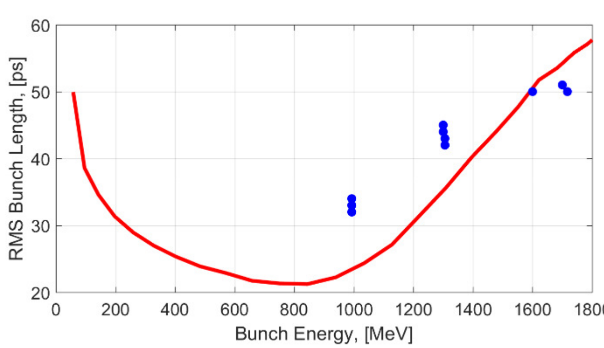

Figure 5: Bunch length as a function of the extracted bunch energy. The red curve is the simulation and the blue dots are measurements.

For the bunch energy of 1700, 1300 and 1000 MeV there were several measurements of the bunch length with a small deviation of energy or phase to find an optimum. The observed discrepancy with the numerical simulation need to be further studied and, moreover, more data points at different energies are needed to be measured.

CONCLUSION

Bunch properties at the BESSY II booster synchrotron can be measured by the storage ring diagnostics during the first turns. Ramping down the energy of the storage ring as well as the transfer line allows the bunch properties characterization during the energy ramp of the booster.

Presented technique can be used for the bunch length measurement at the BESSY II booster, until other diagnostics become available there. Measuring the synchrotron oscillation just after injection, the injection phase and energy can be reconstructed and optimized to decrease the oscillation amplitude and possible decrease particle loses during injection.

As an alternative for the bunch length measurement at the booster the optical dissector, as described in [7], can be used. This is a diagnostic device similar but simpler than a streak camera and can be routinely used in the accelerator tunnel. It provides sufficient temporal resolution for the expected bunch lengths in the booster.

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