ORBIT STABILITY IN THE 'LOW ALPHA' OPTICS OF THE BESSY LIGHT SOURCE*

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Abstract

Running the storage ring based light source during dedicated shifts in the so-called 'low alpha' mode, BESSY serves two user groups: THz experiments take advantage of intense, coherent synchrotron radiation generated by the short bunches. Time resolved experiments appreciate the very short, high intensity VUV and X-ray pulses in the ps range. With decreasing momentum compaction factor alpha the sensitivity of the storage ring with respect to energy and horizontal orbit deviation is substantially increased while the user experiments require the same beam stability as in 'normal' mode. In this paper an overview of the operational conditions of this specific user mode, the stabilization measures taken, observations and available diagnostic results as well as the achievements and shortcomings of the adapted slow orbit feedback are given.

INTRODUCTION

BESSY operates a high brilliance VUV to soft X-ray synchrotron light source. Today 7 helical and 5 planar permanent magnet undulator structures outside the vacuum chamber with gaps closing down to 11mm occupy 10 out of 16 straight sections. Strong superconducting (SC) wavelength shifters (WLS) and a 17 pole wiggler (MPW) with fields up to 7 T are installed in 4 sections.

The typical user service mode consists of three full energy injections per day, where 350 out of 400 buckets accumulate 250 mA at 1.7 GeV (multi-bunch, MB). One of the 50 buckets in the ion clearing gap is filled with more than 5 mA [1]. For data taking 8 h of decaying beam is available at 28 insertion device and 20 bending magnet beamlines. Specific operation modes are offered during dedicated beamtime periods: single bunch (SB) for time resolved experiments, optics with small momentum compaction factor ('low-α' mode) for ps-pulses and coherent synchrotron radiation [2], low current (pA) and (very rarely) low energy (0.9 GeV) for metrology purposes. In one sector a 1 mrad beam separation bump serving the femtoslicing experiments is introduced or removed on demand during the beam delivery interruption at injection time.

The low-α mode of operation has been provided to the users for the first time during a dedicated week in November 2003. Primarily the stable and intense THz radiation emitted by the compressed bunches has been offered for experimental usage. But very early the short pulses also attracted the community of time resolved synchrotron radiation (SR) experiments: despite the delicate operation mode of the storage ring and in contrast to the THz experiments short pulse SR experiments need full control of insertion device gaps and at the same time the same position and pointing accuracy of the electron beam orbit as in normal mode. Up to now there have been four dedicated weeks of low-α operation since it's introduction and interest and proportion of beam conditions for short pulse physics have been increasing.

OPERATION SPECIFICS: SET-UP, PROCEDURES

To be able to run the storage ring in low-α mode for user experiments operational experience for two phases is needed: (1) the initial stage of setting up and fine tune the storage ring to conditions that allow to offer stable low-α beam characteristics and (2) the beam delivery stage where adaptive or corrective actions should have only minimal perturbing effect on the experimental conditions.

The initial set-up is an iterative and largely empiric procedure: Taking the dipole mode of the synchrotron frequency $f_s \sim \sqrt{|\alpha|}$ as hallmark the starting point for a reduction of α is a well settled configuration at $f_s = 7.2$kHz, the same value as in normal user optics. Magnets are cycled to the established set points of this initial low-α optics. There all base properties have to be re-installed: figures of merit are transverse tunes, reasonable injection rates, flattened orbit, even fill pattern etc. Then the quadrupole settings for the user mode value of $f_s \sim 1.75$kHz are loaded and from the resulting situation (that is at best near the desired user conditions) a way back to a well defined situation is searched. In the limit of zero bunch current the bunchlength scales to f_s: 13ps at 7.2kHz and 3ps at 1.75kHz[2].

Crucial for the final set-up is the proper RF-frequency: the minimal digitally controllable change of the RF frequency (1 Hz) is unusable for continous orbit and path length correction. Minimal modifications of the RF-frequency result in significant coupled changes of f_s, energy and orbit. The optimal point of origin for the RF-frequency of a low-α week is empirically found by running the orbit correction (without RF-frequency) and using the RF-frequency to center the beam (i.e. minimize the average value of horizontal BPM readings).

When insertion devices are operated they have to be as 'transparent' as possible over the whole tuning range to minimize perturbations during wavelength scans. Generally gap (and shift) dependent tune and beta beat correction is accomplished by appropriate current offsets applied to the ring main quadrupoles [3]. In normal mode the aim of

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the feed-forward scheme is the optimization of beam lifetime. For low-α optics a specific set of tables has been experimentally determined for the f_s = 1.75kHz adjustment. It is applied only to a quadrupole sub-set to get sufficient resolution. The most sensitive figure of merit is a constant and intense THz signal.

Orbit Correction

Global orbit correction becomes mandatory as soon as position and pointing stability of the SR source matters: Residual or transient perturbations not only from the insertion devices as well as drifts have to be corrected. If not properly compensated the enhanced sensitivity of the low-α optics in the horizontal plane would result in large displacements due to ambient temperature changes or thermal effects of the decaying beam.

The orbit correction system at BESSY has been running robust and reliably with nearly unmodified base parameters over the past 6 years: 109 BPMs, 64 vertical, 48 horizontal correctors and the RF frequency are used for automatic correction running at 0.2Hz. In the vertical plane a SVD cut off parameter is chosen where about half the number of eigenvectors is used for correction. In the horizontal plane full matrix inversion is necessary due to the small number of correctors[4].

Sensitivity Matrix

Usually most of the orbit control tasks are solved with model based procedures. Under ‘pathological’ conditions (low-α modes, optics distorted by the MPW at 7T) the orbit correction switches to measured sensitivity matrices.

In low-α mode the model based orbit correction converges between $f_s \sim$ 7kHz and $f_s \sim$ 5kHz. For the experimental determination of a sensitivity matrix there is only a small α window: User mode quality sensitivity matrices have been measured for f_s = 3.5kHz and 1.7kHz. Reasonable data exist for 700Hz and 350Hz and hints on the scaling exist for 300Hz. For $f_s <$ 1kHz tiny fluctuations result in big orbit jumps (see Fig. 2) that obscure any data taking procedure. Attempts to set up a smoother and less noisy orbit correction for $f_s \sim$ 700 and 350 Hz by going to smaller corrector subsets have been unsuccessful so far.

Insertion Device Kick Compensations

Gap and shift dependent kicks are compensated with built-in dipole correctors. Corrections interpolated from 2-dimensional tables are applied at a 10 Hz rate.

Set points for the correction tables are determined in a semi-automated procedure: the SR is put into a ‘stable’ state (possible perturbation sources blocked, thermal equilibrium, small currents, etc.). For the low-α mode ‘stable’ means a relaxed f_s = 3.5kHz. The sensitivity matrix of the dipole correctors of the ID to be compensated is measured. With this 2x2 matrix the automatic orbit correction runs while the gap is closed (or shift is changed). The applied compensating currents are recorded, converted to the feed-forward table format, downloaded to the insertion devices and also valid for f_s =1.75kHz.

For reasons of commissioning time and SR stability only planar devices (or elliptical devices in planar mode) have been compensated in low-α mode. For shift changes the settings valid for normal mode operation are applied and changing speed has been limited to 0.2 mm/s (normal mode: 1.5 mm/s) to allow the orbit correction to catch up and compensate the residuals.

ESTABLISHED ACHIEVEMENTS, LIMITATIONS

Low-α optics have 10–200x increased horizontal orbit sensitivities. In this mode the RF-frequency cannot be used for path length corrections during beam delivery with the existing orbit correction set-up at BESSY.

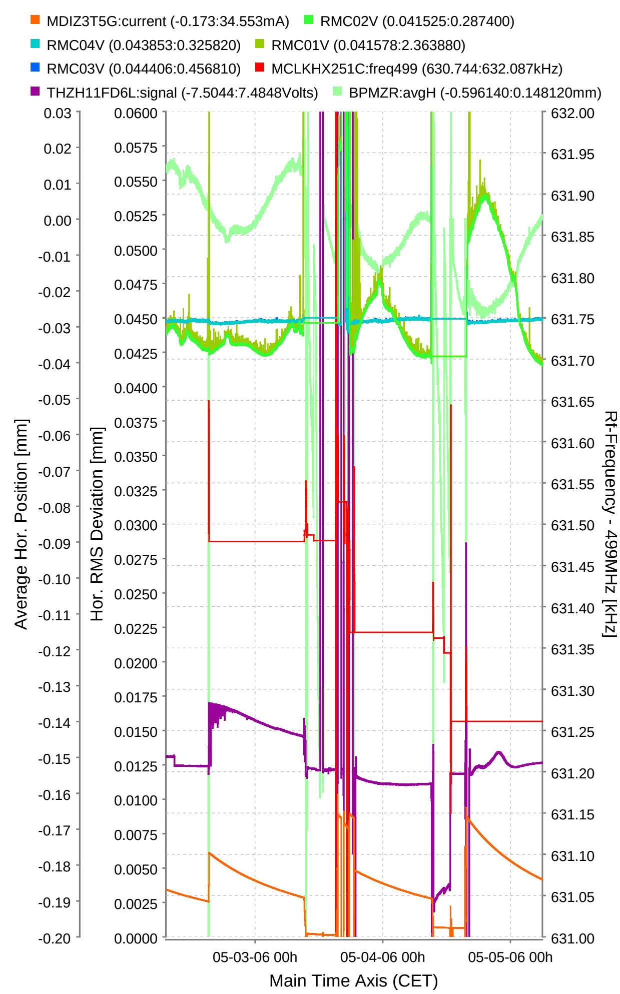

Figure 1: Overview of beam and orbit parameters during the low-α week in May 2006. See text for description

Operation conditions of a typical low-α week is summarized in Fig. 1. The upper part of the diagram shows characteristics of the orbit correction: the light green curve

(BPMZR:avgH) displays the average horizontal beam position wander of $\pm 20\mu$m. The other green curves describe the RMS orbit deviation in the horizontal plane as measured by the orbit correction program (RMC01V, olive) and predicted for the next correction step (RMC02V). A difference band between RMC01V and RMC02V provide a measure of aliasing effects. The flat blue curves RMC03V and RMC04V are the corresponding values of the stable vertical plane. The middle red curve (MCLKHX251C:freq499) displays the taken RF-frequency steps spanning the usual 300Hz/week. In the lower part of the diagram beam current (MDIZ3T5G:current $<$ 30mA) and intensity of THz-radiation (THZH11FD6L:signal) are shown. The two morning shifts May 4/5 with relatively low current and uncorrected orbit have been optimized for short pulses with f_s between 950Hz and 1.2 kHz. The interruptions in the afternoon of May 4 are due to hardware problems.

Dependent on α (or the synchrotron tune f_s) large and fast horizontal orbit jumps have been observed that may be due to tiny energy fluctuations: 0.1 mm changes at f_s=1.3 kHz and 3mm jumps at f_s=0.3kHz have been documented (Fig. 2).

Under these conditions orbit correction at 0.2Hz is justified only by the ability to keep the beam within its useful bounds. The aliasing effect of fast orbit jumps and the slow corrective actions introduces unfavorable additional noise. This can only be avoided by fighting the non-magnetically transmitted perturbations at the likely source (e.g. RF-phase control). It has to be investigated if a fast orbit feedback is appropriate to overcome and damp the fast horizontal orbit instabilities.

Going to the limit of very short pulses requires both low current and very small α. Orbit correction in this region seems to be less a problem of insufficient signal conditioning: during test shifts at I$<$1mA and $f_s = 950$Hz and at I $\sim$ 2mA and $f_s = 1.2$kHz no orbit correction has been attempted. A drift of the average horizontal beam position of 100 μm/h has been observed.

OBSERVATIONS, PECULIARITIES

Fast beam motions are measured at all BPMs and routinely analysed in the frequency band of 0.5 to 25Hz[4]. In low-α mode the known pattern (booster peak, girder modes etc.) is reproduced - due to the higher sensitivity in the horizontal plane with bigger amplitudes. At $f_s = 950$Hz the spectrum appears to be less structured at even higher amplitudes.

There have been a couple of strange events: a sudden slow beam loss without any hint on a possible countermeasure happend when the SR has been set-up not very carefully after an operators mistake. The only cure back to stable beam conditions was the tuning of the RF frequency toward a recentered orbit. There have been increased noise due to aliasing effects in the horizontal orbit correction that varied on the time scale of days and could be correlated with the ambient temperature. There have been sudden in-

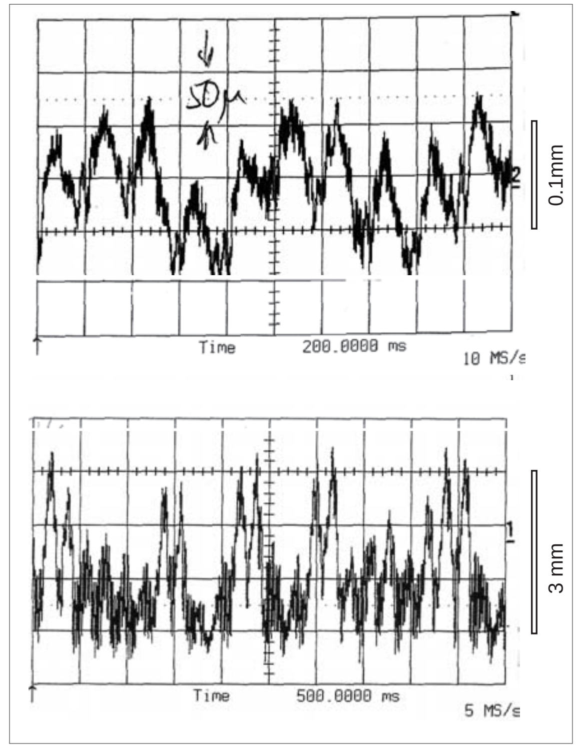

Figure 2: Oscilloscope traces showing 0.1 mm changes at 20Hz measured at a certain BPM at f_s=1.3 kHz (upper screen) and 3mm jumps at 44Hz modulation at f_s=0.3 kHz (lower screen)

creases of the THz intensity that had no obvious origin: There are still numerous unknown parameters where tiny changes can have a big effect on the operating condition.

SUMMARY

Despite its enhanced sensitivity a carefully prepared low-α mode at $f_s = 1.75$kHz has similar stability properties for experimental usage as the standard mode. Key parameter for a successful low-α week seems to be the initial choice of the proper RF-frequency.

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